ENCYCLOPEDIA OF

FLIGHT

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Encyclopedia of

FLIGHT

Volume 1

Accident investigation - Guernica, Spain, bombing

Indexes

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Publisher's Note

Many books on aviation and other aspects of flight are written either at a very basic level, designed for a juvenile audience, or at a technical level, intended for members of the aviation industry. The *Encyclopedia of Flight* bridges the gap between theoretical concepts and practical applications, between scientific information and historical issues. A unique addition to the market, this illustrated, three-volume work provides information about animal and human-made flight in a way that is accessible to high school and undergraduate students, general readers, and aviation enthusiasts. It examines a wide range of topics, from birds and balloons to jets and spacecraft.

The broad scope of the *Encyclopedia of Flight* allows readers to gain a rich understanding of the more than two-hundred-year-old history of human flight and the natural factors and aerodynamic principles that led to its development. The encyclopedia addresses all categories of flying craft, both civil and military, including kites, gliders, dirigibles, biplanes, hovercraft, rockets, missiles, and satellites. In addition, entries can be found on numerous types of aircraft, from Sopwith Camels and B-52's to stealth fighters and the space shuttle, as well as on several famous aircraft from history, such as the *Spirit of St. Louis*, the *Spruce Goose*, and the *Hindenburg*. Also discussed are the principles of aerodynamics and design. Some entries focus on flying insect and animal species. Articles such as "Avionics," "Ailerons and flaps," "Guidance systems," "Instrumentation," and "Turboprops" cover the mechanical and technical aspects of flying. Readers can learn about the features of the 707, DC, and MD plane families.

The encyclopedia also analyzes many procedural and social issues pertaining to the contemporary airline industry, from ticketing and airport security to air rage and hijacking, and it offers profiles of major aircraft manufacturers and air carriers, both past and present. Biographical entries highlight many pioneers in aviation and aeronautics, such as Sally Ride, Alberto Santos-Dumont, Konstantin Tsiolkovsky, the Wright brothers, and Chuck Yeager. The use of flight in various world conflicts is examined, from pigeons and balloons in the Franco-Prussian War (1870-1871) to Patriot missiles in the Gulf War (1991). Many topics in the history of spaceflight are covered, such as "Astronauts and cosmonauts," "Apollo Program," and "Orbiting." It should be noted, however, that travel in space is not the primary focus of this encyclopedia; more extensive information can be found in our three-volume *USA in Space* (2d ed., 2001).

The ability of human beings to take to the skies in flight had become routine, even mundane, by the start of the twenty-first century. For many people, that attitude changed on September 11, 2001, when hijacked commercial jetliners became weapons of mass destruction at the World Trade Center in New York City and the Pentagon in Washington, D.C. The *Encyclopedia of Flight* was in its final stages of editorial work, and many articles written in prior months—such as "Terrorism," "Hijacking," and "Airport Security"—were quickly updated to reflect the new aviation landscape and to speculate on the future finances and regulations of this worldwide industry.

The 321 alphabetically arranged entries in the *Encyclopedia of Flight* range from one to six pages in length. Each article begins with ready-reference top matter that defines the topic and outlines its significance. Dates and alternate names are given where applicable. The main text was written with the needs of students and general readers in mind; for example, articles such as "Aerodynamics," "Mach number," and "Wind shear" present clear discussions of these topics, explaining any terms or references that may be unfamiliar. Every essay ends with an annotated bibliography that directs readers to further sources of information. Cross-references at the end of the article direct readers to related topics, forging connections between events, inventions, and biographies. Distributed throughout the *Encyclopedia of Flight* are valuable photographs, line drawings, charts, tables, and maps, as well as historical time lines describing developments in the history of flight as well as significant disasters. Boxed sidebars discuss important concepts, key developments, or examples to expand on topics mentioned in the text.

The *Encyclopedia of Flight* contains a number of useful tools to aid readers in locating entries in their areas of interest. An Alphabetical Index of Entries and a Categorized Index of Entries appear at the end of each volume. In addition, volume 3 concludes with a Glossary of relevant terms, a general Bibliography, a directory of helpful Web Sites arranged by category, an annotated list of flight-related Organizations and Agencies, contact information for major Flight Schools and Training Centers in North America and for notable aviation Museums of North America, annotated lists of International Airports and of major Air Carriers throughout the world, an extensive list of various Airplane Types grouped chronologically, a Time Line of important events in the history of flight, a list of Air Disasters and Notable Crashes, and a full Subject Index.

Reference works such as the *Encyclopedia of Flight* would not be possible without the help of many experts in the field. More than one hundred contributors, including pilots, professionals, and academicians, have lent knowledge and insight to this project. Their names and affiliations are listed in the pages that follow. We are particularly grateful to the project's consulting editor, James F. Marchman III, Professor of Aerospace and Ocean Engineering at Virginia Tech in Blacksburg, Virginia, whose hand helped guide the project at every step.

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Introduction

Few words better capture the dreams, desires, fantasies, and fears of humankind than "flight." The English language is filled with its imagery. People have flights of fancy, let their imaginations soar, aspire to greater heights, fly into the face of adversity, rise to the occasion. They sometimes refer to their apprehensions about life as "fear of flying." To fly is to go fast, to excel, to be excited, to live life to its fullest. Yet, except for a tiny fraction of the span of human existence, flight could only represent a dream.

Images of flight have been an important part of humankind's experience for thousands of years. Ancient myths and legends are pervaded with fantasies of flight. The earliest known civilizations used everything from cave paintings to stone carvings on temple walls to record visions of gods and animals and even humans endowed with wings. There are legends of flying carpets, flying broomsticks, flaming flying chariots, lions and horses with wings, ancient rulers carried aloft by giant birds, and numerous mortals who fell to earth while attempting to soar on birdlike wings. Sacred writings of most religions tell of gods and their messengers who migrate through the skies to communicate with humankind. To fly is to emulate the gods, to dare to enter their heavenly domain. Flight was, and still is, a kind of magical fantasy, capable of transforming the toils, frustrations, and limitations of day-to-day existence into the world of dreams.

Children often dream of flying with Peter Pan to far-off lands and adventures. They may drape towels over their shoulders and run down the nearest hill, hoping that their next leap into the air will send them soaring like their favorite comic book hero. Children and adults may share similar fantasies as they read of fictional wizard Harry Potter swooping above a playing field on his broomstick. Adults gaze at travel brochure illustrations of jet planes gliding through the clouds, imagining that they are carried off to dream vacations in distant, exotic locales.

Some people take their fascination with flight a step further than mere imagination. History is filled with those who dared to take that step, one which for thousands of years only led to disaster. The first were those who were convinced that they could take to the air like birds, if only they could build their own set of wings. Although these early "tower jumpers" ranged from commoners to kings and lived in ancient lands in all parts of the world, their story was always the same—gravity proved too strong a bond between person and planet. Today people can build their own wings and hang glide with relative ease, but it took centuries of ill-fated experiments before this became possible.

Most who dreamed of flight spent hours watching the motions of birds and, like early engineering geniuses such as Leonardo da Vinci, thought the key was in devising the means of using a human's limited muscle power to flap a set of strong yet lightweight wings. This method worked well for birds, so it seemed that it should be the best way for humans to take to the skies. There were, however, fundamental flaws in this approach, one being that a human's power output-to-weight ratio was no match for that of a bird. Another was that a bird's wings do not merely flap up and down; they rotate and change shape and angle as they flap. There is no record that Leonardo da Vinci ever attempted to fly the machine in his drawings, but many others apparently tried to emulate birds. From Icarus in ancient Greece to King Kai Koos of Persia to King Bladud (father of King Lear) of medieval England to the hapless but determined experimenters seen in old-time newsreels, only broken wings and bodies were left in their wakes.

Finally, in the mid-1800's, experimenters and scientists such as Sir George Cayley of England realized that if people were ever to fly, they must separate the two tasks of propulsion and lift and must learn to emulate the actions of a bird's tail in providing balance in flight. Meanwhile, in the previous century, the Montgolfier brothers in France had successfully taken to the air in balloons, carried aloft by captured hot air from open fires and propelled, sometimes unintentionally, by the winds.

It was balloons filled with hot air and later with hydrogen and helium, rather than birdlike wings, that first took human beings into the sky. Early balloons were often tethered to the ground for safety and used primarily to provide their passengers never-before-seen views of the surrounding landscape or of their enemies in wartime. By the end of the nineteenth century, these structures had evolved into helium- or hydrogen-filled bags that carried boatlike craft equipped with crude propellers and rudders which, on rare windless days, could transport one or two passengers for a few miles in a selected direction. Flight, of a sort, had finally entered the realm of the possible for humankind.

Meanwhile, the attempt to fly using wings continued, coming closer with each new trial success. Gliding flight was achieved by experimenters such as Otto Lilienthal in Germany. He learned through trial and error the proper way to suspend himself beneath batlike wings and to shift his weight from side to side and forward to aft to maintain equilibrium as he soared a few feet above his artificial hillside. In the United States, Octave Chanute corresponded with Lilienthal and others while conducting experiments of his own. His publications on flight inspired others in the United States, including Samuel Pierpont Langley, head of the Smithsonian Institution, and Orville and Wilbur Wright in Ohio to their own efforts to turn their dreams to reality.

Adding primitive propellers powered by steam or early internal combustion engines to gliders of widely varying sizes allowed inventors and adventurers of all type to experience everything from utter disaster to the thrill of a short powered "hop" into the air. Others around the world claimed success in momentarily getting a heavier-than-air machine off the ground with a person on board. Langley sent his powered but pilotless aerodrome on a successful flight down the Potomac River near Washington, D.C.

Virtually alone among all their peers, the Wright brothers learned that successful flight required successful control, and their patient experimentation and analysis culminated in their first flight in December, 1903, on the sands of Kitty Hawk, North Carolina. In the same month, Langley's second attempt to launch his scaled-up and piloted aerodrome from a houseboat in the Potomac River ended in failure, with his fragile craft lying broken in the water and the newspaper headlines bemoaning the waste of government funds on his fantasy.

In the years since that day at Kitty Hawk, flight has grown far beyond the wildest dreams of those early "aeronauts." Not even the Wrights envisioned their invention being able to carry large numbers of passengers or tons of cargo over thousands of miles. Any mention of flight faster than the speed of sound was thought of as lunacy for at least the first third of the twentieth century. Children now play with flying model aircraft and rockets that are far more sophisticated than the vehicles imagined by their great-great-grandparents. Today's programmable, rechargeable, battery-powered, radio-controlled craft were not predicted by Jules Verne in his novels of the time.

Verne did foresee space travel, however, although his imaginary flight to the Moon was launched from a gun instead of a solid- or liquid-fueled rocket booster. The rocket has gone from its roots as a Chinese invention used for celebration and warfare to become the basis for sending people and scientific probes into ever-expanding reaches of space. Proponents of spaceflight such as Robert H. Goddard experimented with multistage, liquid-fueled rockets that would take their payloads far above the realm of winged flight. After World War II, U.S. and Soviet scientists built upon German weapons technology to design rockets capable of reaching orbit.

The 1957 launch of the Soviet Sputnik satellite shocked the United States out of its scientific complacency, and since that time, space exploration and travel has moved from science fiction beyond the solar system into deep space. In 2001, Dennis Tito, the world's first paying "space tourist," launched on a Russian rocket for a stay in the International Space Station. In 1969, the world watched with anxiety and elation as men from Earth left their footprints in the loose soil of the Moon. Today's dreamers focus on Mars, the planet that has fascinated stargazers and readers of science fiction for centuries. Will scientists find water there or dig up evidence of long-extinct microbes which populated a once-living planet?

Spaceflight continues to capture the imagination of young and old alike, as did the adventures of daring aviators such as Charles A. Lindbergh in the 1920's. For many of today's young people, the start of their path into space will begin at a local airport just as it did for those of Lindbergh's time who looked to the skies and envisioned their futures in Ford Tri-Motors and DC-3's. Today's local airports may bear little resemblance to the dirt- and grass-covered airstrips of the 1920's and 1930's, but they remain, for many, the point of departure from forces of gravity to the skies and beyond. Instead of the open-cockpit, fabric-covered, and wire-braced biplanes of an earlier era, today's student pilots make their first flights in instrument-filled cabins of Cessna and Piper aircraft. They will be guided by a GPS signal or a VOR needle instead of railroads and highways below. Soon NASA's Highway-in-the-Sky-based Small Airplane Transportation System will allow pilots to navigate from home to destination virtually automatically.

If one lingers long enough at any small airport, one will be fascinated to watch student pilots, young and old, anxiously anticipating their next trip into the sky with a flight instructor. Even though many hours of flying are required before new pilots pass the flight test for a license, there is little that compares to the excitement of the student pilot's first solo flight. Students may feel like they have been doing "touch-and-goes" forever, learning to handle the small aircraft in the most demanding parts of any flight, takeoffs and landings. There is a building passion finally to test one's new knowledge alone in the cockpit, to fly solo. The student's training has included slow flight and stalls, and the instructor is relatively confident that the student can handle the plane alone. After a couple of routine trial takeoffs and landings, the plane pulls to the side of the runway and the teacher steps out, telling the student to go it alone.

As a nervous instructor looks on, the student, with a combined feeling of absolute elation and rising fear, taxis the plane out to the end of the runway and begins accelerating toward takeoff. It takes a minute to recover from the shock felt as the small plane lifts off the ground much sooner than it had in previous flights, now relieved of one-half its normal payload. Right away it is time to think about landing as this first solo is a mere loop around the field in the airport traffic pattern, and the lone pilot begins to wonder how different this landing will be from the scores of touchdowns made previously with a heavier plane. The plane turns onto the final approach and descends, ever so slowly because of its light weight. Sweat breaks out as the student pilot begins to think the wheels will never reach the ground as they glide farther along the runway than ever before.

Finally, the wheels touch and an excited student pilot fights to control both built-up emotions and crosswinds while taxiing proudly back to the hangar and to the waiting, and now much less nervous, teacher. Then, a time-honored ritual is carried out by the flight instructor, who cuts off a portion of the student's shirt back and, with an appropriate blend of seriousness and celebration, writes the student's name and the date of the flight on the cloth and pins it to the bulletin board in the pilot's lounge. The student's "tail feathers" have been cut, both literally and symbolically. A new pilot-to-be is ready to take to the sky, free and alone. Although many hours of further instruction remain, both student and teacher are now confident that the license to fly is within reach. A pilot's future awaits, perhaps as an airline or fighter pilot or even as an astronaut. For most, a pilot's license will lead to a life-long hobby that will add depth and dimension to life.

Other seekers of flight will head for the mountains and the seaside dunes, finding their ultimate adventure in hang gliding, a modern-day return to the experiments of Lilienthal, Chanute, and the Wright brothers. Some will add a small motor to such a lightweight craft and enter the world of ultralight aviation. Others will opt for the new sport aviation class of aircraft, which will offer much of the improved safety of conventional small airplanes at lower cost and with less regulation.

Others who may never pilot their own craft will play a role in the world of flight by becoming aerospace engineers, airport managers, mechanics, technicians, or one of the hundreds of other professionals who are needed to design new airplanes and spacecraft and to keep them flying. It takes thousands of engineers to design and certify a new airliner and years of research and testing to develop new space probes. Highly trained electronic and computer technicians and engine mechanics are needed to keep these planes and spaceships flying. It takes thousands of people with all manner of educational backgrounds to keep the world of aviation operating.

For most, however, dreams of flight will be realized through the hustle and bustle of airport hubs in business or vacation travel, an environment in which the dream can easily become a nightmare in the crowded skies of the twenty-first century. In contrast to every jaded and seemingly bored business traveler on today's packed airliners, however, there is one excited five-year-old or equally enthusiastic eighty-year-old who looks out the airplane window with eyes full of wonder as the engines roar and the ground disappears beneath them.

It is for those people whose interest in flight ranges from idle curiosity to jubilant enthusiasm that these volumes are intended. The *Encyclopedia of Flight* should provide a handy first reference for those wanting to know a bit more about aircraft and spacecraft, how they are designed and built, and how they operate. In addition, the *Encyclopedia of Flight* covers a wide range of related topics, both historical and technical. It is designed to give authoritative definitions, explanations, biographical sketches, and general information about hundreds of flight-related topics. Every entry is written by an identified expert in the field and has been edited to ensure that it will be understood by the nonengineer or nonscientist. Each entry includes references recommended by its author that can provide the interested reader much more detail and depth about the chosen subject.

Flight has been the dream of humankind for all of recorded history. For a fortunate few generations, flight has become a reality, but human curiosity and excitement about flight, whether to Walt Disney World or to Mars, is as great as ever. Whether one's interest is in how an airplane flies, in how a rocket engine works, in the history of flight, or in any one of the scores of aviation and space-related topics, the *Encyclopedia of Flight* should prove an outstanding resource, either giving the quick answer being sought or providing a starting place for an adventure of discovery.

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A

Accident investigation

Definition: The examination into the causal factors of an aircraft mishap or incident.

Significance: The investigation of aircraft accidents is important to the aviation industry for many reasons. The study of accident factors helps airlines determine accountability, educate inexperienced pilots, and prevent future accidents.

Perceptions and Realities

Those of the flying public who are not airline pilots, and even some pilots who fly as passengers, are sometimes nervous while doing so. Although airline accidents occur infrequently, those that do occur can be catastrophic events involving a great loss of life. Media coverage of airline accidents is usually extensive, fueling the uneasy feelings many people have about airline travel. However, the periods after aviation accidents are often the safest times in which to fly. Further, contemporary aviation accident rates are very low, in relation to other types of accidents, such as automobile accidents.

Because aviation always involves the risk of an accident, accident investigation is an important element of aviation education. By studying the accidents of other pilots, less experienced aviators can avoid making similar mistakes.

Accident Patterns

A commonly noted pattern in aviation accidents is that there is rarely only a single reason for the accident. Experienced pilots refer to the events leading up to an accident as an error chain. Individual links of the chain, when combined, cause an accident to happen. For instance, bad weather alone might not cause an accident, but bad weather combined with darkness and the fact that the pilot became lost might. The error chain is weather, darkness, and becoming lost. The elimination of any one of these factors may prevent the mishap. In other words, if one link of the chain were broken, the accident would not happen.

The key to accident investigation, then, is to determine the error chain leading up to the event. Rectifying the situation regarding an accident under investigation is impossible, because the accident has already happened. However, accident investigators can study each link of the chain and prepare documents to report their findings. In turn, other flight crews can study the reports and avoid the same fate.

The vast majority of aviation accidents result from human-factor errors. All those who have roles in launching an aircraft, including pilots, mechanics, air traffic controllers, cabin attendants, and baggage handlers, can make mistakes that may cause an airplane accident.

Accident Rates

In the study of aviation accident investigation, an important statistic is the number of accidents compared to the hours flown. The number of accidents per 100,000 hours determines a figure known as the accident rate. With the exception of the mid-1990's, the accident rate has been declining since 1982. The number of accidents has declined, as has the number of fatalities. The Federal Aviation Administration (FAA) and others in the industry attribute better pilot education and technological advances for improvement of aviation safety statistics.

Causal Factors

According to statistics compiled by the industry, approximately 70 percent of air carrier accidents are the results of flight crew error. Maintenance error constitutes another 5 percent, while air traffic control or other airport issues account for about 4 percent. Human error is responsible for a total of almost 80 percent of the commercial airline accidents worldwide. Of the remaining 20 percent, mechanical failures make up 11 percent, weather factors account for about 4.5 percent, with the remainder categorized as miscellaneous or other.

Pilots and first officers are responsible for most of the human error accidents. Reasons for the flight crew's mistakes are many, including loss of situational awareness, flight crew fatigue, and training and operational issues.

Accidents can occur during all phases of flight, from pushback to arrival at the destination gate. However, the majority of accidents, almost 56 percent, happen during the approach and landing phase of the flight.

The reasons for approach and landing accidents vary. If a flight has been a particularly long one, crew fatigue can play a significantly greater role at the end of a flight than at the start. Being tired or fatigued can impair a crew's decision-making process. Poor destination weather combined with a tired flight crew could be a recipe for disaster.

Post-Accident Sequence of Events

During an accident investigation, there are many simultaneous issues requiring attention. The first and most important consideration is to assist the injured. Medical personnel are needed immediately to administer to those on site, and provisions are needed to transport patients to the nearest medical facility as quickly as possible. The rescuers also need to determine where the injured were sitting in the aircraft and where they ended up after the accident. The next task is dealing with the survivors of anyone killed in the accident; if there is even one fatality, the loss touches many people.

After the first officials arrive on the scene, their first order of business is to secure the area. Another important task is to observe evidence that is transient in nature. For instance, a popular twin-engine aircraft seemed to be crashing for no reason. It took four such crashes of a similar nature before investigators arrived at the wreckage quickly enough to determine that ice forming on the aircrafts' horizontal stabilizers had caused the accidents. After the previous accidents, the ice had melted before anyone could see or record its presence.

After first seeing to the injured, personnel guarding the accident scene have several responsibilities. They must make certain the wreckage is not disturbed, because if someone moves the wreckage, aviation accident investigators will no longer be able to see the parts of the aircraft as they came to rest after the accident. Consequently, investigators will lose many clues that may help them determine a probable cause of the accident. Another essential task is to determine whether hazardous materials were being transported and are present at the scene. If so, personnel must take measures to protect everyone on scene from the dangers of the hazardous materials.

It is important for the accident investigators to photograph the scene. Photographs of the wreckage can preserve the visual evidence of the accident for later analysis and should include all aspects of the accident: from individual parts of the aircraft to any fatalities where they lie. Marks caused by the craft's hitting the ground and aerial photos are important to show the path of the aircraft as it crash-landed.

In addition to photographs of the crash scene, the investigators should also draw sketches and maps of their observations. By using the photographs, sketches, and maps, they will be able to create a diagram of the last moments of the flight. This diagram of the flight's last moments is essential to understanding the decisions made by the crew.

Guarding the wreckage is an important responsibility for those tasked with the job. Guards should be somewhat familiar with aviation. They must protect the property, the wreckage, and the crash site from being disturbed. They have the difficult duty of making sure that people do not wander through the area. They also collect the names, addresses, and telephone numbers of anyone who may have witnessed the crash. If an accident occurs in a remote location and all aboard sustain fatal injuries, eyewitness statements may be nonexistent. Anyone with knowledge of the accident must be located because witnesses can be very important in helping to determine the cause of an aviation accident.

The best witnesses to an aviation accident are not other pilots, or those involved in the industry. In fact, they are not even adults. Children often provide the most accurate and unbiased statements about aviation accidents. Adults often tend to put their own spin on an accident. Pilots who witness accidents may inject far too much opinion into their account of what happened. Children very simply report what they see.

National Transportation Safety Board

Once notification of a major aircraft mishap reaches the authorities, the National Transportation Safety Board (NTSB) launches a go team. The team originates from Washington, D.C., where the members of the NTSB rotate the duty of being on the team. While the go team is en route, it is the job of the local authorities on scene to organize the agencies to start the rescue or recovery procedures.

The accident investigator is indeed a detective. Typically, it is very difficult to determine exactly what caused an aircraft accident. The investigator's first order of business is to sort through the pieces of wreckage, cataloging the more and less obvious clues leading to the most probable cause of the mishap. In many cases, it is much like looking for the proverbial needle in a haystack.

Once the team is on site, it will survey the wreckage to determine where the aircraft initially struck the ground. Damaged shrubbery and trees may mark the path of the airplane into the crash scene. The investigators will note the general condition of the wreckage while trying to account for all the parts. If parts or components of the aircraft are missing from the accident scene, this may be indicative of an in-flight structural failure. If the empennage, or tail, or the wing of the aircraft came off the airplane at a high altitude, that could well be the cause of the accident. Those parts, once separated from the main aircraft, will fall to the

Image Not Available

ground sometimes miles away from the main site of the wreckage.

The investigators begin with the physical aspects of the accident. They collect parts, examine each one, and map its final placement against the original installation on the aircraft. They also have to be certain that the aircraft is complete; parts of the aircraft missing from the wreckage site suggest an in-flight breakup in which other essential components of the airplane have landed elsewhere.

From the physical evidence, the investigators can then determine the aircraft's approximate angle and speed of impact. They can also determine whether the engines were working at the time of impact. They map and photograph the wreckage to preserve as many of the clues as possible. After this work is complete, they will begin their true detective work.

This detective work begins with a review of the pilot's qualifications and an examination of the pilot's training and certification documents and medical records. The investigators conduct interviews with the pilot's friends, peers, and relatives. They review autopsy results. They create a pathological history for a seventy-two-hour time period leading up to the accident and conduct weather data analysis, among other things. The investigators check into the pilot's physical and psychological makeup and try to determine the pilot's state of mind at the time of the accident. They question the pilot's aeronautical decision-making abilities, look into recent history of the pilot's judgment, and even evaluate the pilot's training and experience.

Investigators also try to determine whether the weather was a factor in the accident, relying upon official weather reports and forecasts. They look for indications of low visibility, turbulence, extreme wind shear, or heavy rains that may been contributors.

Reconstruction

Finally, investigators examine the aircraft wreckage to determine whether mechanical malfunctions may have caused the crash. This is one of the more intense segments of the investigation. The aircraft will undergo reconstruction in a secure hangar or other facility. Plans of the aircraft are helpful in determining that all parts of the aircraft have been retrieved from the wreckage site and adjacent areas.

The aircraft's reconstruction helps the examiners find signs of structural failure. The key to determining structural failure involves asking whether engine failure caused the accident or whether it caused the breakup of other parts of the airplane. Investigators try to figure out where such a breakup first occurred. This is the most intriguing part of accident investigation, and it may go well beyond the expertise of the investigators. On many occasions, expert witnesses, such as metallurgists, are necessary to assist in finding the answers.

Every aspect of the aircraft is under dissection during the accident examination. Disassembly of each component and system of the aircraft will follow for investigation of any possible failures. Examination of the flight controls may reveal a frayed cable or a broken bearing; a control pushrod may have become bent, allowing aerodynamic flutter to start. That aerodynamic flutter may have caused an actual structural failure of the elevator or rudder, hastening the accident.

Investigators also check switch positions at the time of the crash. They are especially interested in the positions of the switches and controls and the relative positions of the associated components. These indicate whether the pilot may have done something improper to cause the accident, such as raising the flaps at the wrong time or unintentionally dumping fuel, resulting in fuel exhaustion. A component failure may be indicated if a switch was properly set and the component discovered is not positioned per the switch selection.

Investigators are also intensely interested in the instrument readings at the time of impact. After removal from the crash site, each instrument is sent to an appropriate laboratory for intense post-accident analysis. At the time of impact, each needle on the face of an instrument leaves impact marks that allow the technicians to determine exactly what measurement the instrument was indicating at the time of the crash. With this technique, investigators can determine the speed of the aircraft. They can also make corroborations between engine operations and other instrument indications that may help in explaining the accident.

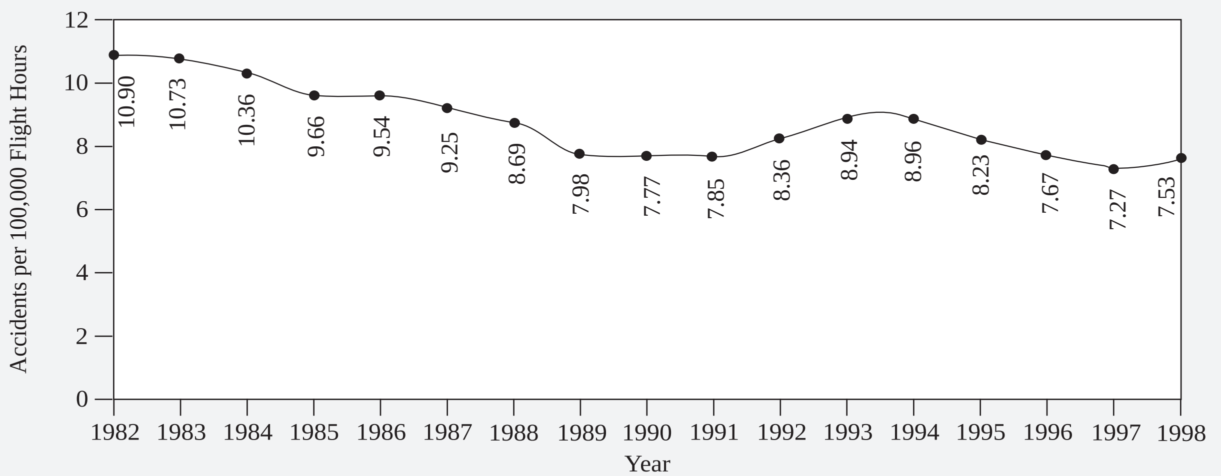
The investigators have a high interest in the navigational instruments and radios, along with everything else in the cockpit. This is particularly true if the accident happened in poor weather. By careful analysis of the frequencies selected, the switch positions of the units, and the readings at impact, examiners can determine if a navigational error factored into the cause of the accident. All other systems in the airplane, such as the generators or alternators, the vacuum systems, pneumatics, and hydraulics, are also scrutinized during the investigation.

Flight and Cockpit Recorders

Flight recorders and cockpit voice recorders, carried in the tail of an aircraft, are important elements in accident investigation. They provide critical clues in solving the mysteries associated with many of the world's air disasters and are invaluable in helping to prevent future accidents. Although they are known as black boxes, they are actually painted bright orange to aid in their recovery following an accident.

Aircraft flight recorders record many different operating conditions of a flight and provide information that may be difficult or impossible to obtain by any other means.

Number of U.S. General Aviation Accidents per 100,000 Flight Hours, 1982-1998



Source: National Transportation Safety Board, 2000.

Cockpit voice recorders record the flight crew's voices, as well as other sounds within the cockpit, including communications with air traffic control, automated radio weather briefings, and conversation between the pilots and ground or cabin crew. Sounds of interest to an investigation board, including engine noise, stall warnings, landing gear extension and retraction, and any clicking or popping noises, are also typically recorded. Based on these sounds, important flight parameters, such as speed, system failures, and the timing of certain events can often be determined.

In the event of an accident, an investigation committee creates a written transcript of the cockpit recorder tape. Local standard times associated with the accident sequence are determined for every event on the transcript. This transcript contains all the pertinent portions of the cockpit recording. Due to the highly sensitive nature of the verbal communications inside the cockpit, a high degree of security is provided for the cockpit recorder tape and its transcript. The timing of release and the content of the written transcript are strictly regulated.

Autopsies

The examiners find the pilot's autopsy results particularly important in determining whether pilot incapacitation caused the accident. The pilot may have experienced a heart attack, stroke, or some other medical factor that caused incapacitation. The pilot may have passed out due to hypoxia or carbon monoxide poisoning. The results of the autopsy enable the investigators to assign probable cause to the pilot or rule out incapacitation.

The airplane also undergoes a mechanical autopsy of sorts. After an aviation accident, the maintenance records and logbooks of the accident aircraft are collected. NTSB examiners examine the records in search of evidence of possible material defects or mechanical malfunction. The inspectors may determine that there were metallurgical or manufacturing defects in the history of the aircraft. They may uncover improper maintenance procedures, such as that a life-limited part has been allowed to exceed its time in service. These are only a few of the possible explanations for the accident.

These observations and examinations comprise the bulk of the investigators' work. The compilation of information on the accident and the examination of evidence may take months, or even years. Many people in the agency are involved in the search for answers about the cause of the accident. As the work is completed, many more people await the results, some patiently, others less so.

The meticulous work of the accident investigators takes time, however. Although this challenging work is sometimes tedious and demanding, it must always be thorough. Its reward is the promise of the prevention of future accidents.

Joseph F. Clark III

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See also: Flight recorder; National Transportation Safety Board; Runway collisions; Safety issues

Advanced propulsion

Definition: Any means for launching or propelling spacecraft beyond the use of traditional chemical rocket engines.

Significance: If humanity is ever to explore the solar system and access resources beyond Earth, cheaper, faster, and more efficient propulsion systems must be developed.

The Fundamentals

If the space shuttle's external fuel tank were placed on the pedestal of the Statue of Liberty, it would stand just taller than Lady Liberty's torch. At launch, the mass of the space shuttle is about 2,040 metric tons (4.5 million pounds), but it can deliver only 6.5 percent of that mass to low-Earth orbit, and that costs $20,000 per kilogram ($9,100 per pound). For comparison, in 2001, gold sold for about $9,000 per kilogram. To achieve a stable low-Earth orbit, the payload must simultaneously be lifted about 300 kilometers above Earth's surface and accelerated to a horizontal speed of nearly 8 kilometers per second (about Mach 23, or twenty-three times the speed of sound).

At 111 meters (364 feet), the Saturn V rocket that took the Apollo astronauts to the Moon stood over twice as tall as the space shuttle. In ascending to low-Earth orbit, the Saturn's first three stages burned for a total of 11.5 minutes, using 75 terajoules (75×10^{12} joules) of chemical energy. That was about 1.5 percent of all of the energy in the world produced from fossil fuel during those 11.5 minutes. Only 6 percent of that energy went into lifting and accelerating the Apollo payload into orbit, while most of the remaining 94 percent was expended on lifting and accelerating the fuel used on the way up.

There are many plans for more efficient spacecraft. The Venture Star project featured the more efficient aerospike rocket engine. Solar sails, plasma bubbles, gravitational slingshots, the Pegasus spacecraft, and laser- or microwave-launched spacecraft are schemes that leave all or part of the main power source behind and thereby reduce the spacecraft's mass. Scramjets gather part of their fuel, the oxidizer, in flight, and the hypothetical Bussard interstellar ramjet would gather fusion fuel in flight. Ion drives, plasma drives, and drives using nuclear fission and fusion are all schemes to increase the exhaust velocity of the propellant.

Aerospike Engines, Scramjets, and Pegasus

Worldwide, there are a number of projects under way to develop a fully reusable launch vehicle that will orbit payloads for one-tenth the cost of the space shuttle. The X-33 "Venture Star" is a sleek, wedge-shaped craft designed to take off vertically like a rocket and glide to a landing like an airplane. It pioneered the use of lightweight graphite composites in its structure and fuel tanks, and its efficient lifting body shape allowed it to fly with only stubby wings for stabilizers. Although many important technological advances were achieved, development problems led to the withdrawal of support by the National Aeronautics and Space Administration (NASA) in March, 2001, but work continued on the X-33's Boeing Rocketdyne XRS-2200 aerospike engines.

A conventional rocket engine has a combustion chamber that opens into a bell-shaped nozzle. Fuel and oxidizer are mixed and burned in this chamber, and high-speed combustion products escape through the nozzle. For greater efficiency, the pressure of the exhaust plume should match the surrounding air pressure. The aerospike nozzle is V-shaped and is turned inside out: Fuel and oxidizer are mixed in ten combustion chambers (five on each side of the V), and the exhaust plume sprays down the outside of the V. Since the outside of the exhaust plume is open to the atmosphere, it automatically blooms outward until it matches the ambient pressure, while the inside of the plume pushes against the V and provides thrust.

A scramjet is a supersonic combustion ramjet. Scramjets can be more efficient than rockets because they use oxygen from the air and must carry only the oxygen that they will use in space. A scramjet engine has no moving parts; it uses its supersonic speed (about Mach 10) and internal shape to compress air coming into its engine instead of using the rotating compressor of a normal jet engine. Hydrogen fuel is injected into the airstream in the engine, and the hot combustion gases (mostly water vapor) escape from the rear of the engine to provide thrust. A scramjet must be launched at supersonic speed before it can fly. In June, 2001, a B-52 aircraft lifted an X-43A scramjet mounted on a Pegasus-based rocket 6,000 meters (20,000 feet) into the atmosphere and launched the combination. The rocket was to accelerate to the scramjet's cruising speed and then release it. Unfortunately, a structural failure occurred shortly after rocket ignition and the mission was terminated.

Several nations are working on scramjets. In August, 2001, India announced plans to develop the Avatar, a 25-metric-ton craft believed to be able to cheaply carry a 1-metric-ton payload into a 100-kilometer-high orbit. The Avatar will take off and land like a conventional airliner using a combination of turbofan, ramjet, and scramjet engines fueled with hydrogen. A unique feature is that it is to cruise at Mach 8 for an hour at an altitude of 10 kilometers while it takes in and liquefies 21 metric tons of oxygen before it uses a hydrogen-and-oxygen-fueled rocket to push into space.

The Pegasus rocket has placed dozens of satellites into orbit and is the most successful small commercial launch vehicle in the world. The "Stargazer" Lockheed L-1101 aircraft carries Pegasus to a launch point 12 kilometers high, above the densest and most turbulent part of the atmosphere. The three-stage rocket is then released and ignited. It can carry a 450-kilogram payload into low-Earth orbit.

Solar Sails and Plasma Bubbles

The surface of the Sun is a fearsome place—a seething, turbulent ocean of blinding incandescent gases, incessantly rocked by sonic booms as gigantic gouts of matter race upward through the photosphere. The flood of energy from the Sun tears particles from its outermost part, the solar corona, and constantly drives this sun-stuff into space. This is the solar wind: electrons along with ionized hydrogen and helium atoms streaming outward at an average speed of 400 kilometers per second.

Earth's magnetosphere is the region surrounding the planet that is dominated by its own magnetic field, not the Sun's. Geophysicist Robert Winglee of the University of Washington realized that the solar wind pushing against Earth's magnetosphere pushes Earth away from the Sun, except that Earth is far to heavy for this to produce any measurable effect. However, Winglee proposed that if a light spacecraft could generate a large magnetic field, the solar wind would propel the spacecraft. He calls this hypothesis Mini-Magnetospheric Plasma Propulsion, or M2P2.

Winglee and his colleagues suggest that a 200-kilogram spacecraft (including 50 kilograms of helium) might be built around an electromagnet coil powered by solar cells. Winglee's group demonstrated that injecting ionized helium into a coil's magnetic field forces the field to expand like a bubble, becoming a mini-magnetosphere. They calculate that in space this magnetosphere would be 15 to 20 kilometers in radius, and with the solar wind pushing on it, the craft should reach speeds of 50 to 80 kilometers per second after three months. This is ten times faster than the speeds previously reached by chemical rockets. Such a craft could reach Saturn in six months instead of the seven years required for the Cassini mission.

The mini-magnetosphere is not really spherical. Its shape depends upon its interaction with the solar wind and on the parameters of the coil. To oversimplify, a mini-magnetosphere may be pictured as a flat sheet of paper orbiting the Sun. If the sheet is tilted so that its leading edge is closer to the Sun than its trailing edge, solar wind particles bouncing off of it will push it forward in its orbit and make it go faster and spiral outward from the Sun. Conversely, if the trailing edge is closer to the Sun, solar wind particles will slow it in its orbit, and the Sun's gravity will pull it inward. Since the magnetosphere is practically without mass, it should be easy to maneuver it by simply rotating the field-generating coil.

The concept of propelling a craft with solar sails is similar to M2P2, but these sails are propelled by sunlight, not the solar wind. At the orbit of Earth, the pressure of sunlight is about 9 newtons (2 pounds) per square kilometer. An 820-meter square-rigged sail, named "the clipper" by its designers, is expected to have a mass of about 2,000 kilograms. Carrying a 2,000-kilogram payload, it could travel from Earth to Mars or to the outer planets in about the same time, or less, than a chemical rocket would require. Once solar sail technology is achieved, its use would be cheaper than the use of chemical rockets because it requires much less mass to be lofted into Earth orbit for each mission. Solar sails are also reusable. They can be returned to Earth orbit, but their sunward speed is limited by the relatively weak pull of solar gravity. Energy Science Laboratories of San Diego, California, has developed a novel sail fabric, a very porous mesh of carbon fibers. They have demonstrated that the fabric is light enough to be pushed by laser light, and that it can withstand temperatures of 2,500 degrees Celsius. This is important because, someday, solar sails may be given a push by shining a battery of high-intensity lasers on them.

Electric Propulsion

The thrust produced by a rocket depends upon how much reaction mass is ejected per second, and how fast it is ejected. Chemical rockets can deliver a large amount of thrust because they can push out a great deal of mass per second, but ejection speed is limited by the amount of energy released by the chemical reaction of fuel and oxidizer. Electric propulsion engines typically deliver a small thrust with high efficiency since they can handle only a small amount of mass per second, but they can eject it at very high velocities. With a few exceptions, electric propulsion has been commonly employed only in the thrusters used by satellites for station keeping (staying where they are supposed to be).

Resistojets use electric resistance to heat propellent gases and thereby increase their ejection speed. They have operated with ammonia, biowastes, hydrazine, and hydrogen. Arcjets ignite an electric arc in the propellant flowing through a rocket nozzle. Arcjets are twice as fuel efficient as chemical thrusters, but ion engines are more efficient yet. The 480-kilogram spacecraft Deep Space 1 (DS-1) is propelled by an ion engine and powered by 2,400 watts from solar arrays. Launched on October 24, 1998, its mission was to test twelve new technologies, including the ion drive and a relatively autonomous navigation system. While DS-1 came within 26 kilometers of asteroid Braille on July 28, 1999, problems kept it from obtaining any closeup images. Its extended mission was to fly through the coma (head) of comet Borrelly on September 22, 2001, when it sampled the materials of the coma and photographed the comet's nucleus.

DS-1's ion engine uses xenon, a gas 4.5 times heavier than air, for a propellent. Xenon in the engine chamber is bombarded by electrons that ionize the xenon. The rear of the chamber is fitted with two wire mesh screens; the first is positively charged, while the second is negatively charged with up to 1,280 volts. Positive xenon atoms passing through the first screen are accelerated to 28 kilometers per second by the voltage on the second screen. The ejection of these ions into space propels the craft forward. Electrons sprayed into the exhaust stream keep the craft from building up a static charge. Although the engine exerts no more force than the weight of a sheet or two of paper, its 82 kilograms of xenon is enough for 6,000 hours of operation and can increase DS-1's speed by 4 kilometers per second. It is ten times more efficient than a chemical engine with the same weight of fuel.

Nuclear Power

The great attraction for using nuclear power in space is that nuclear reactions pack millions of times more energy than chemical reactions. While the United States placed a single nuclear reactor in space in 1965, the former Soviet Union has used small nuclear reactors to provide electrical power on dozens of satellites. Both nations have used radioisotope thermoelectric generators (RTGs) that convert the heat from radioactive decay directly into electricity, but neither nation has used nuclear power for propulsion. Since they have no moving parts and are well constructed, RTGs are considered to be relatively safe, but they are not very efficient. However, using electricity from an RTG to power an ion engine in the regions beyond Mars, where solar power is weak, is an attractive possibility.

The Nuclear Engine for Rocket Vehicle Application (NERVA) was almost ready for flight testing when the project was canceled in 1972. Under development for a manned mission to Mars, the NERVA engine heated hydrogen by passing it through the reactor core and then expelled it from a rocket nozzle. Uranium carbide fuel elements were coated with carbon and niobium to protect them from corrosion by the hydrogen propellent. The Mars craft would be assembled in Earth orbit and, using nuclear engines, it could travel to Mars, stay for two months, and return to Earth in the space of about one year. A program to develop a nuclear engine code-named Timberwind began in the 1980's and continues under the Space Nuclear Thermal Propulsion (SNTP) Program. Fluidized bed reactors and other advanced reactors that can operate at higher temperatures are being studied since they should be more efficient than the NERVA engine.

The most audacious nuclear engine is the nuclear pulse rocket that was the basis of the ORION project, which ended in 1965. The mass of the ORION vehicle was a grandiose 585 metric tons. The rear of the vehicle was connected by shock absorbers to a massive pusher plate. Every few seconds, a small fission bomb with a ten-ton yield was to be dropped out the back end and exploded about 100 meters behind ORION, so that the blast wave would drive ORION forward. About 2,000 bombs would be required for a 250-day round trip to Mars. To prove the concept, a small prototype was successfully launched from the ground with tiny chemical bombs, but international treaties now prohibit nuclear explosions in space, and therefore the ORION project is unlikely to be revived.

None of the proposed nuclear engines are very efficient at converting nuclear energy into a means of propulsion, but they are still attractive because of the large amount of energy in nuclear fuel. If the rare artificial element americium-242m could be produced in significant quantities, a much more efficient engine might be constructed. The key is that a thin film of americium-242m can sustain a chain reaction. High-energy fission fragments escape from a thin film and can be directed by magnets out the rear of the craft to provide propulsion. A spacecraft with such an engine might travel to Mars in two weeks instead of the eight to ten months required by chemical rockets.

Tethers and Bolos

Tethers up to 20 kilometers long have already been tested in space. A tether is a cable that can be unreeled from an orbiting craft such as the space shuttle. A mass on the far end of the tether will help keep it stable. The tether may be deployed upward by letting centrifugal force carry it farther from Earth, or it may be deployed downward by letting Earth's gravity carry it down. If the tether includes a conducting cable, it can be used to convert a satellite's momentum into electrical energy, since a conductor moving in Earth's magnetic field will act like a generator. To keep a current flowing in the cable, electron guns will expel electrons into space and prevent the buildup of a static charge. If used long enough, this system will bring down a satellite from low-Earth orbit, and thereby save the roughly 20 percent of rocket fuel that is reserved to deorbit spent satellites. If solar cells are used to produce a current in the tether, the generator becomes a motor, and the spacecraft's orbit will be raised. Because of the air resistance that exists in low-Earth orbit, the International Space Station needs a boost from time to time. If it were boosted with tethers powered by the station's solar panels, up to two billion dollars in fuel costs might be saved over ten years.

A bolo consists of two masses connected by a tether and set spinning. The end masses are equipped with grapples and thrusters to adjust position. Long tethers will probably be Hoytethers, a loosely woven Kevlar web. Their open structure makes Hoytethers less likely to be severed by meteoroids. If a bolo station (at the center of mass of the bolo) is in low-Earth orbit and therefore has a speed of 7.7 kilometers per second and the rotating tether's tip speed is 2.4 kilometers per second with respect to the station, the bolo's rotation direction is such that the tip speed subtracts from the orbital speed for the tip closest to Earth. A spacecraft launched from Earth need only be traveling at 5.3 kilometers per second when it rendezvouses with, and is seized by, the lower grapple. If the bolo is much more massive than the spacecraft, the spacecraft will be lifted and accelerated by the tether so that the spacecraft is traveling at 10.1 kilometers per second when the tip is farthest from Earth.

At the appropriate time, the bolo will release the spacecraft to travel to its next destination, perhaps a second bolo in geosynchronous orbit, which in turn might pass it on to a bolo in lunar orbit, which might set it on the Moon. The great efficiency of such a system is that it minimizes the fuel that must be lifted and accelerated from Earth. However, the bolos will slow down or fall into lower orbits as they give energy to the spacecraft. The bolo in low-Earth orbit could be boosted by using solar panels and a conducting tether. Other bolos might be boosted with solar-powered ion engines. Only steering energy would be required if the amount of mass going from the Moon to low-Earth orbit were the same as that going from low-Earth orbit to the Moon. (The falling mass would provide the energy to lift the rising mass.) A nearly constant flow of traffic would be required to make a bolo system cost-effective.

Charles W. Rogers

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See also: Advanced Space Transportation Program; Jet Propulsion Laboratory; National Aeronautics and Space Administration; Propulsion; Rocket propulsion; Rockets; Saturn rockets; Space shuttle; X planes

Advanced Space Transportation Program

Date: Established on August 5, 1994

Definition: A collection of research projects of the National Aeronautics and Space Administration (NASA) designed to improve space transportation beyond technologies existing at the beginning of the twenty-first century.

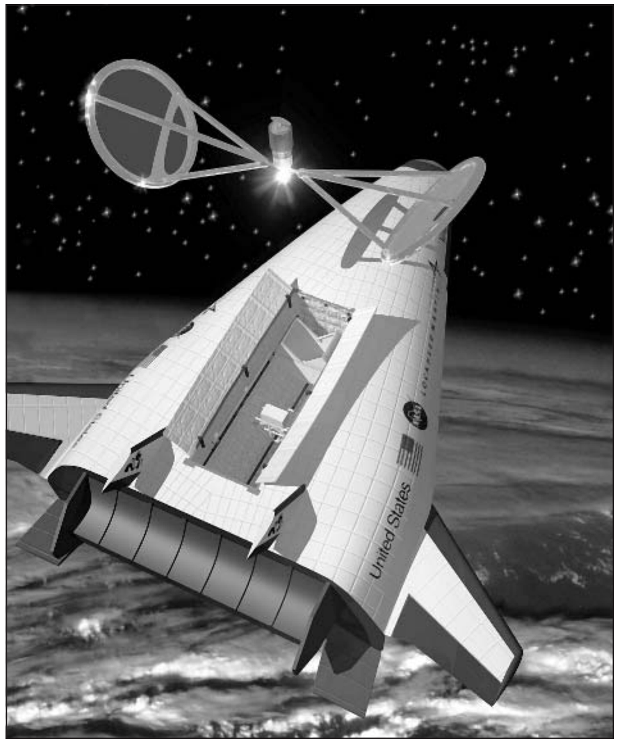
Significance: The goal of the Advanced Space Transportation Program (ASTP) is to develop new technologies to make space travel safer and more economical in the future than it is currently. In order to accomplish this task, the ASTP seeks to develop new methods of propulsion and new spacecraft designs.

Background

During the early days of space exploration, many of the top rocket designers in NASA thought that the best way to fly into space was with a self-contained spacecraft, reusable in much the same way that an aircraft is reusable after each flight. However, the technology to develop such a reusable spacecraft did not exist in the 1960's. In order to compete with the Soviet Union to develop a crewed space program, NASA decided to adapt existing missile technology as boosters for crewed spacecraft. Thus, the early Mercury and Gemini Programs used Redstone, Atlas, and Titan missiles as boosters. The difficulty with these boosters was that they had a tendency to fail in flight. Special care, therefore, was given to the individual boosters used in the crewed space program. The Saturn rockets, developed for the Apollo Program, were designed from the beginning as boosters for crewed spaceflight. The Saturn rockets, however, were essentially very large versions of the type of rocket used on earlier flights. Though not a single Saturn rocket ever failed catastrophically in flight, it was not considered to be much safer than earlier rockets. The designs of the Saturn rockets were an upgrade of existing technologies. Upgrading existing technologies was a way of achieving a lunar vehicle in the shortest time possible, with a goal of beating the Soviet Union to the Moon. Though mishaps occurred during the Apollo missions, none resulted in loss of life while in flight due to rocket failure.

In addition to the safety issues surrounding early rocket designs, another difficulty was that the spacecraft and rockets could be used only one time. A great deal of effort and expense went into the construction of the rockets, but they were used for only a few seconds to launch the spacecraft from the Earth. The spacecraft itself was a small capsule that was designed to be used for only one flight. With each space mission requiring its own rocket booster and spacecraft, space travel proved to be extremely expensive. As early as the 1970's, before the Apollo missions had even finished, NASA was investigating the possibility of a new spacecraft that would be safer and cheaper to operate. Such a spacecraft would be reusable numerous times. Due to budget considerations, the resulting spacecraft, the space shuttle, was a compromise solution. Only part of the spacecraft was reusable. Furthermore, the space shuttle was launched into space using modifications to existing technologies used to launch some uncrewed spacecraft. The space shuttle ultimately proved to be not nearly as reliable and safe as had been hoped. Following the solid rocket failure and the resulting explosion that destroyed the space shuttle *Challenger* on January 28, 1986, NASA implemented new stringent safety measures that added to the cost of space shuttle missions. Even with these new safety measures, it was recognized that there remained a significant chance for additional catastrophic launch vehicle failures that could result in loss of the spacecraft and crew.

One of the goals of the space shuttle program had been to provide an inexpensive and safe transportation system into low-Earth orbit (LEO) in order to promote and assist future space activities, such as launching and repairing satellites or constructing and servicing LEO space stations. The space shuttle has achieved a tremendous success record, and has made important strides toward opening LEO to greater development. However, by the late 1980's, NASA had come to realize that the space shuttle was far too expensive and unreliable for the needs of the foreseeable future. Ideas began to emerge for a replacement to the space shuttle as the primary workhorse of the crewed space program.



Reusable Launch Vehicles (RLVs) are part of NASA's Advanced Space Transportation Program, intended to lower the cost and efficiency of the United States' space program. (NASA)

Origins

The early work on a replacement for the space shuttle tended to be unfocused and was conducted by different departments and divisions within NASA. The National Space Transportation Policy of 1994 finally formalized the goal to develop new space transportation systems. This policy statement divided the responsibility of developing new space transportation systems into two categories: new reliable, expendable launch vehicles and new reusable launch vehicles. Research toward developing new expendable launch vehicles was to be done by the Department of Defense. Research on the development of a second-generation reusable launch vehicle was to be NASA's responsibility. Soon afterward, NASA organized the Advanced Space Transportation Program (ASTP) to oversee the development of new reusable spacecraft. The ASTP is headquartered at the Marshall Space Flight Center in Huntsville, Alabama. Research related to the ASTP, however, is conducted at nearly all NASA centers and in many university and aerospace industry laboratories.

The primary goals of the ASTP are to reduce the costs of launching payloads into LEO from more than $10,000 per pound in the year 2000 to about $1,000 per pound by approximately the year 2010, and as little as about $100 per pound by 2025. The ultimate goal is to reduce payload launch costs to only about $10 per pound by 2040. Such inexpensive launch technology would permit a great expansion of space-related activities by both government agencies and private enterprises. In addition to reducing costs, the ASTP seeks to increase safety. Upgrades and improvements to the space shuttle are expected to increase safety margins by a factor of ten by the year 2010, when new space transportation systems may become available. Within twenty-five years, NASA hopes to make space travel one hundred times safer, and within forty years, to make space travel nearly one thousand times safer. In order to achieve the increased cost-effectiveness and safety, NASA cannot simply rely on improvements to the space shuttle. New technologies and spacecraft must be developed. This was the responsibility of the ASTP.

Integrated Space Transportation Plan

The National Space Transportation Policy of 1996 reinforced the policy statements of 1994. The ASTP was enlarged and expanded and became the Integrated Space Transportation Plan (ISTP). The ISTP goals and timetables were the same as the ASTP's for reducing costs and increasing safety for space travel. The first steps toward those goals were to upgrade and improve the space shuttle fleet, NASA's first generation of reusable launch vehicles. The ISTP would also upgrade technologies to develop a new reusable vehicle to service the International Space Station (ISS). This new vehicle is to be a second-generation reusable launch vehicle operating similarly to the space shuttle, but much more efficient and advanced. The second-generation vehicle is expected to achieve the cost and safety goals for 2010. To achieve the remaining goals, however, requires the development of entirely new technologies and systems, not just revisions and upgrades of existing technologies and systems. Thus, the ASTP was incorporated within the ISTP to develop the third- and fourth-generation reusable launch vehicles needed for the future.

One of the ASTP's areas of research is in new rocket systems designed to operate with more efficient engines or using new propellants. Another consideration is the possibility of using radically new types of propulsion, such as nuclear or solar power. Further considerations include using external propulsion, in which the rocket is pushed into space by some force outside it, such as magnetically levitated craft, beamed energy systems, or tethers. In addition to researching new propulsion systems, the ASTP also is investigating new spacecraft designs capable of higher-speed atmospheric flight, and self-diagnostic systems capable of detecting failures before they occur. Most ASTP projects are still in the planning stages, and a majority may well never be constructed as new ideas emerge. Because the technologies envisioned with the ASTP do not yet exist, it is difficult to say exactly what form they will take.

New Rocket Designs

New rocket designs range from more efficient uses of existing technology to radical new technologies. An example of an engine based on existing technology is the Fastrac engine, designed with a small number of readily available existing parts. The engine is reliable and inexpensive to build; it may ultimately cost as little as 10 percent of the construction costs of current rocket engines. A new rocket engine technology is the pulse detonation rocket engine. This engine operates in pulses rather than continuously, as with most rocket engines. Propellant is injected into the reaction chamber and detonated with a spark plug, creating a short burst of thrust. Such an engine can be made to be very powerful and efficient.

In addition to new designs for rocket engines, ASTP researches new propellants. Currently, launch boosters require separate fuel and oxidizers. A monopropellant, a propellant that is self-oxidizing, would require less storage space in a rocket and fewer propellant tanks, thus saving rocket weight and permitting heavier payloads to be lifted for the same cost.

Another strategy being considered for more cost-effective rockets is an air-breathing rocket. Current rockets carry both fuel and oxidizer as propellant. If a rocket could take oxygen from the atmosphere as it flies, in much the same way that a jet engine does, then there would be no need to carry oxidizers and the savings in weight could be used to carry additional payload. Such an engine could conceivably permit a spacecraft to take off and land in a manner similar to that of a commercial jet aircraft, and may be completely reusable, reducing spacecraft cost.

New Spacecraft Designs

In order to utilize some of the new propulsion technologies, new airframe designs are needed to permit hypersonic flight many times the speed of sound. Furthermore, lighter-weight yet strong airframes would permit heavier payloads to be carried, reducing the per-pound cost of launches. Spacecraft design goals include improvements to permit a single spacecraft to operate for up to one thousand missions, a tenfold increase beyond the operational lifetime of the space shuttle. Furthermore, spacecraft servicing is expected to be simplified, so that a spacecraft may be serviced, much like a transoceanic airliner, between missions by only a few dozen personnel in less than a day. These innovations could reduce the cost of putting a payload into LEO to only a few hundred dollars per pound within two decades. To facilitate quick and effective maintenance, an integrated vehicle health management system is envisioned. In such a system, all parts of the spacecraft would have sensors that would be linked to a central computer that would monitor vehicle health and performance. The goal of an integrated vehicle health management system would be to detect weaknesses and defective parts before they become problems. This would make maintenance both easier and much less expensive.

New Propulsion Systems

In order to achieve the goals of the ASTP, entirely new propulsion systems may be required. Areas of research include both active and passive propulsion. Passive propulsion systems include magnetically levitated vehicles that would accelerate up to 600 miles per hour prior to takeoff along a magnetic track in much the same way as a magnetically levitated train. This initial velocity would mean that less rocket propulsion would be needed to achieve orbit. Focused-beam energy systems, such as high-powered lasers or microwave transmitters, could also be used to push objects into space. In such a system, fuel would not be needed and the spacecraft could be designed to carry primarily a payload.

Many payloads need to be deployed beyond LEO. Once in space, miles-long tethers can be deployed to utilize the Earth's magnetic field to change spacecraft orbits without the need of rockets. A tether system was tested with limited success from the space shuttle in 1996. Away from Earth, solar electric ion propulsion may be used for uncrewed interplanetary trips. Solar cells can create electricity from sunlight, and this electricity can be used to accelerate ions from the engine to propel a spacecraft. NASA tested such an ion-propelled spacecraft, called Deep Space 1, in 1998. Other proposals include the use of nuclear reactors to power spacecraft. The nuclear reactor could be used to power an ion engine. If a suitable fusion reactor could be developed, then it may even be possible for a spacecraft to scoop hydrogen atoms from space as it travels to use as nuclear fuel, thus minimizing the need to carry vast amounts of hydrogen with it.

It is hoped that the ASTP will yield new technologies such as these or even ones not yet considered. These new technologies will gradually displace the current generation of chemical-powered rockets used for space travel, thus yielding a safer and more cost-effective space transportation system.

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See also: Advanced propulsion; Apollo Program; Gemini Program; Mercury project; National Aeronautics and Space Administration; Rocket propulsion; Rockets; Saturn rocket; Space shuttle; Spaceflight

Aer Lingus

Also known as: Aer Lingus Teoranta

Date: Founded and incorporated on May 22, 1936

Definition: Government-owned international airline of the Republic of Ireland. Aer Lingus is a member of the oneworld Alliance.

Significance: Aer Lingus is the national flag carrier of the Republic of Ireland. The state-owned company was originally made up of two separate airlines: Aer Lingus Teoranta and Aerlinte Eireann Teoranta. These separate entities merged into one corporate structure during the 1970's.

Origins

The name Aer Lingus originated from the Gaelic term *aer loingeas*, which means "air fleet." The first Aer Lingus flight took place on May 27, 1936, when a De Havilland 84 took off on a flight to Bristol, England, from Dublin's old Baldonnel airfield. Beginning in 1946, operations were divided between Aer Lingus Teoranta for regional and European activities and an associate company, Aerlinte Eireann, for international flights.

Events in Aer Lingus History

1936: Aer Lingus Teoranta is established by the Irish government.
1947: Aer Lingus's associate company, Aerlinte Eireann, plans international service.
1958: Aerlinte Eirann makes first transatlantic flight from Dublin to New York.
1984: Aer Lingus Commuter airline is established.
1987: An independent Irish carrier, Ryanair, creates low-fare competition for Aer Lingus.
1999: Aer Lingus adds service to Los Angeles.
2000: Aer Lingus joins the oneworld Alliance.

Routes and Expansion

In 1938, Aer Lingus relocated to Dublin's new airport at Collinstown. The company grew steadily, and flight operations continued during World War II, with scheduled flights between Dublin and Liverpool and the Isle of Man. After the war, Aer Lingus's expansion accelerated, and service was initiated to London and Paris. Transatlantic flights to New York were attempted in 1947, but the Irish government soon decided to cancel these flights due to the high costs of operation. In the 1950's, Aer Lingus expanded its network to various European destinations. In 1958, the flights to New York resumed and by the early 1960's, the company started service to Boston and Canada.

During the late 1970's and 1980's, Aer Lingus found itself in the middle of a crisis. To remain competitive in the changing marketplace, the company was forced to initiate a major reorganization, to abandon numerous overseas destinations, to reduce its air fleet, and to close several of its international sales offices. However, the airline continued to grow regionally. In 1984, a subsidiary, Aer Lingus Commuter, was created to serve the shorter routes. In the 1990's, Aer Lingus reestablished itself as a leaner and more competitive carrier. Several of the routes that had previously been eliminated were reinstated, and flights to Chicago, Newark, Los Angeles, and several continental destinations were added to the airline's schedule.

Fleet and Safety

The first Aer Lingus aircraft was a six-seat De Havilland 84 Dragon biplane, which entered service in May, 1936. Operating initially with different versions of the DH-84 and DH-89, the airline added two Lockheed 14 and two Douglas DC-3 aircraft to its fleet in 1939. However, after acquiring seven Vickers Vikings in 1947 for continental services, the company decided to make the switch to more reliable DC-3 aircraft.

In 1954, Aer Lingus took delivery of its first jet-prop aircraft, the Vickers Viscount 707. Fokker F-27's were added in 1958. During the same period, Aer Lingus was leasing Super Constellations for the service to New York, but these aircraft were soon replaced when company management decided to purchase its first real jets: the B-720. Later that decade, B-707's were introduced on the transatlantic routes and BAC 1-11's on the continental routes. The company continued to change its fleet mix to become more efficient. In the 1970's, Aer Lingus introduced the B-747 to its fleet and purchased several B-737 aircraft. The following decade, Aer Lingus Commuter entered service with Irish-made Shorts 330/360 aircraft. However, by the late 1990's, the company was operating British Aerospace BA-146's and Fokker 50's on many of its routes. Also, several older, midrange aircraft were replaced with more modern Airbus A321 equipment. In 1995, Aer Lingus retired all its B-747's and decided to lease Airbus A330 aircraft to serve the transatlantic routes. By 2000, the Aer Lingus fleet, serving both Europe and the United States, consisted of about forty aircraft, among which were fifteen European Airbuses, thirteen B-737's, and twelve regional jets. Overall fleet modernization continued well into the new millennium, as new continental destinations were added to the flight schedule.

Early hull losses at Aer Lingus were significant. Between 1947 and 1952, the carrier lost two DC-3 aircraft in crashes. Twenty-three people died in a 1952 accident at Gwynynt Lake, England. Three more airplanes, Vickers Viscount aircraft, were destroyed during the period from 1967 to 1968. Sixty-one people died in the accident that occurred in Wexford Harbor, Ireland, in 1968. After the 1968 disaster, however, Aer Lingus's safety record improved significantly. For the period from 1969 to 2000, no mishaps were reported.

Company Strategy and Alliances

From its inception, Aer Lingus was managed as two separate companies. In the mid-1970's, Aer Lingus Teoranta and Aerlinte Eireann completely merged all operations under the umbrella of Aer Lingus, and the parent company adopted its distinctive shamrock logo. During that same period, Aer Lingus, like many other airlines, decided to diversify. The company acquired a major stake in the Irish Intercontinental Hotels, invested in engineering firms and aircraft brokerage companies, and actively developed its own air-charter business.

During the challenging 1980's, Aer Lingus's company management scaled back its previous ventures, eliminating many to focus on the airline's core business. During this period, Ryanair, a new low-cost Irish carrier, became a major competitor for Aer Lingus on many of its United Kingdom and continental routes. Aer Lingus struggled through the early 1990's but got back on track when air traffic rose by 30 percent in the middle of the decade. However, to deal with the market pressures and the rapidly changing global airline environment, Aer Lingus management decided to pursue partnerships with other international carriers. In 2000, Aer Lingus joined the oneworld Alliance, made up of American Airlines, Qantas, British Airways, and many others, allowing the company to extend its global reach as an established international carrier.

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See also: Air carriers; Airports

Aerobatics

Definition: Any aerial maneuver involving abrupt or extreme bank or pitch angles, unnecessary for normal flight.

Significance: Aerobatics are an integral part of military flight tactics, air show demonstrations, and sport flying. An aerobatic pilot's ability to retain spatial orientation and control an airplane in three dimensions provides an extra measure of safety in the event of an accidental upset.

Regulations

Most aerobatic flying is for pleasure, but regional and national contests are held every year, and a world championship contest is held every other year. Although there is no separate aerobatic rating, aerobatics can be safely learned only in an aircraft that is certified for the maneuvers and only under the tutelage of an experienced instructor.

Specifically, the U.S. Federal Aviation Regulations require approved parachutes when two or more occupants in an airplane intentionally exceed a bank of 60 degrees or a pitch angle of 30 degrees relative to the horizon. The basic aerobatic maneuvers are the slow roll, loop, spin, snap roll, aileron or barrel roll, and the wingover/hammerhead stall. Competition and air show figures combine these basic maneuvers into complex upright and inverted versions. In the absence of a special waiver and to protect passengers and the general populace, intentional aerobatic maneuvers must be performed away from crowded air space, above only sparsely populated areas, and at altitudes greater than 1,500 feet above the surface.

Aerobatic aircraft include some gliders and helicopters. Because aerobatics places extra structural and stability demands on an aircraft, only approved maneuvers may be performed in a particular aircraft. For aerobatic certification in the United States, an airplane must be capable of withstanding g-load factors from minus 3 to 6 without permanent deformation and loads of up to 50 percent greater (minus 4.5 to 9) without structural failure. The g-load factor, popularly known as the number of "g's," refers to the acceleration of gravity. Sitting still on Earth, one experiences an acceleration of 1 g, or a gravitational force of 1, the normal sensation of gravity. During periods of changing acceleration, such as a banking turn in an airplane, the so-called g-loading will change. Although the g-load factor in upright level flight is 1, it becomes minus 1 in inverted level flight. The best aerobatic aircraft, including those suitable for competition at the highest level, are stressed for load factors of 12 or more g's.

Aerobatics places extra physical demands on the pilot as well: loss of consciousness (positive g-load factors) or burst blood vessels (negative g-load factors) result from sustained high load factors. Military pilots have g-suits that help keep blood in their heads during positive load factors, whereas competition pilots use reclined seats and muscle tensing. A pilot's tolerance to g-loads increases with practice.

Slow Roll

The slow roll is the most basic roll maneuver and the hardest to learn. It must be mastered before solo aerobatic flight should be considered. In this maneuver, the aircraft is rolled about its longitudinal, or nose-to-tail, axis without altering the direction of flight.

Differential aileron deflection provides the torque that produces the roll. The other two controls, the elevator and the rudder, are used to keep the airplane from turning. When the roll is initiated, the opposing rudder must be used, and this reaches a maximum at about one-quarter, or about 90 degrees, through the roll. As the wings lose lift, the elevator must simultaneously be moved toward neutral. For the next quarter-roll, the rudder pressure is reduced, and forward elevator is added, as the wings are asked to generate negative lift. For the next 90 degrees of roll, rudder pressure in the direction of the roll is added and the elevator is gradually neutralized. In the last 90 degrees, elevator pressure is increased to the value before the roll was initiated, in level flight. The roll can be stopped at any point by neutralizing the ailerons; a momentary stop every 90 degrees, for example, yields a four-point roll.

The slow roll is difficult to learn because elevator and rudder inputs are constantly changing in a manner completely different from those of other maneuvers, because the forces on the pilot are so different and constantly changing, and because even a small error can place the aircraft in an inverted dive from which a safe recovery can be difficult. If the roll is initiated from level flight, the pilot senses an apparent weight that varies from normal to zero to upside down to zero to normal, corresponding to g-load factors varying from (at least) 1 to 0 to –1 to 0 to 1.

Attempts to teach oneself this maneuver will almost certainly cost a great deal of altitude and exceed design speeds and loads. Beginning pilots often fail to add enough opposite elevator as they near inverted flight, causing the nose to drop and allowing the speed to drop and then build very rapidly. At this point, pilots are disoriented and distracted by hanging from their shoulder harness and will relax the aileron pressure, causing the roll to stop. The natural and almost guaranteed reaction is then to pull back on the stick or wheel, attempting a recovery with a dangerous half-loop. A similar disastrous reaction can be expected from a nonaerobatic pilot when wingtip vortices or atmospheric turbulence flips the plane well past a 90-degree bank.

The slow roll has been mastered when the control inputs are instinctive, based on what the pilot wants the nose to do. Rudder pressure on one side always moves the nose in that direction, and forward movement of the stick or wheel always moves the nose away from the pilot. Once this concept is learned, slow rolls in any direction—straight up, straight down, or at an angle to the horizon—can be safely executed. However, the vertical, climbing roll is always a challenge, because it lacks a forward reference point and poses the danger of an inadvertent tail slide.

A slow roll is anything but slow in a modern, competition aerobatic airplane, in which roll rates of 720 degrees per second are not uncommon. The roll can be completed so rapidly that there is little time in which to encounter difficulties. Jet fighters can roll very rapidly without requiring rudder input.

Loop

A loop is one of the prettiest and most enjoyable aerobatic maneuvers, but skill is required to perform it safely and well. If the pull-up is made too abruptly, the aircraft can suffer either structural damage or a high-speed stall and will not complete the top of the loop. If the pull-up is too gradual, or if there is inadequate speed, the aircraft will run out of speed and fall inverted out of the maneuver.

A smooth but noncircular loop requires a g-load factor of 3 to 3.5, whereas a competition-quality circular loop may require a g-load factor of 6. Good aerobatic aircraft are fully symmetrical and can loop from level flight from either erect or inverted flight. A wingtip can be used for spatial reference during the second quarter of the loop, when the horizon will be hidden but, once over the top, the pilot will look overhead for the beautiful sight of the reappearing horizon. Competition-quality "square" loops can generate momentary g-load factors of 10 or more.

The first pilots to perform the loop, in 1913, were Petr Nesterov of Russia and Adolphe Pégoud of France. In 1928, Speed Holman of Minnesota broke the world's upright looping record by performing 1,433 consecutive loops in a five-hour period.

Spin

A spin's downward spiral makes it a crowd pleaser, although it is not a particularly pleasant maneuver for the occupants of the plane. A spin is normally initiated at a speed close to the stall speed with power off, neutral aileron, and full rudder and elevator deflection. After about one turn, the spin should stabilize in a nose-low position, and the airspeed should stabilize at a relatively slow speed, because both wings should be stalled, one more than the other, creating considerable drag. Recovery is usually effected with full opposite rudder to stop the rotation and then at least a relaxation, if not a reverse deflection, of the elevator control. Pulling out of the resulting dive generates a g-load factor of 2 or more. All aerobatic pilots must be very well versed in the spin characteristics of their aircraft, because any failed maneuver often degenerates into a spin.

In a true, stable spin, the spin can be continued as long as altitude remains and the airspeed does not increase. Utility aircraft certificated for spinning may appear to give a good spin entry, but the spin may become a diving spiral, increasing the speed. The same will happen in a good aerobatic airplane if the pilot does not hold full elevator and rudder deflection.

Heavy aircraft such as fighter aircraft may show wild gyrations upon spin entry and an oscillating pitch attitude once the spin is established. The World War II P-51D Mustang, for example, would oscillate from near-vertical to above the horizon and would lose about 1,000 feet per turn; spins were not to be performed below 12,000 feet.

Fully aerobatic aircraft can perform inverted spins as well as upright spins, but the aircraft recovers to inverted, stalled flight when the rotation is stopped, from which recovery to level flight should be made with a slow roll to minimize altitude loss. The rudder may suffer less blanking in inverted spins, allowing recovery to be faster. The inverted spin is much more disorienting than an upright spin and the pilot must concentrate on maintaining full elevator deflection, or the spin will transition to a diving spiral with rapidly increasing speed. If recovery from an upright spin is forced with down elevator and power, some aircraft will flick into an inverted spin.

If the aircraft is not certified for spins, or if the center of gravity is too far aft, the spin may be an unrecoverable flat spin with the nose on the horizon, yawing almost entirely rather than exhibiting nearly equal yaw and roll. Modern aerobatic aircraft with fully inverted fuel and oil systems, however, can force an upright or inverted spin to go flat with power and aileron deflection against the spin. These flat spins not only are recoverable but also form an important part of many air show routines.

Because it is such an important maneuver, the spin is the only aerobatic maneuver required of pilots seeking to become flight instructors. The requirement for parachutes is waived if an instructor is teaching an instructor-student. Considering that a low-altitude stall that degenerates into even an incipient spin remains a leading cause of fatal accidents, it would seem reasonable for more pilots to become familiar and comfortable with efficient recoveries from incipient spins, entered in the same fashion as accidental spins. Lieutenant Wilfred Parke of England is generally credited with first using what became the classic spin recovery method, in 1912.

Snap Roll

A snap roll, also known in England as a flick roll, uses the same control inputs as the spin, but in a snap roll, the controls are applied with power on and at speeds well above the unaccelerated stall speed. The resulting differential lift of the wings produces a rapid roll that can be very difficult to stop at a precise point. Good aerobatic aircraft can execute three or more consecutive snap rolls, both upright and inverted, before the axis of the roll changes excessively and the roll degenerates into a power spin. The load factor varies, as the square of the entry speed is divided by the unaccelerated stall speed, but a considerable twisting moment is also applied to the fuselage. This maneuver, among others, teaches the aerobatic pilot that an aircraft can exceed the critical angle of attack at any airspeed and at any angle relative to the horizon.

Aileron Roll

The most comfortable rolling maneuver is the aileron roll, also known as the barrel roll. It is performed through coordinated use of the ailerons and rudder, basically continuing a climbing steep turn to a 90-degree bank, letting the nose fall through the horizon with reducing elevator pressure as the roll continues to inverted flight and then recovering with increasing elevator pressure back to upright flight. The nose will trace out a sort of circle around a point on the horizon. The radius of the circle depends on the roll rate; if the roll is slow, the circle must be large and the top of the circle must be far above the horizon to keep the nose from dropping too low and building up a great deal of speed in the lower half of the maneuver. G-load factors of close to 1 throughout the maneuver are achievable. An expert pilot can perform this kind of roll in almost any airplane; in 1955, test pilot Tex Johnston barrel-rolled the prototype Boeing 707 airliner at a flight demonstration for potential customers.

Wingover and Hammerhead Stall

The hammerhead stall and the wingover are the most common turnaround maneuvers used by air show performers to maintain their presence in front of the audience. A wingover is a maneuver that changes the flight direction through 180 degrees with negligible net change in altitude. It is performed by simultaneously raising the nose and smoothly banking to a 90-degree bank angle as the flight direction changes by 90 degrees and then smoothly reducing the bank angle to 0 degrees in a descending turn to level flight in the opposite direction. Load factors should be in the range of 0 to 2 for a smoothly executed wingover, because there is no attempt to maintain level flight in the steeply banked turn.

In the hammerhead stall, known in England as the stall turn, the aircraft is pitched straight up with power on until it is pointing straight up. Shortly before the craft runs out of airspeed, full rudder is used to rotate the nose to the right or the left, and the rotation is stopped when the aircraft is heading straight down. Recovery may be to either upright or inverted level flight. Load factors need not exceed 2 or 3 if the initial entry and the pullout in recovering are smooth and to upright flight. The "stall" part of the maneuver's name is a misnomer, because the angle of attack is close to zero during the maneuver, and no stall buffet should be felt. An aircraft with a clockwise propeller rotation from the pilot's view will rotate best to the left. The greatest danger is waiting too long to use full rudder, allowing the aircraft to slide back on its tail, known as a tailslide, which could damage some of the control surfaces on otherwise aerobatic aircraft.

Advanced Aerobatic Maneuvers

The Immelmann turn, named after German World War I fighter pilot Max Immelmann, is a half-loop followed by a half-roll to upright flight. If the speed is low or the loop is stopped too abruptly, a sudden flick into an inverted spin is possible.

The Cuban Eight combines three-quarters of a loop, a roll to upright, another three-quarters of a loop, and a roll to upright again. From the ground it appears in the form of a horizontal eight.

The rolling turn, a very demanding maneuver to do well, combines a 360-degree turn with a roll, either to the inside or the outside of the turn. The square loop attempts to minimize the radius of the turns at the top and bottom of the loop and generates some of the highest momentary load factors.

The lomcovàk is a spectacular, twisting, tumbling maneuver invented by the Czech Ladislav Bezák in 1957. It is usually entered from a climbing, inverted snap roll and is commonly demonstrated at air shows.

Another spectacular maneuver is the torque roll, in which the airplane is rolled pointing straight up, and the roll is continued, with the help of engine torque, for a number of fuselage lengths in the ensuing tailslide.

Powerful aerobatic airplanes can generate enough fuselage lift and horizontal thrust component to maintain level flight in a 90-degree bank, known as knife-edge flight. Russian pilots have demonstrated the cobra maneuver, in which a jet fighter, flying in level flight, is abruptly pitched up through 90 degrees of rotation or more, recovering to level flight with relaxation of the stick.

Aresti Symbols

The distinguished Spanish aerobatic pilot Colonel José Luis de Aresti Aguirre developed a shorthand notation for aerobatic maneuvers. First published in 1961, Aresti symbols have become universally used to outline aerobatic routines for both contests and air shows. Each figure in Aresti's dictionary includes a difficulty, or "K," factor, by which, in contests, judges' scores—from 0 to 10—are multiplied.

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See also: Air shows; Airplanes; Barnstorming; Skywriting; Wing-walking

Aerodynamics

Definition: The study of airflow over bodies.

Significance: Knowledge of aerodynamics allows for the prediction of the forces and moments on airplanes. This allows the design of safe and efficient aircraft that can perform a large variety of tasks ranging from small radio-controlled craft to airliners and supersonic military airplanes.

Historical Aspects

In the late seventeenth century, English physicist Isaac Newton laid the foundations for not only modern mechanics and calculus but also fluid mechanics. Newton's analysis of fluid flow considered air to be composed of individual particles that struck a body's surface. This analysis was applied to determine the drag of an object in a moving fluid stream but gave poor results, because it did not account for the effect of the wing or body on the oncoming air. Interestingly, it later proved to be far more valuable in hypersonic flow analysis. Swiss mathematician Daniel Bernoulli and his father, Johann I, both published treatises in the 1740's that greatly clarified the understanding of the behavior of fluid flows. Eighteenth century Swiss mathematician Leonhard Euler noted the problems with Newton's model and proposed a more accurate formula for drag in 1755.

Subsequent aerodynamic theories developed in the 1800's and early 1900's were based on the works of Newton, Euler, and the Bernoullis. In 1894, British inventor Frederick William Lanchester developed a theory that could predict the aerodynamics of wings. However, Lanchester published this work many years later, in 1907. An acquaintance with Lanchester's theory might have saved considerable effort for Orville and Wilbur Wright, who first flew a heavier-than-air craft in 1903. Instead, the Wrights gained an understanding of aerodynamics through numerous wind-tunnel experiments conducted in their homebuilt wind tunnel. Subsequent advances in aerodynamics are associated with individuals, including Max Munk, Adolf Busemann, Ludwig Prandtl, and Robert Jones, who developed the principles of aerodynamic analysis.

Aerodynamic Flight Regimes

Fluids comprise both gases and liquids. A major difference between a fluid and a solid is that a fluid deforms readily. The major distinction between a gas and liquid is that a liquid is difficult to compress. The atmosphere is a gas composed of 78 percent nitrogen, 20.9 percent oxygen, 0.9 percent argon, 0.03 percent carbon dioxide, and in very small quantities, neon, helium, krypton, hydrogen, xenon, ozone, and radon, based on their volume. The study of the behavior of a body immersed in a moving liquid is called hydrodynamics; in a moving gas, gas dynamics; and in air, aerodynamics.

Aerodynamics may be categorized as either low- or high-speed, depending on where the fluid behavior changes. A common demarcation is subsonic and supersonic flow, where the latter has airspeeds greater then the speed of sound. Transonic flow, where both sub- and supersonic flow may exist, is also usually treated as a distinct regime. Increasing airspeed sees supersonic flow evolving into hypersonic flow at about five times the speed of sound. Difficulty in the analysis of airflow has additionally resulted in airflows being divided into viscous flows and inviscid flows, in which the latter are assumed to have no viscosity and are generally much simpler to analyze. The basic principles underlying aircraft flight are well described assuming inviscid flow.

Basics

The flow of air over a body is governed by the so-called continuity equation and the momentum equations. These equations state that mass can be neither created nor destroyed and that the sum of the forces experienced by a body equals its rate of change of momentum, or its quantity of motion. Analysis of these equations applied to various flight problems laid the foundations of aerodynamics. As air flows over an airplane, the plane causes the air to change its velocity, which also leads to changes in the static pressure distribution over the aircraft. The static pressure is the pressure that is felt when moving at the speed of the airstream. The static pressure distribution causes forces and moments, or torques, over the aircraft. The equation that relates velocity and static pressure is referred to as Bernoulli's principle.

Subsonic Airflow over Airfoils

The forces and moment that an aircraft experiences are affected by the air density, which in turn is affected by air pressure, temperature, and the amount of moisture in the air, as well as the speed and size of the airplane. As the aircraft flies through the air, it displaces air downward. By pushing the air down, the aircraft's wings experience a reaction force that tends to push the airplane up, creating lift. The lift is defined as being perpendicular to the oncoming airstream. One may imagine the lift of a wing flying along a wave of high pressure to be somewhat like a surfer on a surfboard riding an ocean wave.

In cross section, the wing of an airplane is composed of an airfoil profile. The shape of the airfoil profile's camber line, which is the line equidistant between the upper and lower surface of the airfoil, increases the lift generated at a given angle of attack if the airfoil has positive camber. Positive camber indicates that the leading edge and trailing edges, or the front and back of the airfoil, are curved down. If the airfoil has negative camber, the lift generated at a particular angle of attack is reduced compared to that of a flat airfoil with no camber. Consequently, positive camber or curvature of the camber line has the effect of increasing the lift by a constant amount for a given angle of attack, compared to a flat or symmetrical airfoil. The larger the camber of the airfoil, that is, its curvature, the greater the lift the airfoil will generate. This effect is most pronounced as the location of the maximum camber, or highest point of the airfoil, moves to the trailing edge, or back of the airfoil. The thickness of the airfoil, with reasonable accuracy, does not directly affect the lift the airfoil section generates, but it may affect the nature of the airfoil's stall.

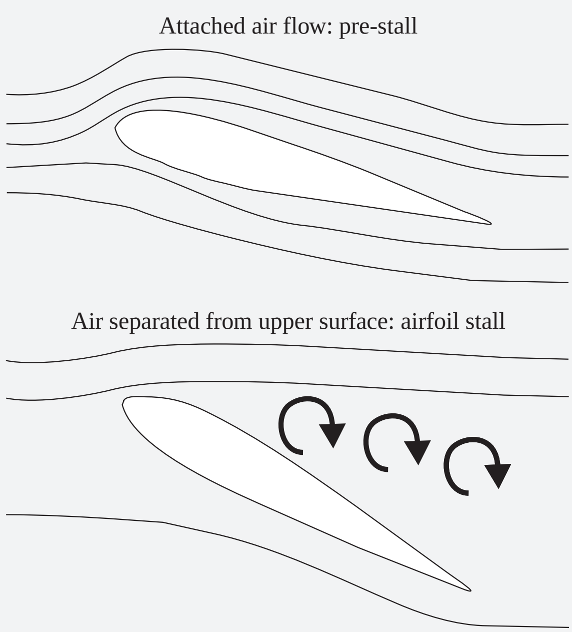
The shape of the airfoil profile and its thickness distribution have a profound effect on the nature of the airfoil's stall. When an airfoil's angle of attack is greater than approximately 12 degrees, the majority of airfoils will stall. This condition is due to the air's viscosity and is caused by a disruption and separation of airflow over the airfoil's upper surface. Stall causes lift to decrease as the airfoil's angle of attack is increased. Flow separation also causes a large increase in drag, referred to as pressure drag. For very thin wings, or a flat plate, for example, the stall is quite moderate, and the loss of lift is gradual. For airfoils with a maximum thickness in the 9 percent range, where the maximum thickness of the airfoil divided by the length, or chord, of the airfoil is 0.09, the nature of the stall is quite sharp, and the loss of lift is dramatic. Thicker airfoil profiles, analogous to very thin airfoils, also have weak stalls, with a gradual loss of lift.

Numerous methods and devices have been developed to delay the stall of airfoils. These usually comprise a modification to the nose of the airfoil and typically involve pointing the nose down or extending it off the airfoil and rotating it down. These devices are referred to as leading-edge flaps, or slats. Some birds use a similar concept with a feather called the alula, which forms a slat and stops the bird's wing from stalling. For a given angle of attack below stall, these leading-edge devices generally do not much change the lift of the airfoil. However, they do extend the lift range of the airfoil and can increase it up to 10 degrees beyond the typical stall angle. These types of devices can be seen, and often heard extending or retracting, on airliners extending from the front of the wing at takeoff or landing.

On modern aircraft, all components are streamlined, that is, smoothly blended. The importance of streamlining became evident in the 1920's, when it was found that smoothly faired, or joined, bodies, such as aircraft wheels with aerodynamic fairing, had much lower drag than non-faired bodies. The fairing allowed the air flowing over the wheel to conform smoothly to the surface. Without the fairing, air would separate off the wheel and form large turbulent eddies, or swirling motions, in the wake behind the wheel, greatly increasing drag. The effect of streamlining is to reduce the tendency of the flow to separate off the surface. This separation is caused by the viscosity of the air.

Theoretically, at low speed in an inviscid airstream, an airfoil does not suffer any drag. This condition is known as d'Alembert's paradox, after eighteenth century French mathematician Jean le Rond d'Alembert, who calculated this apparent anomaly but was unable to explain it. The reason for the paradox was the exclusion of the effects of the air's viscosity in d'Alembert's calculations. Due to viscosity, airfoils experience a component of drag called skin friction drag. The skin friction is caused by the viscosity of the fluid layers near the airfoil surface. On the wing surface, the speed of the air is zero, a condition referred to as the no-slip condition. However, at some small distance above the airfoil surface, the airspeed reaches that which would occur if the flow were inviscid. The region between the surface and this point is referred to as the boundary layer. The nature and behavior of this boundary layer have a significant impact on the skin friction drag and stalling characteristics of the airfoil.

Airfoil Stall



Airplane manufacturers quickly realized that sleek, streamlined aircraft flew most efficiently. This P-51 Mustang, photographed in 1942, illustrates the principles of aerodynamic design. (Library of Congress)

The boundary layer can either be laminar, turbulent, or transitional from laminar to turbulent. A laminar boundary layer is composed of air moving in orderly lines. A turbulent boundary layer has air moving close to the airfoil surface in swirling motions. A laminar boundary layer has far lower skin friction drag than the turbulent boundary layer; however, it is also more prone to separate from the airfoil surface. Thus, most airfoils have an initially laminar boundary layer that flows from the front of the airfoil back along the surface. At some point, the boundary layer transitions from laminar to turbulent and is typically turbulent from this point to the trailing edge of the airfoil. Boundary layer transition can be caused by disturbances of insects, ice crystals, high airspeeds, and roughness or imperfections on the airfoil surface. To improve performance at high angles of attack by keeping the boundary layer attached to the airfoil upper surface, an aircraft designer may choose to cause the boundary layer to transition from laminar to turbulent at some point on the airfoil. This may be achieved using small protuberances attached to the airfoil's surface.

Ultra Low-Speed Flight

Efficient flight at very low speeds, such as those of slow-moving birds and insects, presents unique complications. Typical airfoil shapes do not generate much lift at these low airspeeds. The boundary layer at these low speeds is normally always laminar, and so easily separates off the airfoil surface. When this occurs, the lift of the airfoil decreases significantly and its drag increases. Insects and small birds such as hummingbirds use complicated wing motions to create lift at their low airspeeds. These insects and birds develop both so-called steady and unsteady lift, the latter of which is caused by the acceleration of the wing and its carefully performed motion through the air.

Subsonic Flow over Wings

If the wingspan of the aircraft were infinitely long and the air were assumed to have no viscosity, the wing would theoretically generate a lift force and a moment but no drag. However, aircraft do not have infinite wings, and thus an aircraft in steady cruise experiences lift and drag, as well as a pitching moment, which tends to move the aircraft nose up or down, and possibly either a side force, or yawing moment, which tends to displace the nose from side to side, or a rolling moment, which causes the aircraft to roll about its fuselage such that one wing is higher than the other. The lift of an airfoil is reduced when the airfoil is incorporated into a wing of finite length. The shorter the wingspan is relative to the chord of the wing, the less lift is generated. The largest losses of lift are near the wingtips.

On a finite-length wing, air from the lower surface of the wing tries to curl up around the wingtip to the upper surface, causing the formation of two tornado-like structures, known as wingtip vortices, that trail from both wingtips backward. These vortices possess high rotational speeds and pose a significant threat to other aircraft that may fly through them. These vortices require delays between takeoffs and landings of aircraft using the same runways at airports, in order that vortices may have time to weaken.

The component of drag due to the aircraft having a finite-length wing is called vortex drag. Generally, a wing's vortex drag is independent of its span. Thus, wings with either a large or a short span will, to a first approximation, develop the same vortex drag. The larger-span wing will, however, generate far more lift, and thus the vortex drag will have a greater effect for short-span wings. To keep the amount of vortex drag low compared to the lift generated, a wing should have a large span. This is the reason why airliners have wings with large spans, and also the reason why gliders have narrow-chord, large-span wings.

Aircraft may have many different types of wing shapes that are dictated by the aircraft's function. A glider flies at low speed but needs to generate a large amount of lift with little drag. As a result, glider wings have large spans but small chords. An airliner needs to fly efficiently but is limited in its wingspan by airport considerations. A large wingspan results in a heavy wing, which is required to support the wing structure. As a result, airliner wings have a large span but not as large as their chord.

As aircraft fly faster and approach the speed of sound, the flow over the wing changes. Shock waves may appear on the wings, even though the aircraft is still flying subsonically. An airfoil accelerates the air flowing over its upper surface such that it may become locally supersonic. A shock wave is a very thin flow discontinuity that occurs in supersonic flow and causes the airflow through it to slow down significantly. Shock waves are accompanied by large increases in drag on the airplane and are thus undesirable. A way to delay the onset of shock waves on wings is to sweep the wings back, a commonly seen design on airliners, in which most wings have a sweep of about 20 to 30 degrees. This sweep effectively reduces the airspeed that causes the shock waves to form and so allows the plane to fly closer to the speed of sound, normally about 760 miles per hour at sea level. The speed of sound varies with the square root of the air's temperature.

Supersonic Aerodynamics

When the airspeed is greater than the speed of sound, the airflow is said to be supersonic. Aircraft that are designed to fly supersonically have distinctive design features. At supersonic speed, a new component of drag, called wave drag, appears in addition to the vortex, pressure, and skin friction drag. The wave drag is usually caused by the presence of shock waves on the wing or airfoil. This drag component is sensitive to the thickness of the wing and the lift that the wing is generating and increases with both. To keep wave drag as low as possible, supersonic airplanes may have very thin wings, such as those seen on fighter aircraft, highly swept wings, or a combination of both.

The wing on the Concorde is an excellent example of a supersonic wing design. A popular wing planform shape is the delta, or triangular, wing, upon which the Concorde's wing is based. The design requirements for efficient flight at supersonic speed and subsonic speed are contradictory. At low speeds, a large-span wing is desirable, whereas at high speeds, a highly swept wing is most effective. These requirements have led to the development of the so-called swing wing, seen on aircraft developed in the 1960's and 1970's, such as the European Panavia Tornado and the U.S. B-1 bomber. For low-speed flight, the wings sweep forward, whereas for high-speed flight, the wings sweep rearward. However, this design's prohibitive cost and structural weight have generally hindered its widespread use.

A problem with wings designed for supersonic flight is that, due to their large sweep and small wingspans, they are poor lift generators. That is, they do not develop a large amount of lift for a particular angle of attack, which can pose serious difficulties when these aircraft either take off and land at very high speeds requiring long runways. One way to alleviate this problem is by designing the highly swept wing to have a sharp nose or leading edge. This design causes the airflow over the wing to form two tornado-like vortices that lie above the wing. These vortices may be clearly seen in photographs of the Concorde taking off or landing on humid days. These vortices greatly increase the lift of the wing, but they also significantly increase drag.

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See also: Aeronautical engineering; Airfoils; Airplanes; Birds; Concorde; Forces of flight; Heavier-than-air craft; Insects; Ludwig Prandtl; Supersonic aircraft; Wind tunnels; Wing designs; Wright brothers

Aeroflot

Date: Founded in 1932

Definition: The major airline company of the Russian Republic.

Significance: Aeroflot is the major airline of the Russian Republic. Before 1991, it was the national airline of the Soviet Union, but privatized after the breakup of the Soviet Union.

History

The Russian Federation of Soviet Socialist Republics formed its first airline, Dobrolet (an acronym for “Russian volunteer air fleet”) in 1923, and two years later, Ukrainian Airways, or Ukvozdukhput, was started. In 1928, the Soviet government merged the two lines into a national airline under the name “Dobroflot” (also known as Dobrovolnii Flot, “volunteer fleet”). In 1932, during the period of the First Five-Year Plan, the government reorganized the company as the Main Civil Air Fleet Administration, or Aeroflot, and also established aircraft and aircraft engine plants. By 1935, Aeroflot had routes throughout the Soviet Union.

Aeroflot handled all civilian air service, including passenger and freight transport on international and domestic routes, and engaged in other air activities such as crop spraying, aerial surveying, air rescue, and medical transport. During the Soviet period, Aeroflot used Soviet-made aircraft exclusively, initially making Li-2’s with twenty-four seats modeled on the Douglas DC-3. The company introduced the Ilushin Il-12 during World War II and the Il-14 in 1947. The Il-14’s and Li-2’s became the airline’s standards. To meet the growing need for passenger service, in 1956 Aeroflot became the first airline in the world to introduce nonmilitary jet service with Tu-104 turbojets carrying one hundred passengers. From 1957 to 1959, the company added the turboprops Il-18, Tu-114, An-10, and An-24, and in 1965 the turboprop Antei (An-22), the world’s largest transport plane. In 1968, it became one of the first companies to use supersonic aircraft, the Tupolev Tu-144, for civilian flights. The Tu-154, also introduced in 1968, carried 164 passengers at a speed of 1,000 kilometers per hour.

In 1991, Aeroflot had 5,400 planes, including more than 1,300 airliners, plus thousands of smaller craft, and carried 138 million passengers to over 3,500 cities in the Soviet Union as well as 100 countries on its international routes. Aeroflot was then the world’s largest airline, accounting for 15 percent of all scheduled commercial civilian traffic. However, with the breakup of the Soviet Union in 1991, the company was greatly reduced. It remained the airline of the Russian Republic, changing its name to Aeroflot-Russian International Airlines, and invited private investors to participate along with the government in backing the company. The airline faced new problems associated with operating in free markets, such as competition from private companies and airlines of the other former Soviet republics not only in domestic travel but also on international routes. Furthermore, in 1999 the Russian government charged the company with embezzling funds through connections with Boris Berezovsky, a Russian oil and media magnate suspected of criminal activity. The line’s general director, Valery Okulov, son-in-law of then Russian president Boris Yeltsin, continued in his position, however. Okulov fired ten top executives and discontinued routes which had been involved with the embezzlement. Yeltsin’s and Okulov’s opponents questioned the latter’s leadership of the airline, but in 2000 the airline improved its image and performance.

Organization

In June, 1992, the Russian Federation reorganized Aeroflot into a public joint stock company, with the Russian govern-

Events in Aeroflot History

February, 1932: Aeroflot is established by the Soviet government as the nation's official airline.
1937: Russian pilots discover the shortest transpolar air route, flying from Russia over the Arctic Ocean to Vancouver, Canada.
September, 1956: Aeroflot inaugurates regular passenger turbojet service, two years ahead of British and American airlines.
December 31, 1968: The first supersonic airliner, the Tupolev Tu-144, developed by Aeroflot, makes its maiden voyage.
1977: Aeroflot begins offering supersonic passenger service, which is suspended the following year.
1998: Aeroflot Boeing 777's begin making regular flights between New York and Moscow.

ment owning 51 percent of the stock. The other shareholders included both Russian (chiefly the company's fourteen thousand employees) and foreign investors. In 1997, Okulov was appointed general director. The company had 151 representatives abroad and 3 in Russia: St. Petersburg, Novosibirsk, and Khabarovsk. In the post-Communist period, Aeroflot bought foreign airplanes as well as those made in Russia. At the end of the twentieth century, the fleet had well over one hundred planes, including Boeing 737's and 767's, Airbus A310-300's, and Ilushin 96-300's. Some of the Ilushins had American Pratt & Whitney engines. The company carried about four million passengers and 90 tons of cargo annually. In contrast, a competing airline such as Delta had over 550 planes and carried over ninety million passengers. After 1991, over three hundred spinoff lines called "babyflots" emerged, taking over much of Aeroflot's equipment and routes. At the beginning of the twenty-first century, Aeroflot flew to 150 cities in 93 countries. It still provided 70 percent of all Russian air travel.

Like other post-Communist Russian companies, Aeroflot presented a flashy exterior, with luxurious corporate offices in New York and London, attractive reports and brochures, a World Wide Web site, an offshore subsidiary in Switzerland (which was, however, connected to the Berezovsky scandal), but it still had problems stemming from Soviet inefficiency, and depended on the Russian government for subsidies and keeping monopolies on internal Russian routes. In 1997, American and European banks loaned the company $1.5 billion to buy planes. Although Aeroflot service on domestic flights was inferior, its international service improved and its prices were very competitive. It also retained smoking sections, unlike other airlines. Nevertheless, in 2000, travelers voted Aeroflot the world's worst airline.

Crashes

During the Soviet period, crashes were not reported and are difficult to track. In the post-Communist period, when news of air disasters was reported, the world became aware of the dismal record of Aeroflot. In 1994, there were a record number of domestic crashes and the United States embassy warned its personnel not to use the line for travel within Russia. In the same year, an Airbus A310 crashed on its way to Hong Kong, after the pilot allowed his teenage son to fly the plane. The company worked with the U.S. Federal Aviation Administration to improve its safety record, and the crash rate declined. Nonetheless, on August 29, 1996, an Aeroflot plane carrying 140 passengers crashed in Norway.

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See also: Accident investigation; Air carriers; Airbus; Airports; Boeing; Federal Aviation Administration; Safety issues; Supersonic aircraft; Andrei Nikolayevich Tupolev

Aeromexico

Definition: A major Mexican air carrier of passengers and cargo.

Significance: Aeromexico is the second largest air carrier in Mexico.

Background

The North American country of Mexico has a long and rich aviation tradition. Mexico's airlines are not as well known as those of many other countries because they have not developed the extensive international route networks

The Aeromexico Fleet

Aircraft	*Number in Service*	*Length (meters)*	*Wingspan (meters)*	*Seats*	*Cruising Speed (kilometers per hour)*
Metro 23-11	23	18.1	17.4	19	500
Saab 340-B	9	19.7	21.4	33	530
DC-9-30	17	36.4	28.5	97	820
MD-87	5	39.8	32.9	109	820
MD-82/83/88	34	45.1	32.9	142	820
Boeing 757-200	8	47.3	38.0	175/177/180	820
Boeing 767-200 ER	4	48.5	47.6	179/181	850
Boeing 767-300 ER	1	54.9	47.6	209	850

Source: Data taken from (www.aeromexico.com/ingles/acerca_am/flota/flota.htm), June 5, 2001.

for which carriers of the United States and Europe are famous. However, the early history of aviation in Mexico was as turbulent and exciting as that of any country in the world. In the first half of the twentieth century, over one hundred airlines started domestic service in Mexico. Many of these airlines later merged with one of Mexico's two national carriers, Mexicana and Aeromexico. These two carriers have been competitors almost since their beginnings. Each has strived to be the predominant domestic and international carrier of Mexico. Through a series of mergers, Aeromexico developed a strong domestic route structure linking Mexico City, the United States, and Canada to most of the tourist destinations of Mexico. Although its international network continues to be weaker than that of Mexicana, it has grown to serve destinations in the United States, Central America, South America, and Europe.

Early Years

Aeromexico, then called Aeronaves de Mexico, began as a small regional carrier serving the Pacific coast of Mexico in 1934. At that time, it operated flights between Mexico City and the newly developing tourist destination of Acapulco. It continued as a small, regional carrier until the U.S. air carrier Pan Am World Airways purchased 40 percent of its equity in 1940. With the new capital provided by Pan Am, Aeronaves de Mexico began acquiring a series of other small carriers along Mexico's Pacific seaboard. In 1952, the airline expanded into north central Mexico with the acquisition of Lineas Aereas Mineras, S.A. (LAMSA) from the U.S. carrier United Air Lines. The following year, Aeronaves de Mexico purchased Aerovias Reforma to further serve the Pacific coast. The 1957 opening of service to New York City heralded Aeronaves de Mexico's entry into the international air transport market. This same year they joined the International Air Transport Association (IATA), an organization of airlines affiliated with the United Nations and responsible for promoting safe and secure air travel throughout the world. IATA is the premier organization for coordinating airline policies and procedures and training airline personnel in all aspects of aviation.

Financial Troubles

Aeronaves de Mexico's expansion was temporarily halted when a strike in January, 1959, threatened the company's financial health. The Mexican government moved quickly to assume control of the company, taking official ownership in July of that year. The board of directors appointed by the Mexican government proceeded to upgrade Aeronaves de Mexico's fleet and merged it with Aerovias Guest, the first Mexican carrier to serve Europe. Aeronaves de Mexico continued to expand its domestic and international route structure throughout the 1960's. Its acquisition of Servicios Aereos Especiales (S.A.E.) in 1970 left Mexico for all intents and purposes with only two airlines, Aeronaves de Mexico and Mexicana.

Aeronaves de Mexico underwent a second financial crisis in the early 1970's. In an attempt to revitalize the airline, the aircraft color scheme was changed to red, the Aztec warrior tail design was modernized, and the company name was shortened to Aeromexico. The company's financial health improved following efforts to upgrade its fleet and enter new markets in North America opened up by the United States deregulation of its own airline industry in 1978. However, Aeromexico was forced to declare bankruptcy in 1988 due to economic uncertainty and overcapacity in the Mexican market. The company was reorganized under the name Aerovias de Mexico, retaining the Aeromexico name for marketing purposes. As part of the reorganization, Aeromexico laid off approximately ten thousand staff, hired industry outsiders to help them improve quality and financial performance, and strengthened their route structure. The company also purchased 47 percent of the shares of Aeroperu in 1992, allowing it to open a hub in Lima, Peru. This provided the first South American connecting point for Aeromexico, allowing them to tie together the Americas from Canada to Argentina.

The financial crisis that struck Mexico in 1994 brought Aeromexico and its competitor Mexicana to the brink of bankruptcy. In 1995, both companies were purchased by the Corporacion Internacional de Aviation (CINTRA), a consortium of banks. The two airlines now cooperate on ground handling, training, and computer reservations. These efforts have allowed the two carriers to improve service and lower costs. Although both companies are subsidiaries of CINTRA, they remain separate entities and continue to compete in many areas. Aeromexico continues to be the stronger domestic competitor and maintains a fleet of Boeing aircraft. Mexicana remains the dominant international competitor and has begun purchasing Airbus aircraft to serve its markets. Aeromexico has joined the SkyTeam Alliance composed of Delta, Air France, and Korean Air Lines. Mexicana is a member of the STAR alliance, whose chief members include United Air Lines, SAS, Lufthansa, Varig, Air Canada, and Singapore Air Lines.

With the growth of the North American free trade area, which is lifting trade restrictions between the United States, Canada, and Mexico, the prospect for further growth in the Mexican air transport market looks promising. In addition, growing trade between South America and the United States is providing Aeromexico with opportunities to link both areas. Despite several periods of financial crisis, Aeromexico has survived and looks forward to continued growth.

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See also: Air carriers; Airports; Pan Am World Airways; United Air Lines

Aeronautical engineering

Definition: The study, design, and manufacture of aircraft and spacecraft.

Significance: Aeronautical engineering is responsible for the development of and advancements in aviation and spaceflight.

Engineering

In the first century of crewed flight, which began in December, 1903, the application of the new science of aerodynamics was translated into flying machines by people who understood engineering and problem solving. The industry that grew from this small beginning made amazing strides in the first century of air travel. It is an industry built around visionary engineers and pilots.

Aeronautical engineering had its true beginning before Orville and Wilbur Wright but the two brothers were the pioneers in the techniques, processes, and system testing that were at the heart of the engineering design and development of aircraft and spacecraft. The conceptualization of an aircraft begins with the identification of something useful to be accomplished by an air machine. The process begins with sketches of an air vehicle to fulfill the performance expectations for the aircraft. In the first two decades of aircraft design and operations, many concepts were proposed, but by the end of World War I, the basics of successful aircraft design were established. Future refinements would come through better tools, materials, and concepts. At the beginning of the second century of crewed flight, the process involves digitally created drawings that are sent to machines that make the basic parts, which are then assembled, tested, and prepared for flight test.

Twentieth century aircraft engineering refinements moved at a speed unseen in any previous period of the industrial world. The motivation and excitement of flying higher, faster, and with larger payloads seemed to drive innovation and to demand engineering solutions. By the end of World War II, the aviation industry was fully established as a significant contributor to the economic and military strength of the United States. European aerospace also produced leaders in this field. Companies were built on the talents of engineers and the skills of craftsman. Engineering disciplines expanded, and in the late 1950's, aeronautical engineering became aerospace engineering. In most aircraft manufacturing firms, the engineering department was second in size only to the production groups.

Typically, in the middle of the twentieth century, modern aerospace companies spread their products between commercial enterprises and government contracts. The bread-and-butter contracts came from the federal government until the end of the Cold War. Commercial applications of engineering ideas were spun off from aircraft and missiles that had been developed for the military. However, by 1990, the industry was in decline. Following the Gulf War in 1991, the downsizing of the air arms of the military accelerated. The demand for large numbers of new and different military aircraft came under such scrutiny that few of the new programs survived. On the commercial side of the industry, the engineering of new and better transports and aircraft destined for the air carrier markets stopped in favor of building on existing concepts to build bigger aircraft with bigger engines. Airspeed, comfort, and passenger loading ceased to be major requirements and took a back seat to economically viable air transport.

William H. Pickering, James A. van Allen, and Wernher von Braun, the engineers behind the Explorer 1, show off a model of the satellite in January, 1958, shortly before it was launched into space. (NASA)

Research and Development

There are three significant eras in the expansion of the aerospace industry. These coincide with technology improvements as well as political changes that affected the industry. The first period started with the Wright brothers' successful efforts at powered flight and ended with the advent of the jet engine. The next period began when jet engines were being put into all new aircraft designs, and this period saw rapid advances in aircraft performance. The last period began with the introduction of digital computer controls for the aircraft. This development made it possible to design and build incredibly safe and reliable aerospace systems.

Out of World War II came large bombers and cargo aircraft. When jet engines were added to these aircraft they held promise for faster and higher, hence more efficient and comfortable, air transportation for the public. The first such jet transport built for the British Overseas Airway Corporation (BOAC, which became British Airways) was the Comet. However, the understanding of structural issues arising from rapid changes in pressure on certain parts of the aircraft, along with manufacturing techniques from the 1940's, resulted in an unsafe aircraft. After two exploded in flight due to structural failure and one burst during ground pressure testing, the world of aeronautical engineering became aware of fatigue failures and the need to design fail-safe structures. At the time, the U.S. Air Force had Boeing designing and building a jet tanker using technology similar to that applied to its highly successful swept-wing B-47 jet bomber program. What came out of that work was the most successful aircraft transport design in history. The Boeing 707 model was the forerunner of all of today's large jet transports.

The Industry

After World War II, the growth in the aviation industry, both commercial and military, saw a proliferation of new prime contractors who were building and selling aircraft. A prime contractor was defined as the company that was responsible for the concept, design, development, and final introduction of the new aircraft into operational use. In short, a prime contractor was responsible for all aspects of the life cycle of the aircraft. The prime would have subcontractors, perhaps hundreds, with which it did business.

At the start of the 1970's, and at the height of the Vietnam War, there were many primes in the aerospace business. The biggest and most successful were Boeing Aircraft, Douglas Aircraft, McDonnell Aircraft, Lockheed Aircraft, Republic Aircraft, General Dynamics, Grumman Aircraft, North American Aviation (North American Rockwell), Northrop Aviation, LTV Aerospace (part of LTV, which used to be Chance Vought), Northrop Aircraft, Bell Airplane and Bell Helicopter, Sikorsky Helicopter, and a handful of general aviation companies, including Cessna, Beech, Piper, and others. At the end of the twentieth century there were only three major aerospace companies left, with all others being absorbed into the remaining companies or having gone out of business. Boeing took over McDonnell Douglas, which used to be McDonnell Aircraft and Douglas Aircraft. Lockheed Martin absorbed General Dynamics Aircraft Division and Martin Marietta. Northrop and Grumman joined, adding pieces of LTV and others. In addition, Raytheon Corporation, which was a small missiles and electronics outfit in the 1960's, took over Beech Aircraft and other subsidiary companies. Cessna and Piper nearly went out of business during the 1970's and 1980's, due to changes in liability laws. Chance Vought became Ling Temco Vought in the mid-1960's and changed its name to LTV Corporation in the 1970's. It was one of the first prime contractors that attempted product diversification, with markets in steel, appliances, missiles and aircraft; the corporation went bankrupt in 1986.

Future Developments

Compared to the days of the Wright *Flyer* and the Curtiss JN-4, aircraft which were very difficult to control and which carried very small payloads, the F-22 automated advanced fighter and the Boeing 777 automated, large twin-engine transport are engineering marvels. At the beginning of the twenty-first century, there are several different paths that may provide the next major step forward in aeronautical engineering.

In June, 1963, President John F. Kennedy, speaking at the commencement of the fifth class to graduate from the United States Air Force Academy, announced that the federal government would seek to develop the world's first supersonic passenger transport (SST). This never happened, for two reasons. The first was the economic issue. Such an aircraft, designed using late 1950's and early 1960's technology, would be very expensive. Airlines could not justify the costs to operate them. The second issue was environmental. Warnings and concerns about the pollution or damage to the upper atmosphere from turbojet engines and problems with sonic booms, which are caused by the shock waves from a supersonic aircraft, led to a premature end of the SST. Europe, in a cooperative move between British and French aircraft firms, did pursue a smaller version of the SST, called the Concorde. It operated successfully starting in January, 1976, although it was under a limitation forbidding it from flying supersonically over the United States. Technology improved during the twenty-two years the Concorde was operating, and by the late 1990's, the National Aeronautics and Space Administration (NASA) attempted to resurrect the SST concept. By then, the problems of jet exhaust and its impact upon the upper atmosphere had been nearly resolved. Ways to reduce the pressure from the sonic booms were being planned. The program ended in 1999 when, for the second time, the economic issues surrounding operational costs of a large SST overrode advances in the aerospace engineering field.

The next hope for large transport aircraft lies in engineering a craft that will cruise just under Mach 1. Most large aircraft can cruise efficiently at Mach .75 to .9 (the percent of the speed of sound) but if they could fly efficiently at 95 percent of the speed of sound this would mean a 5 to 20 percent increase in true airspeed (35 to 155 miles per hour). A speed increase of that magnitude would shorten the flight time from New York to Paris by approximately an hour and fifteen minutes. The potential savings in fuel, the increase in the number of aircraft that could fly the same route, and other factors make this an appealing possibility. It is not an easy engineering task, but then, most of the history of aviation has faced such challenging engineering tasks.

The ultimate flight would be one that takes the passenger into low-Earth orbit and flies across both continents and oceans. That aircraft will probably come about once the space program has fully established the safety and reliability of such travel. Aeronautical engineering and the companies that have come to the forefront in both engineering and applied sciences for aerospace purposes will be able to achieve these ideas.

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See also: Airplanes; Boeing; Concorde; Forces of flight; McDonnell Douglas; Manufacturers; Military flight; Spaceflight; Supersonic aircraft

Aerospace industry, U.S.

Definition: Manufacturers directly involved in the production of aircraft, engines, and ancillary products for use in aviation and space travel.

Significance: The aerospace industry became a critical part of the U.S. economy following World War II. The industry benefitted from the postwar emphasis on military and commercial aviation, as well as spaceflight.

The Aerospace Industry Through 1945

The United States' adventure in aviation went from its first flight in 1903 to flights to the Moon in 1969. Despite this impressive record of accomplishment, aircraft manufacturing proved to be a difficult business. Early companies, notably the Wright Company, founded by Wilbur and Orville Wright, and the Curtiss Aeroplane Company, established by Glenn H. Curtiss, sold a handful of planes to the military but did not find a lasting market for their aircraft. The federal government recognized the importance of aviation by establishing the National Advisory Committee for Aeronautics in 1915 but did little to help struggling manufacturers. Although World War I forced the United States to produce greater numbers of aircraft, most American pilots flew French planes during the conflict.

Although U.S. airplanes did not make an impact during the war, they did serve to train postwar aviation enthusiasts. These surplus planes undercut manufacturers to some degree, but the demand for increased performance gave companies an opportunity to introduce new designs. Despite widespread interest in aviation in the years leading up to World War II, the industry catered primarily to the military. Even companies, such as Boeing and Lockheed, that aggressively targeted the commercial market with private planes and airliners looked to the military for a significant proportion of their business. Other companies, notably Grumman and Douglas, dealt almost exclusively with the military.

World War II put a stop to commercial aviation plans and forced all manufacturers to focus on military aircraft. The leaders of the U.S. postwar industry clearly emerged during this period. Boeing, North American, Lockheed, Grumman, and Douglas all established themselves as mainstays in aerospace manufacturing. The war also necessitated enormous advances in technology. By the end of the war, jet fighters had taken to the air, heralding the future of the aviation industry. Finally, World War II established aviation as an indispensable component of both military and civilian life in the years to follow.

Postwar Industry Trends

The aerospace industry became increasingly important during the Cold War. The United States relied on technology to offset the numerical advantage of the Soviet Union. Many of the aircraft manufacturers that had done well during World War II remained at the forefront of the industry. These companies concentrated on four areas: military aircraft, missiles, rockets and space exploration vehicles, and commercial aircraft. The advent of space exploration prompted journalists to coin the term "aerospace" in the 1950's, reflecting the new era of U.S. aviation manufacturers. The aircraft, aerospace, and parts industry had become the largest U.S. employer by 1959, and cities connected to the industry, including Los Angeles, Seattle, and Phoenix, exploded in population.

Military Aircraft. Aerospace manufacturers worked hard to win lucrative government contracts following World War II. The United States demanded advanced fighters and bombers to meet the Soviet threat. While these contracts provided the backbone of the industry, they also placed extraordinary demands on the manufacturers. The new planes required expensive engines and complicated alloys, both of which added a great deal of expense to the planes. Construction of the aircraft usually necessitated new techniques and equipment. Government designs often included overly complicated ideas that added to the weight of the aircraft. The industry did not help matters by overpaying executives and using unnecessarily expensive components. These problems led the U.S. Congress to require new levels of bureaucracy and paperwork to control costs. Furthermore, Congress could decide at any point to cancel a project, leaving the contractors heavily in debt with no potential market.

Despite these problems, aerospace companies could not disregard the billions of dollars that the government contracts offered. The enormous sums granted to various manufacturers also allowed much more funding for research and development, accelerating advances in technology. The United States ended World War II somewhat behind Great Britain in jet engine construction, but by the mid-1950's, American manufacturers Pratt & Whitney and General Electric had become the leaders in jet technology. The increasing reliance on computers in the design stage led to continual improvements in microtechnology. Talented individuals such as Clarence "Kelly" Johnson at Lockheed and Ed Heinemann at Douglas created brilliant designs that exceeded government specifications and kept costs down.

The biggest problems aerospace manufacturers faced after World War II were not the technical demands of the new aircraft. Given enough time and money, men such as Johnson and Heinemann could overcome those obstacles. Unfortunately, the political demands of the defense issue often took precedence. Companies simply could not afford to spend several years and millions of dollars to develop an aircraft that would not enter service. Consequently, manufacturers went to great lengths to make their projects successful. Lockheed received a considerable amount of bad publicity in the 1970's when investigations revealed that the company had relied heavily on bribery to ensure foreign contracts for its F-104 fighter during the preceding decade. Northrop also suffered for its use of bribery in the Middle East in an effort to find a market for its F-S fighter. Even companies that avoided politics could not disregard the new era in the industry. In the late 1960's, Grumman expanded its facilities to begin manufacturing the Gulfstream II corporate jet. The company, which had always eschewed marketing, placed its new facility in Savannah, Georgia, which was represented by an important member of the House Armed Services Committee and the home state of another influential member of the Senate Armed Services Committee.

American defense cutbacks forced manufacturers to consider other markets. In the mid-1970's, General Dynamics designed the single-engine F-16 fighter. The lower cost associated with using only one engine made the plane attractive to European nations with limited budgets. General Dynamics did have to allow European countries to manufacture some of the planes, but the consortium reduced costs for all companies and promoted sales around the world. Difficulties in controlling costs finally forced U.S. competitors to begin working together as well. Northrop, with little experience in carrier aircraft, had to turn to McDonnell Douglas for help with a new carrier-based fighter. The result, the F-18 Hornet, became a great success. Not only did the Navy and Marine Corps adopt the plane, but its low cost ensured brisk sales to air forces around the world. The F-18 program convinced manufacturers that collaboration had become necessary to control spiraling costs.

The early 1980's saw a resurgence in Cold War tensions. President Jimmy Carter reinstated previously canceled programs such as the MX Peacekeeper intercontinental ballistic missile (ICBM) and the B-1 bomber. The new U.S. military buildup offered greater opportunities for military manufacturers, but these advantages were offset by the fact that the government demanded small numbers of extremely complex aircraft. This trend accelerated after the end of the Cold War, as the United States slashed its defense budget even further. The Air Force could not afford advanced programs such as the F-22 fighter and B-2 bomber, the Navy canceled its search for a new attack plane after well-publicized cost overruns, and crashes of new aircraft eroded public confidence, leaving manufacturers to fight over a shrinking sector.

Missiles. As military aircraft contracts forced manufacturers into hard-fought competition, America's missile program gradually came to represent a larger share of the industry's production. Between 1956 and 1961, airframe companies increased the percentage of missiles within their military business from 5 percent to 44 percent. In missile technology, many of the same manufacturers that dominated aircraft production also took a leading role in missile development, but companies such as TRW and Morton Thiokol made significant contributions to the industry.

The United States saw missiles as an important part of the nation's Cold War arsenal. The government took great pains to secure the services of Germany's leading missile designers at the end of World War II, but the growing Soviet threat made the development of ballistic missiles a high priority. These weapons, like the aircraft and space vehicles of the Cold War, proved much too expensive for individual companies. Missile projects required subcontracting and cooperation between manufacturers. By 1960, U.S. ballistic missile projects included two thousand contractors and forty thousand employees.

In the late 1950's, the United States' first intermediate range ballistic missiles (IRBM) entered service. Thor, produced by Douglas, and Jupiter, produced by Chrysler, went into installations in Britain, Italy, and Turkey. The United

States soon succeeded in fielding ICBMs, which could be launched from the United States and attack targets within the Soviet Union. The first two ICBM programs were Atlas and Titan. These programs used separate contractors for each major system in order to facilitate competition and force companies to deliver their products on time.

The Air Force did not like the complicated Atlas and Titan missiles and granted a contract to Boeing to manufacture the Minuteman, which entered service in 1962. The Minuteman program did not use separate contractors for each system, but allowed Boeing to subcontract the component manufacturing. Morton Thiokol, Aerojet-General, Hercules Incorporated, North American, Sylvania, Avco, and General Electric all supplied systems for the Minuteman, which were then assembled by Boeing. This approach proved much more effective, and Boeing produced more than one thousand Minutemen, making the missile the foundation of the U.S. ICBM arsenal, even after the MX Peacekeeper missile entered service in the 1980's.

Space Exploration. American interest in rocket technology before World War II scarcely existed. Robert H. Goddard conducted pioneering research in the field, but few people gave his theories much notice. During World War II, tactical rockets for battlefield use proved their effectiveness and teams at American universities and corporations began work on the weapons. The success of these weapons combined with the German breakthroughs in ballistic missile technology ensured that rockets would be a key component of national defense.

A logical outgrowth of work on ballistic missiles was the idea of space travel. Goddard had theorized about using rockets to reach the Moon, and the conquest of space quickly became an important Cold War achievement. The Soviet Union's successful launch of Sputnik in October, 1957, revealed that the U.S. space program lagged behind its rival. In response, the United States took a number of drastic steps to improve the nation's position in the space race. Schools instituted new curriculums with heavy emphasis on math and science, while the government combined military and civilian rocket research and in 1958 created a new agency, the National Aeronautics and Space Administration (NASA), to replace the National Advisory Committee for Aeronautics (NACA).

The Soviet lead in the space race allowed it to put the first human in space in 1961, but the United States soon made up the gap. The focused space program administered by NASA stressed corporate cooperation rather than competition. The tremendous cost of developing space vehicles prevented any one company from dominating the field. Instead of using one contractor, NASA used components from a wide variety of manufacturers to create finished products. Companies that failed to meet NASA's specifications and deadlines risked losing contracts after having spent millions of dollars on research and development. Grumman, General Electric, and North American all revamped their manufacturing and management techniques after aggressive analysis from NASA.

The Apollo Moon-landing program illustrated NASA's approach. No individual company could develop the equipment necessary for such a task. The agency used a variety of contractors to produce a handful of rockets and spacecraft. The Saturn rockets that carried the crews to the moon were a result of components produced by companies including Chrysler, Boeing, and North American. The Saturn V rocket stood 363 feet high and had a diameter of 33 feet, dwarfing any rocket the United States had yet produced. The huge size required companies to invest in new jigs and welding fixtures, new techniques in fabrication, and static test stands that were far larger than any in existence. The research and development and production costs of the Saturn rockets alone totaled $9.3 billion. Grumman, the main contractor for the Lunar Module, also faced tremendous challenges and suffered through numerous delays and cost overruns before delivering the finished product. The companies involved often complained about NASA's unrealistic expectations, but the two sides generally found mutually agreeable solutions and manufacturers often found ways to streamline their manufacturing processes.

Following the conclusion of the Apollo Program in 1972, American interest in space exploration waned. NASA conducted Skylab missions and a joint mission with the Soviet Union in 1975, but these offered little financial security for contractors. When the United States launched the first space shuttle mission in 1981, the space program enjoyed a brief resurgence, but this comeback ended with the explosion of the shuttle *Challenger* in 1986. NASA resumed crewed flights two years later, but the enthusiastic days of Apollo had gone forever. The increasing costs of space missions forced NASA to increase its participation in joint international missions. Despite these setbacks, contractors found new ways to remain active in space missions. In 1989, private corporations took over the launching of commercial payloads from NASA. McDonnell Douglas, Martin Marietta, and General Dynamics all sent satellites into orbit at less than half the cost of a space shuttle mission.

Commercial Aircraft

The United States' affluence and desire for travel following World War II represented an important market for aerospace manufacturers. Companies used the technology developed for the military during the war to produce faster and more comfortable passenger planes. Just as with military aircraft, the more advanced civilian designs proved more costly, and a failed project could leave a manufacturer deeply in debt. Even a successful design could require years to become profitable.

Douglas and Lockheed led the immediate postwar commercial programs. The DC family from Douglas and Lockheed's Constellation provided both intercontinental and transatlantic service and proved very popular. However, these piston-engine planes did not represent the future of the commercial airline industry. Britain's De Havilland Comet, the world's first jet airliner, entered service in 1952, proving that just as in the military sector, American companies trailed their British competitors in passenger jet technology. Unfortunately for De Havilland, a number of mysterious accidents grounded the Comets for two years, giving American manufacturers time to cut into De Havilland's technological lead.

Leaders Douglas and Lockheed did not embrace jet airliners as enthusiastically as did Boeing. The Seattle-based company realized that the company's development costs for the B-52 bomber, KC-135 tanker, and a civilian airliner would be prohibitive unless Boeing could coordinate efforts on all three aircraft. Boeing used the same basic design for both the KC-135 and what would become known as the 707, the most successful U.S. first-generation jet airliner, which entered service in 1958.

This method of combining operations helped manufacturers offset some of the risk involved in developing new aircraft. Douglas managed to lengthen its DC-8 jet by 37 feet in the mid-1960's, offering room for seventy more passengers. Boeing found that its 707 design did not allow for the same modifications, giving Douglas a significant advantage in the market. Boeing soon recaptured its position at the forefront of airliner manufacturing by developing the world's first jumbojet. Based on Boeing's failed attempt to win the Air Force's competition to build an enormous new transport, the Boeing team modified their design into the 747, which rolled off the assembly line in 1968.

These methods helped manufacturers to control costs and to insure themselves to some extent against failure. Companies also advertised their planes in travel magazines, hoping to win passenger loyalty. However, creating a new design always entailed financial risk. When Boeing began work on the new 727 in the early 1960's, the company found that it would have to sell three hundred of the planes simply to break even. The 727 became remarkably successful, but the three-hundred-plane total was the equivalent of the entire production runs of commercial airliners twenty years earlier. The enormous sums of money that aerospace companies spent on research and production of military, space, and civilian aircraft eventually came back to haunt the manufacturers. In the late 1960's and early 1970's, companies faced the twin threats of reduced military budgets and a slumping economy. Boeing had to cut its workforce by nearly two-thirds, and Lockheed, staggering under the burden of producing the massive C-S Galaxy transport and new L-1011 airliner, nearly went out of business. Lockheed remained afloat solely because the federal government guaranteed the company's credit to potential lenders. High costs also forced some companies to merge, including the 1965 merger of McDonnell and Douglas. Merger trends continued through the remainder of the twentieth century, as manufacturers found themselves unable to compete in the changing marketplace.

This time of transition and economic distress eventually passed, and the commercial sector of the industry emerged with a clear structure. Boeing led U.S. airliner producers and followed up its earlier designs with new airplanes, including the 737, 757, 767, and the next generation of airliners, the 777. McDonnell Douglas and Lockheed maintained secondary positions, while European consortium Airbus entered the U.S. market, providing stiff new competition for Boeing. The U.S. aerospace industry finished the twentieth century as the world's leader, but changing government and commercial needs forced manufacturers to cut costs in order to remain competitive.

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See also: Airplanes; Boeing; Lockheed Martin; McDonnell Douglas; Manufacturers; Mergers; National Advisory Committee for Aeronautics; National Aeronautics and Space Administration; Space shuttle; Spaceflight

Ailerons and flaps

Definition: Hinged sections on the trailing edges of wings.

Significance: Both ailerons and flaps can be deflected to change local wing camber and to increase or decrease local lift. Ailerons are used to control the airplane in roll, while flaps allow flight at lower speeds for landing and takeoff.

Ailerons

Early experimenters with gliders turned their vehicles by shifting their bodies so their weight was to the left or right of their wing's lifting center. This action made the glider roll or bank to help it turn. Wilbur and Orville Wright improved on this effect by twisting or warping their wood and fabric wing with ropes and pulleys so that one wingtip was at a higher angle of attack than the other and the difference in lift on the two wingtips helped it roll. This design gave their airplane much greater maneuverability than early European designs which tried to turn using only a rudder. This wing-warping control system was the essential element in the Wright patent on the first successful airplane.

Glenn H. Curtiss, another American aviation pioneer, patented a different way to control an airplane in roll, using ailerons, originally small, separate wings that were placed between the upper and lower wings of his biplane near the wingtips. The pilot could change the angle between these small wings and the flow to increase the lift on one wing and decrease that of the other. The Wrights claimed that this was a violation of their patent, and the case spent many years in the courts until the U.S. government stepped in to resolve the dispute.

Today's ailerons are built into the trailing edge of wings near the wingtips, and they work by changing the wing's camber, or curvature, instead of its angle of attack. The ailerons deflect either up or down opposite to each other to increase the lift near one wingtip while lowering lift on the other wingtip. This makes the wing roll, with one wing moving up and the other down. Usually the aileron deflecting up produces more drag than the one moving down, which helps the airplane turn. In most turns, the aileron movements are coordinated with the movement of the rudder to create a turn which is balanced so that the airplane passengers feel only a downward force and no sideward force. A coordinated turn not only feels better but also is more aerodynamically efficient.

If the pilot wants to roll the airplane without turning, the rudder must also be used to oppose the turning motion caused by aileron drag; this is called a cross-control maneuver. A similar cross-control use of rudder and ailerons can make the airplane rotate to the left or right in a sideslip motion without rolling.

Flaps

Flaps often resemble ailerons except that they are placed on the wing near the fuselage rather than near the wingtips. Flaps normally are only deflected downward since they are used to increase temporarily the wing's lift on landing and sometimes on takeoff. This maneuver allows flight at lower speeds and landing and takeoff in shorter distances.

Early aircraft did not need flaps because they flew at low speeds and could land in much shorter distances than today's planes; however, as airplanes became more streamlined and could cruise at higher speeds and altitudes, they needed higher speeds for takeoff and landing. Designers added flaps to give additional lift and drag and to reduce landing speeds. The famous DC-3 airliner was one of the first commercial planes to use flaps to combine good cruise performance with reasonable landing and takeoff distances.

There are many types of flaps, from simple plates that deflect down from the bottom of the wing to very sophisticated combinations of little wings that extend down and behind a wing. The split flap was used on the DC-3 and many World War II airplanes. Fowler flaps are more common today, but many smaller aircraft use simple hinges on the rear part of their wings to deflect a plain flap. The Fowler flap increases the wing camber while increasing the wing area. The space that opens up between the deployed Fowler flap and the wing allows an airflow that helps control the pressures over the flap and delay wing stall.

Many airliners designed in the mid-to-late twentieth century used complex flap systems that worked like the Fowler flap but had two or more flap elements that opened out below and behind the wing. These flap systems were very carefully designed temporarily to give very high lift at low speeds on sleek, modern wings that were shaped for flight near the speed of sound. They allowed airplanes that cruise at 500 to 600 miles per hour to land at low speeds and come to a stop on relatively short runways.

Today's commercial transport designs do not need these complex flap systems and tend to use simpler Fowler flaps, which are lighter and easier to build and maintain. This shift is partly because of improvements in wing and airfoil design and partly because most major airports now have longer runways.

Flaperons and Slats

Occasionally, an airplane design needs extra flap area to get lower landing speeds and the ailerons are also used as flaps. This kind of aileron is called a flaperon, and it requires a more complex hookup to the aircraft controls than a standard aileron and flap system.

Some aircraft have flaps on the front of their wings that can also be deflected downward to increase the wing camber. These leading edge flaps, or slats, help control the flow over the wing at high angles of attack and allow the wing to go to a higher angle of attack before it stalls.

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See also: Aerodynamics; Airplanes; Glenn H. Curtiss; Forces of flight; Wing designs

Air Canada

Definition: Major airline company of Canada.

Significance: Air Canada is the major airline of Canada, supported by both private investment and government subsidies.

Government Air Service

Canadian air history began in 1909, when John McCurdy piloted his famous "Silver Dart" on its first flight. After World War I, small so-called bush airlines introduced commercial air flight into the country, and some of these evolved into the modern Canadian lines. James A. Richardson, a Winnipeg businessman, started Western Canadian Airlines, which later became Canadian Pacific Airlines and then Canadian Airlines International. The Canadian parliament passed the Trans-Canada Airline Act on April 10, 1937, creating Trans-Canada Air, which began with a new Lockheed 10A Electra, two used Electras, and a Stearman Model 4. The new company hired the bush pilots, who had to learn instrument flying on the Electras. At first, Trans-Canada Air served as an airmail carrier flying from Vancouver to Seattle, and only began regular commercial passenger service in 1939. The line accepted applications for stewardesses. A thousand applied; twelve were hired.

The postwar period represented an era of continued growth and expansion. The carrier transported more than 180,000 passengers in 1945 and employed more than 32,000 people, compared to 21,000 passengers and less than 500 employees in 1939. In 1945, the airline bought its first Douglas DC-3, which flew until 1983.

Trans-Canada enjoyed a government monopoly on all domestic Canadian air routes from 1937 to 1959, but then the government granted other Canadian companies the right to compete. Many remote northern areas of Canada were accessible only by air, and the country required a broad range of air services that could be met by smaller and intermediate-sized lines in addition to Trans-Canada. Canadian Airlines and Canadian Pacific Airlines (CPA) emerged as major rivals. Four other important regional airlines and hundreds of smaller companies competed as well. On January 1, 1965, Trans-Canada Air changed its name to Air Canada.

Throughout the post-World War II years, the line endured numerous labor and financial problems. Furthermore, it had a difficult time trying to expand into the U.S. market and complained that American government officials favored American companies. In response, Air Canada sought partners in other countries. In 1966, the company signed a key agreement with the Soviet airline Aeroflot, becoming the first North American airline to do so, and setting up routes for both carriers from Moscow to Canada.

Air Disasters

The worst disaster of Trans-Canada Air occurred on November 29, 1963, at St. Thérèse de Blainville, north of

Technical Characteristics of Air Canada's DC-9-32 Fleet

Timetable Code: D9S
Period of Use: 1966-present
Manufacturer: McDonnell Douglas
Number of Aircraft: 17
Engines: JT8D-7B
Typical Number of Seats: 91
Cargo Capacity: 3,410 pounds
Fuel Capacity: 4,260 U.S. gallons
Overall Length: 119.3 feet
Wingspan: 93.3 feet
Top of Fin from Ground: 27.5 feet
Cruise Speed: 490 miles per hour
Range (Full Passenger Capacity): 1,265 miles
Typical Cruise Altitude: 33,000 feet

Source: Data taken from (www.aircanada.ca/about-us/our-fleet/au303k.html), June 5, 2001.

Montreal, when Flight 831, a DC-8F, went down, killing all 111 passengers and 7 crew on board. This was the third fatal crash on the line's passenger flights. The first occurred at Armstrong, Ontario, in February, 1941, when a Lockheed 14 crashed, killing twelve (nine passengers and three crew). In 1947, a Lockheed 18 went down near Vancouver, killing twelve passengers and three crew, and in 1954, at Moosejaw, Saskatchewan, a training plane crashed into a Trans-Canada North Star DC-4M, killing thirty-one passengers and four crew, as well as the pilot of the trainer and a woman on the ground. In June, 1983, a fire in the washroom of Air Canada Flight 797, a DC-9, forced the plane to land at Cincinnati Airport in Covington/Hebron, Kentucky. Eighteen passengers and five crew escaped but twenty-three passengers died in the fire.

Privatization

In 1989, the Canadian government privatized Air Canada, but problems from competitors continued. The airline replaced its Boeing 727's with Airbus A300's and Boeing 767's. In 2000, Air Canada and Canadian Airlines International, which had replaced CPA after the latter ceased operation in 1989, merged after complex negotiations. The merger, however, did not bring all the hoped-for benefits. Air Canada still suffered stiff competition from airlines with low fares and better service. By 2001, Canada 3000 Airlines and Westjet Airlines joined Air Canada as the three largest airlines in Canada. (Canada 3000 would file for bankruptcy by the end of the year, however.) While the national line suffered heavy losses, which they blamed on business layoffs in an economic slump, Westjet Airlines showed a profit. Air Canada bought out and closed another new airline, Roots Air, which also threatened competition. In July, 2001, the airline was fined by the Ontario Securities Commission for stock irregularities by giving information to market analysts in advance of public release.

In 1997, Air Canada, along with United Air Lines, Lufthansa, Thai Airways International, and Scandinavian Airlines System (SAS) had formed the Star Alliance, the foremost international air alliance group joined subsequently by other airlines. By 2001, Air Canada was the seventh largest airline in North America and the twelfth largest in the world. It carried thirty million passengers annually and employed forty-five thousand people. Through its own lines and connecting flights it reached more than ninety airports in Canada and the United States, in total serving 188 destinations directly on five continents. Its major hubs were located in Toronto, Montreal, and Vancouver, and had a fleet of 375 planes.

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See also: Air carriers; Airline industry, U.S.; Airplanes; Safety issues

Air carriers

Definition: That part of the commercial system of air transportation consisting of airlines certified to provide domestic and international service.

Significance: Air carriers are an integral part of the air transportation system. Air travel is vital to the economic and social welfare of most nations. It facilitates business activity by allowing rapid and frequent personal contact between companies, as well as allowing for the rapid shipment of goods worldwide. Air travel links distant communities to important public and private centers of operation. It also supports a number of other travel-related industries such as hotels, rental cars, and travel agencies.

Air Carriers

In 1903, Orville and Wilbur Wright flew the first aircraft for a total of twelve seconds and reached a speed of 31 miles per hour. While many people were fascinated by the accomplishment, few could have guessed the impact that powered flight would have on the world or the progress that would be made in less than a century of innovation. The use of aircraft in World War I gave governments worldwide reason to consider aviation as more than a hobby of the wealthy or a barnstorming circus event. Aircraft now offered serious military possibilities. The years immediately after World War I found airplanes taking on another role as mail carriers. However, commercial development of the aviation industry did not really take off until the end of World War II. Maintaining an accessible, affordable, and safe air transportation network is now considered vital to any nation's infrastructure.

Early Years

At the end of World War I, Europe was faced with extensive damage to the railroad system that had once linked the continent. This provided an excellent opportunity for the fledgling aviation industry. However, early efforts to establish a viable passenger airline proved unsuccessful due to the high operating costs. In order to improve the odds of success, the governments of the major European nations, France, Great Britain, and Germany, became actively involved in the promotion of air operations through direct subsidies to national airlines.

In the United States, the political climate following World War I did not support such direct action to promote commercial aviation. Instead, the aviation industry received assistance from the U.S. Postal Service. The first private efforts to demonstrate the potential value of aircraft for mail delivery were conducted in 1911 and 1912. In 1916, the U.S. Congress made the first appropriation of money to be used to support airmail delivery. A second appropriation was passed in 1918 and the first official airmail route was flown on May 15, 1918, between Washington, D.C., and New York City. On February 2, 1925, the Air Mail Act of 1925, also called the Kelly Act, was passed. The Kelly Act, entitled "An Act to Encourage Commercial Aviation and to Authorize the Postmaster General to Contract for the Mail Service," was intended to get the U.S. government out of the airmail business and support private companies wishing to enter it.

Walter Folger Brown, appointed postmaster general by President Herbert Hoover, was determined to provide greater direction to the aviation industry. To this end, he initiated passage of the Air Mail Act of 1930, also known as the McNary-Watres Act. Officially, the act gave the postmaster general the power to award airmail contracts without the competitive bidding process required by the Kelly Act and lowered the rate paid for airmail delivery by paying carriers for space used rather than weight of mail carried. The McNary-Watres Act had two major effects on the shape of the aviation industry. First, it encouraged consolidation of many small companies after Brown made it clear that airmail contracts would be granted to companies that were large, financially stable, and capable of conducting transcontinental routes. Second, the reduction in airmail rates encouraged air carriers to consider expanding operations to passenger service. Brown did get the consolidation that he wanted as smaller companies began to merge, forming the airlines now known as American Airlines, United Air Lines, and Trans World Airlines (TWA). He also got complaints from smaller carriers passed over for airmail contracts.

While other carriers vied for the domestic airmail routes, Pan American Airways was interested in the international market. With the Foreign Air Mail Act of 1928, Pan American began to establish itself as the foreign airmail carrier. The company went on to establish themselves as the premier U.S. international carrier. Although Pan American would lose its monopoly over international flights after World War II, it would continue to dominate international travel until the 1980's.

When Franklin D. Roosevelt became president in 1933, he named James A. Farley postmaster general. After a U.S. congressional investigation into the awarding of contracts under Postmaster Brown, Farley canceled all contracts on February 3, 1934, and announced that the Army Air Corps would now deliver the mail. In a little over five months of service, the Air Corps recorded sixty-six crashes and twelve deaths, leading Roosevelt to order a halt to the operation. The Air Mail Act of 1934 reauthorized the postmaster general to award contracts based on competitive bidding, created a Federal Aviation Commission to study aviation policy, and required the separation of airline companies and aircraft manufacturers.

Regulating the Industry

With the passage of the Air Mail Act of 1934, there were three federal agencies responsible for regulating the aviation industry in the United States. The Postal Service reviewed applications for airmail routes, while the Interstate Commerce Commission set and reviewed the rates to be paid. In addition, the Air Commerce Act of 1926 had given the Department of Commerce responsibility for insuring safety through the registration and certification of aircraft and the certification of pilots. After several months of study, the Federal Aviation Commission recommended the Civil Aeronautics Act of 1938. The act created the Civil Aeronautics Authority to establish policies relating to the safety and economics of air transport. The 1940 Amendment to the Civil Aeronautics Act gave the Civil Aeronautics Board (CAB) legislative and accident investigation authority, while a separate Civil Aeronautics Administration was charged with promoting and enforcing air safety.

The CAB Years

The CAB was authorized to issue Certificates of Public Convenience and Necessity to any person or business it deemed fit, willing, and able to perform public air transport. No one would be permitted to engage in public transport without such a certificate. These certificates were often very specific in their limitations on the types of services the air carrier was allowed to provide. They might designate certain allowed routes, intermediate stops, through service, and prohibited stops or types of traffic. Passenger fares and cargo rates were also strictly regulated. Carriers wishing to change fares or rates were required to file a petition arguing the just and reasonable nature of the increase. Although route and pricing assignments were the most visible of the CAB's activities, the board also exercised a broad range of other controls over U.S. air carriers, including setting standards for record keeping, maintenance scheduling, mergers, and intercarrier agreements. Labor issues were subject to the Railway Labor Act, which prescribed a detailed system of dispute resolution between parties, including intervention by the U.S. president if all other steps failed.

The Civil Aeronautics Act included a clause, Section 401e, which stated that all carriers that had provided adequate and continuous airmail service between May 14 and August 22, 1938, would be granted a permanent Certificate of Public Convenience and Necessity. The first airline to receive this certificate was Delta Air Corporation. Fifteen other carriers received such a certificate, including American Airlines, Braniff International Airways, Chicago and Southern Airlines, Continental Airlines, Northwest Airlines, Pennsylvania-Central Airlines, Transcontinental & Western Air, Eastern Air Lines, Inland Airlines, Mid-Continent Airlines, National Airlines, Northeast Airlines, United Air Lines, Western Air Express, and Wilmington-Catalina Airlines. Under the CAB, five mergers were eventually approved among this original group. Chicago and Southern and Northeast Airlines merged with Delta. Inland merged with Western. Mid-Continent merged with Braniff. Pennsylvania-Central became Capital and later merged with United. The airlines known as Transcontinental & Western changed their corporate name to Trans World Airlines.

The years between 1938 and 1958 were growth years for the airline industry. The Douglas aircraft, the DC-3, was introduced in 1936 and became one of the most popular passenger aircraft in history. From the airlines' perspective, the two-engine aircraft, which seated twenty passengers, substantially lowered their operating costs, making passenger operations more attractive. The introduction of the first jets into commercial service in 1956 was a watershed event for aviation. Almost overnight, the speed of air travel doubled, but the jet also created problems for airlines not used to maintaining these new aircraft and air traffic systems not used to the speed with which incidents might occur. A series of accidents led to public outcry for government action to improve the safety of the skies.

The Federal Aviation Act of 1958 modified the old Civil Aeronautics Act of 1938, expanded the power of the government over matters of safety, and created the Federal Aviation Agency as an independent agency answerable only to Congress and the president. With the formation of the Department of Transportation in 1966, the agency's name was changed to the Federal Aviation Administration (FAA) and placed under the secretary of transportation. The FAA consolidated all air safety research and development under one agency and assumed responsibility for the creation of safety rules. The fact that air travel increased from just over 1 million passengers in 1938 to 267 million in 1978 meant that the FAA served a vital role in developing a safe air transportation system.

While technological developments continued to improve the safety of air transportation, a growing number of critics began arguing against the economic regulation of the industry. These critics contended that the regulation of route entries and exits as well as prices created fares that were higher than the unregulated intrastate routes. This regulation limited competition on profitable routes and prevented carriers from exiting less profitable ones. In the wake of public distrust with government caused by the Vietnam War and the Watergate crisis, the political climate was ripe for deregulation of the domestic airline industry. The Airline Deregulation Act of 1978 marked the end of an era.

Regulating International Aviation

World War II diverted the attention of many governments from issues of commercial domestic aviation and interrupted international aviation. In the closing year of the war, however, the Allied Powers, led by the United Kingdom, the Soviet Union, and the United States, were ready to begin considering the role of aviation in the postwar world. A conference was held on November 1, 1944, in Chicago, Illinois, involving representatives of fifty-four allied nations to consider matters relating to international aviation. The Chicago Conference, as it is commonly known, considered four proposals for the international aviation environment. Australia and New Zealand suggested creating an airline with international ownership and management. The United States proposal favored individual ownership and unrestricted rights to all international markets with the fares and frequency of flights determined by free market forces. The British also wanted individual ownership, but they favored tight regulation of market entry, fares, and frequency. They suggested the creation of an international body to regulate matters relating to international aviation. The Canadian proposal represented a compromise between the U.S. and British positions. It called for limited competition and a multilateral organization to allocate routes and review questions of fares and frequency. Unfortunately, the representatives were not able to reach agreement on any of the proposals.

Pan American was one of the earliest airlines to shift its focus from mail delivery to world tourism. (Library of Congress)

In 1946, the United States and Great Britain met again to address the question of international aviation. The result of the meeting was an agreement commonly called Bermuda I, after the site of the meeting. This agreement became the first bilateral air service agreement, that is, the first agreement between two countries on the air rights granted to each party. Bermuda I set the pattern that all other agreements would follow. It established the principle of reciprocal rights or the exchange of air rights in air service agreements. Bilateral agreements would also designate the number and sometimes the name of the carriers from each side allowed to operate to each country and would establish limits on capacity and route frequency. As a result of Bermuda I, an international body was established to allocate routes and set fares. This organization, the International Air Transport Association (IATA), was made up of representatives from all airlines providing international service. A second organization, the International Civil Aviation Organization (ICAO), was formed to deal with technical and safety-related aviation matters. Over time, bilateral agreements became the key to international aviation. Agreements would be negotiated by governments, often with the input of their major carriers. These agreements were designed to protect the national carriers from international competition.

The decision by the United States to begin deregulation of its own markets in 1978 also affected international aviation. Invoking U.S. antitrust law, which prohibited competitors from colluding to set price and allocate supply, the U.S. government issued a notice to IATA that it was considered an illegal cartel. U.S. airlines were notified that they could no longer participate in the fare- and route-setting mechanisms of IATA. The U.S. government later announced its intention to pursue a strategy of liberalizing aviation markets by pursuing new bilateral agreements, known as Open Skies Agreements, that reduced or eliminated route restrictions and freed carriers to offer fares responsive to consumer demand.

Era of Aviation Liberalization

Efforts to free air carriers from economic regulation proceeded on both the domestic and international fronts after 1978. Domestically, the Airline Deregulation Act resulted in the phase-out of the CAB and the establishment of the FAA as the chief agency concerned with matters relating to aviation. Although carriers would still be required to file for a Certificate of Convenience and Necessity, they were now free to enter and exit markets based on consumer demands. Fares would now be determined by the market forces of competition and consumer demand.

People Express in many ways typified the fate of the many carriers that arose after 1978. It was the first carrier established after deregulation and one of many carriers to begin operation as a no-frills, low-fare, regional carrier. The demand for its service was tremendous, leading to explosive growth. In only six years, it became the tenth-largest carrier in the nation. However, to achieve this rate of growth it began acquiring new aircraft and eventually whole carriers, including Frontier Airlines, Britt Airways, and Provincetown Boston Airlines (PBA). Its rapid growth and high debt, along with renewed competition from the large, prederegulation carriers, eventually sent People Express to the brink of bankruptcy and resulted in its acquisition by another carrier. Since the beginning of deregulation, over two hundred carriers have started and failed. Most never achieved the size of People Express before high start-up costs and intense competition forced them into bankruptcy. The fate of the established carriers was often not much better after deregulation. Under the CAB, no major U.S. carrier had ever gone bankrupt, because fares were set and new routes allocated to ensure that airlines made a profit. The cost of operation was not a critical factor to success. The new, deregulated start-up carriers would challenge the older carriers with lower costs and lower fares. In 1982, Braniff International became the first major airline in the United States to file for bankruptcy. It would not be the last. Pan American and Eastern eventually ceased operations entirely. Other carriers faced periods of serious financial crisis, as fuel hikes, economic downturns, and low-cost competition threatened profits and forced cutbacks.

On the international scene, the U.S. government began pursuing a strategy of encirclement to encourage liberalization. In effect, the United States would attempt to sign Open Skies Agreements with countries surrounding major restricted markets, such as Great Britain and Japan, in an effort to divert traffic and revenues from them. It was hoped that this pressure would encourage more rapid liberalization. The final step in the liberalization of the international aviation markets would be to allow foreign carriers to fly domestic passengers, known as cabotage. For instance, in 2001, British Airways had the right through bilateral agreement to fly passengers into New York City, but the airline could not pick up passengers in New York City and fly them to another destination in the United States. One of the features of the European Union (EU) has been to allow carriers from any EU state to fly within the territory of another member state. There are proposals to establish such provisions across the Atlantic between Europe, the United States, and Canada.

While there is still debate about the effects of deregulation on national and international markets, there is evidence that fares have declined. In the light of declining fares, carriers have focused on cutting costs, creating hubs to funnel traffic from smaller markets into larger ones, and utilizing technology to manage revenues. More affordable airfares also means that more people are likely to travel by air. In 2001, it was forecast that more than one billion passengers a year would board an aircraft in the United States in 2011. (This prediction was made, however, before the terrorist attacks of September 11, 2001, resulted in a drastic reduction in U.S. air travel due to security concerns.) Internationally, the rate of growth in passenger traffic is higher in the Latin American and Asia-Pacific markets, where developing nations are turning to air transportation to link their countries and support their industries.

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See also: Aer Lingus; Aeroflot; Aeromexico; Air Canada; Air France; Airline industry, U.S.; Airmail delivery; Alitalia; American Airlines; British Airways; Continental Airlines; Delta Air Lines; EgyptAir; El Al; Food service; Frequent flier miles; Iberia Airlines; Japan Airlines; KLM; Korean Air; Lufthansa; Northwest Airlines; Pan Am World Airways; Pilots and copilots; PSA; Qantas; SAS; Singapore Airlines; Southwest Airlines; Swissair; Trans World Airlines; Transatlantic flight; Transcontinental flight; Transglobal flight; United Air Lines; US Airways; Virgin Atlantic; World War I; World War II

Air Combat Command

Also known as: ACC

Date: Activated on June 1, 1992

Definition: Major command responsible for providing air combat forces to the United States' unified combatant commands, including the U.S. Strategic Command, U.S. Atlantic Command, U.S. Central Command, U.S. Southern Command, U.S. European Command, North American Aerospace Defense Command, and U.S. Transportation Command.

Significance: The Air Combat Command provides the air power flexibility required to respond rapidly for defense, peacekeeping, and humanitarian missions globally.

History

The creation of the Air Combat Command (ACC), officially activated on June 1, 1992, occurred as the result of the reorganization of the U.S. Air Force in the post-Cold War period. Prior to 1992, the primary commands of the Air Force included the Strategic Air Command (SAC) and Tactical Air Command (TAC). SAC exercised control over the nation's nuclear arsenal and strategic defense planning, while TAC functioned as the command for tactical, or specific mission, coordination. During the Vietnam conflict, SAC performed many tactical missions while TAC engaged in strategic bombing. The overlapping responsibilities continued through Operation Desert Storm in 1991. After U.S.-Soviet relations improved at the end of the Cold War, Air Force commanders reevaluated the need for the two distinct commands.

Air Force Chief of Staff General Merrill A. McPeak, Vice Chief of Staff General John M. Loh, and SAC Commander in Chief General George L. Butler advocated the restructuring of the Air Force commands in a manner that would eliminate repetitive functions and provide an efficient allocation of resources. Military officials, after reviewing the proposed changes, agreed to merge most of SAC and TAC under a new command, the Air Combat Command (ACC), and to reorganize the Military Airlift Command (MAC). The goal of the ACC was to provide the Air Force with the power to implement policy on a global basis.

On June 1, 1992, ACC officially replaced TAC in a brief ceremony conducted at Langley Air Force Base, with the former commander of TAC, General Loh, becoming the new commander of ACC. SAC was then deactivated and the U.S. Strategic Command assumed responsibility for the nuclear weapons of the U.S. Air Force and U.S. Navy. The newly created ACC initially assumed control over all fighter resources within the forty-eight contiguous states, as well as bombers, reconnaissance platforms, intercontinental ballistic missiles (ICBMs), and battle-management resources.

Continuing efforts to streamline and reorganize the Air Force commands resulted in numerous changes within ACC during its first few years of operation. Shortly after the activation of ACC, all combat search-and-rescue units transferred from the Air Mobility Command (AMC) to

ACC. In February, 1993, the Air Rescue Service (ARS) was reassigned to ACC. Several months later, it was renamed the U.S. Air Force Combat Rescue School and assigned to Nellis Air Force Base, Nevada. While ACC gained some resources, it lost others, as the 58th and 325th Fighter Wings, responsible for F-16 and F-15 training, were reassigned to the Air Education and Training Command (AETC) on July 1, 1993. At the same time, ACC lost two of its numbered units when the Twentieth Air Force, responsible for ICBMs and consisting of six missile wings, one test and one training wing, and the base at which they were stationed, F. E. Warren Air Force Base, Wyoming, transferred to the Air Force Space Command. That same day, the Air Force also deactivated the Second Air Force, a unit responsible for reconnaissance missions that ACC had acquired from the merger between SAC and TAC.

Operations

ACC operations include global military and humanitarian missions as well as the peacetime defense of the United States. ACC provided troops, both active-duty and reserve units, during Operation Desert Storm and Operation Southern Watch in the Persian Gulf. ACC has also been involved in the war against drugs and continues to provide Airborne Warning and Control Systems (AWACS), reconnaissance, and fighter aircraft to prevent the transportation of illegal substances into the United States. In Eastern Europe, ACC enforced the no-fly zone against the Serbians in Operation Deny Flight. ACC has also participated in numerous humanitarian missions throughout the world. In Eastern Europe, ACC units supplied aid to Bosnian civilians in Sarajevo. In Turkey, ACC deployed active-duty personnel for Operation Provide Comfort, rendering humanitarian assistance to the Kurdish inhabitants of the northern portion of Iraq who were being persecuted by the Iraqi government. In Africa, ACC troops participated in Operation Restore Hope in Somalia, providing food for the country's starving population, as well as providing similar aid in Operation Support Hope in Kenya and Uganda. ACC also provided relief for the victims of a bloody civil war in Rwanda. Closer to the United States, ACC personnel were involved in Operation GTMO out of the United States Naval Base at Guantanamo Bay, Cuba, for the purpose of providing relief for Haitian refugees. In 1994, ACC assisted in the processing of Cuban refugees during Operation Safe Haven.

ACC continues to defend the United States from foreign enemies while expanding its role to assist people around the world. Quick response and constant preparedness allow ACC to exercise global power for the United States. In August, 1993, two B-52's stationed out of Ellsworth Air Force Base, South Dakota, set a record flying time on an around-the-world flight and in 1994, two B-52's from Barksdale Air Force Base, Louisiana, established the longest jet flight in history during their 47.2-hour flight around the world. By the year 2000, Air Combat Command's original mission had been altered to reflect streamlining within the Air Force and the need for flexible response to rapidly changing worldwide circumstances. Although no longer responsible for many of the duties formerly performed by Strategic Air Command, such as control of ICBMs, ACC maintains a prominent position in the Air Force and is vital for combat, rescue, and theater airlift missions.

Organization

Headquartered at Langley Air Force Base, Virginia, ACC operates fighter, bomber, reconnaissance, battle-management, rescue, and theater airlift aircraft, in addition to command, control, communications, and intelligence systems. ACC operates with 102,000 active-duty personnel and civilians and can mobilize an additional 64,400 members of the Air National Guard and Air Force Reserve during times of national emergency. ACC's numbered air force units consist of 775 aircraft, with the

Air Combat Command (ACC) Bases

ACC Base	*Air Force*
Barksdale AFB, Louisiana	Eighth Air Force
Beale AFB, California	Twelfth Air Force
Cannon AFB, New Mexico	Eighth Air Force
Davis-Monthan AFB, Arizona	Twelfth Air Force
Dyess AFB, Texas	Eighth Air Force
Ellsworth AFB, South Dakota	Eighth Air Force
Holloman AFB, New Mexico	Twelfth Air Force
Langley AFB, Virginia	Ninth Air Force
Minot AFB, North Dakota	Eighth Air Force
Moody AFB, Georgia	Ninth Air Force
Mountain Home AFB, Idaho	Twelfth Air Force
Nellis AFB, Nevada	Twelfth Air Force
Offutt AFB, Nebraska	Twelfth Air Force
Seymour Johnson AFB, North Carolina	Ninth Air Force
Shaw AFB, South Carolina	Ninth Air Force

number of ACC-accessible aircraft totaling 1,700.

The strength of the ACC includes four numbered air forces and two direct reporting units. The First Air Force exercises oversight of the air defense forces for North America under the North American Aerospace Defense Command. It is headquartered at Tyndall Air Force Base, Florida, with additional units stationed at Northeast Air Defense Sector in Rome, New York, and Western Air Defense Sector at McChord Air Force Base, Washington.

The Eighth Air Force, headquartered at Barksdale Air Force Base, Louisiana, controls ACC forces in the central United States, with the direct responsibility for war fighting under the U.S. Atlantic Command, as well as functioning as the Joint Task Force/Bomber for U.S. Strategic Command. The Eighth Air Force consists of units stationed at ten bases. The Second Bomb Wing of B-52's operates out of Barksdale Air Force Base. The Twenty-seventh Fighter Wing with its EF-111's and F-16's is based at Cannon Air Force Base, New Mexico. The Seventh Wing with its B-1 and C-130H aircraft is stationed at Dyess Air Force Base, Texas. Ellsworth Air Force Base, South Dakota, is home to the Twenty-eighth Bomb Wing of B-1 bombers. Lajes Field, Azores, is the home base for the Sixty-fifth Air Wing. The 314th Airlift Wing with its C-130E/H's is based at Little Rock Air Force Base, Arkansas. The Fifth Bomb Wing, composed of B-52 bombers, is stationed out of Minot Air Force Base, North Dakota. Whiteman Air Force Base, Missouri, is home for the 509th Bomb Wing of B-2 and T-38 aircraft. The Eighty-fifth Group, stationed at Keflavik Naval Air Station, Iceland, and the Third Air Support Operations Group out of Fort Hood, Texas, also operate under the Eighth Air Force.

The Ninth Air Force, which is responsible for ACC forces in the eastern United States under U.S. Central Command, is headquartered at Shaw Air Force Base, South Carolina. Units from the Ninth Air Force are stationed at five bases along the Atlantic seaboard. Forces at Langley Air Force Base, Virginia, home of the First Fighter Wing, include the C-21A and the F-15C/D as well as Forty-first Rescue Squadron and Seventy-first Rescue Squadron at Patrick Air Force Base, Florida. The 347th Wing out of Moody Air Force Base, Georgia, includes F-16's, C-130E's and A-10's. At Pope Air Force Base, North Carolina, the Twenty-third Wing includes A-10's, F-16C/D's and C-130E's. The Fourth Fighter Wing of F-15E's is stationed at Seymour Johnson Air Force Base, North Carolina, and the Twentieth Fighter Wing, with its A-10's and F-16C/D's, is located at Shaw Air Force Base, South Carolina. In addition, the Ninth Air Force includes the Thirty-third Fighter Wing, with its F-15C's at Elgin Air Force Base, Florida; the Ninety-third Air Control Wing, with its E-8 Joint STARS, and the Fifth Combat Communications Group at Robins Air Force Base, Georgia; the 823d Red Horse Civil Engineering Squadron at Hurlburt Field, Florida, and the Eighteenth Air Support Operations Group at Pope Air Force Base, North Carolina.

The last of the numbered air forces within the Air Combat Command is the Twelfth Air Force, headquartered at Davis-Monthan Air Force Base, Arizona. The Twelfth Air Force controls ACC forces in the western United States and Panama and operates under the U.S. Southern Command and the U.S. Strategic Command. The Twelfth Air Force shares Joint Task Force/Battle Management duties with the U.S. Strategic Command. Under the Twelfth Air Force are the Ninth Reconnaissance Wing of U-2R/S and T-38 aircraft, based at Beale Air Force Base, California; the 355th Wing of A-10's, and EC-130H/E's, based at Davis-Monthan Air Force Base; the Forty-ninth Fighter Wing of F-117A's, T-38's, HH-60's, and German F-4E's, based at Holloman Air Force Base, New Mexico; the Twenty-fourth Wing of C-21's, C-27's, and CT-43's stationed at Howard Air Force Base, Panama; the 366th Wing out of Mountain Home Air Force Base, Idaho, with its F-15C/D/E's, F-16's, KC-135R's and B-1's; and the Fifty-fifth Wing with its C-21, E-4, RC-135 S/U/V/W, EC-135, KC-135, TC-135 S/W, WC-135, and OC-135 aircraft stationed at Offutt Air Force Base, Nebraska. The Twelfth Air Force also has units stationed at four other bases, with the 388th Fighter Wing at Hill Air Force Base, Utah; the 820th Red Horse Civil Engineering Squadron at Nellis Air Force Base, Nevada; the 522d Air Control Wing and the Third Combat Communications Group at Tinkler Air Force Base, Oklahoma; and the First Air Support Operations Group at Fort Lewis, Washington.

Direct reporting units under the ACC include the Fifty-seventh Wing, with its A-10A, F-15 C/D/E, F-16, HH-60, and Predator uncrewed vehicles, as well as the Air Warfare Center, the U.S. Air Force Air Demonstration Squadron (Thunderbirds), the Ninety-ninth Air Base Wing, and the U.S. Air Force Weapons School located at Nellis Air Force Base, Nevada. The Fifty-third Wing at Eglin Air Force Base, Florida, is assigned to the Air Warfare Center and is responsible for several subordinate units, including the Sixth Electronic Combat Group and the Seventy-ninth Test and Evaluation Group at Eglin Air Force Base, the 505th Command and Control Evaluation Group at Hurlburt Field, Florida, and the 475th Weapons Evaluation Group at Tyndall Air Force Base, Florida. The second direct reporting unit is the Aerospace Command and Control, Intelligence, Surveillance and Reconnaissance Center. The ACC also operates the Aerospace Expeditionary Force Center and is responsible for Air Force search-and-rescue missions within the continental United States.

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Air Force, U.S.

Definition: One of the primary components of the United States armed forces, with the key responsibility for air warfare.

Significance: The United States Air Force, officially established as a separate military service on July 26, 1947, is responsible for the effective prosecution of offensive and defensive air operations.

Foundation of the Air Corps

The U.S. Army Signal Corps organized an aeronautical division on August 1, 1907, only three years after the Wright brothers made their famous flight at Kitty Hawk, North Carolina. Until 1914, however, this division was interested more in balloons and dirigibles than in flying machines. The Army had used manned balloons for the observation of enemy lines during the American Civil War (1861-1865) and the Spanish-American War of 1898. The Wright brothers sold their first airplane to the Army in 1909 but it was used only for experimental purposes. The Wright brothers taught the first officers how to fly. The first operation unit, the First Aero Squadron, was formed in December, 1913, under the command of Captain Benjamin D. Foulois.

Congress provided additional funds in 1914, just a few weeks before World War I began in Europe, and the Army established the Aviation Section of the Signal Corps to test planes and train pilots. In April, 1917, the United States entered the war on the side of the Allied Powers of England, France, Italy, and Russia. Both the Allies and the Central Powers of Germany, Austria-Hungary, and Turkey had developed air forces that were bigger and better equipped than that of the United States.

Despite additional money from Congress, the United States never caught up with the European nations in aviation technology. The vast expansion required mass production of pilots, observers, and mechanics. A network of schools was established for advanced training in aircraft engineering and the aviation section sent officers to the Massachusetts Institute of Technology and similar universities to learn the required skills. On May 24, 1918, President Woodrow Wilson created the Army Air Service within the War Department to develop plans to catch up with the nations of Europe.

When World War I ended on November 11, 1918, the Air Service had 19,000 officers and 178,000 enlisted men. The American aircraft industry had built more than 11,500 planes (mostly training craft) during the fifteen months the United States fought in Europe, but as soon as the war stopped, the number of personnel was quickly reduced as the nation demobilized its military and ended the draft. The production of aircraft came to almost a complete halt.

While in France, American pilots flew mostly French-made planes under the command of Brigadier General William "Billy" Mitchell. Although the air war played only a minor role in the war's outcome, air power had shown its potential for providing cover and protection for ground troops. The British, recognizing the importance of its air power, created an independent Royal Air Force (RAF) in 1918.

Between World War I and World War II (1941-1945), General Mitchell led an unsuccessful and bitter struggle within the War Department and in congressional hearings to create a separate air force. The Army Reorganization Act of 1920 made the Air Service part of the Army, and in 1926, the name of the Army Air Service was changed to the Army Air Corps. In the 1930's, as the Fascist powers of Germany, Japan, and Italy spent heavily to build up their military forces, the United States kept only a small Army, Navy, and Air Corps. Congress appropriated only small amounts of money on the growth or modernization of the armed services, principally because the Great Depression of the 1930's had had a devastating impact on the American economy.

Creation of the Air Force

The horrible battles of World War I, which killed more than twenty million soldiers, led some planners to see the advantages of airplanes as weapons of war. With proper use of airplanes, the bloody massacres of trench warfare, in which armies attacked each other by running across open fields trying to dislodge the enemy from its trenches, could be avoided.

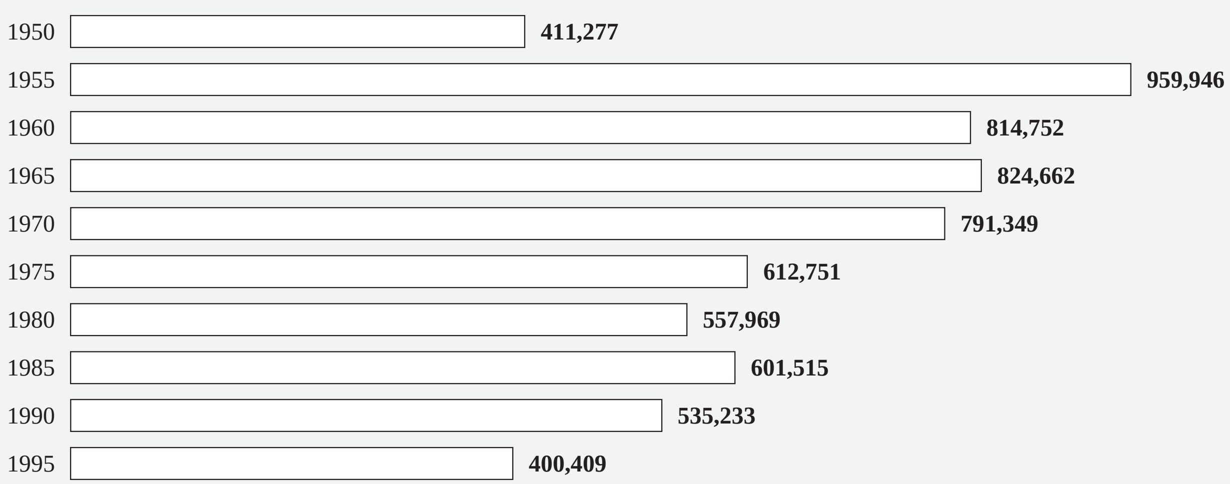
Advocates of air power believed that airplanes would change the nature of warfare by carrying the war to the enemies' factories and supply stations. Bombs would destroy cities and buildings and cause panic among the civilian population. Intense bombing would quickly weaken the morale of the people and destroy their will to fight. Air power would shorten war, would make warfare less expensive, and would save the lives of a nation's ground and naval forces. The bombing of civilians, as savage as that might be, was more merciful than gassing and machine-gunning vast numbers of soldiers.

General Henry Harley "Hap" Arnold became chief of the Air Corps in 1938. A graduate of West Point who had been trained in flying by Orville Wright, Arnold pushed for increased appropriations, but not until after the Japanese attack on Pearl Harbor on December 7, 1941, did Congress respond. Arnold and Mitchell had tried to teach these lessons to War Department observers in the 1930's, but only a real war would convince doubters that air power was a crucial factor in victory.

In 1941, the Air Corps began an expansion in response to events in Europe and the Pacific. After American entry into the war, all Army air units were merged into the Army Air Force (AAF) under General Arnold. The AAF quickly grew into a powerful organization composed of 16 air commands (12 of them overseas), 243 combat groups, 2,400,000 officers and men, and almost 80,000 aircraft.

During the war, two U.S. air commands, the Eighth and the Fifteenth, joined with the British RAF Bomber Command in the strategic bombing of Germany. Strategic bombing was defined by Mitchell as the use of air power against the enemy's heartland and industrial base. Although the night-and-day bombing of Germany destroyed its war industries, the bombing proved far less accurate than expected. Because bombardiers could not see through the cloud cover over northern Europe, precision was lost. Radar helped, but pinpoint targets often disappeared in the cluttered radar images of large cities. Another problem for

U.S. Air Force Personnel on Active Duty, 1950-1995



Sources: The data used in this graphic element are based on information found in *Historical Statistics of the United States: Colonial Times to 1970* (2 vols., Washington, D.C.: Government Printing Office, 1975) and *The Time Almanac 2000*, edited by Borgna Brunner (Boston: Information Please, 1999).

the Allies was their lack of air defense; during long-range strikes, unescorted Allied bombers were knocked out of the sky with appalling accuracy by German ground fire. Almost 75 percent of Allied crews never returned from bombing missions. Not until the introduction of a new escort fighter, the North American P-51 Mustang, were the skies reclaimed from German control to become safer for American and British pilots.

In the Pacific, the Tenth Air Force in the China-Burma-India theater and the Fourteenth in China supported the British and Chinese against the Japanese. The Fifth, Seventh, and Thirteenth Air Forces joined with the Army and Navy in the series of island invasions and conquests that were the stepping-stones to the attack of Japan. The Tenth Air Force carried supplies over the Himalayan Mountains, playing a key role in preventing a Japanese victory in China.

Because of the vastness of the Pacific Ocean, strategic bombing of Japan remained impossible until after the B-29 bomber was produced and bases were established close enough to Japan to allow U.S. forces to strike at Japanese industrial cities. When sustained bombing of Japan did begin in May, 1944, the Japanese military leaders recognized that they were close to defeat. From the Mariana Islands, the B-29 bombers of the Twentieth Air Force carried out a bombing campaign against Japan that ended with the atomic bombing of Hiroshima and Nagasaki in August, 1945. The Pacific war was ended on August 12, and the armed forces began a swift demobilization. Despite the reduction in force, however, the United States still had the most powerful military in the world, with about 300,000 officers and men in the AAF at the end of 1947.

Organization

In March, 1946, the basic pattern of unit organization for the AAF was established in descending order as follows: command, air force, air division, wing, group, squadron, and flight. On July 26, 1947, the National Security Act created the independent U.S. Air Force. Stuart Symington became the first secretary of the Air Force, and he appointed General Carl Spaatz the first chief of staff. One month later, Air Force pilot Captain Charles E. "Chuck" Yeager flew the Bell X-1 rocket plane beyond the speed of sound. From this time on, the Air Force was crucial in the development of supersonic flight and atomic bombs and other weaponry.

The U.S. Air Force was charged by President Harry S. Truman to organize, train, and equip air forces for air operations, including joint operations with the Army and Navy; to gain and maintain air superiority over other nations; to develop a strategic air force and conduct air reconnaissance operations; to provide airlift and air support for airborne operations; to furnish air support to land and naval forces, including occupation forces; and to provide air transport for the armed forces, except as provided by the Navy for its own use. The first opportunity the Air Force had to display its power came in 1950.

The Air Force in the Korean War

During the early hours of June 25, 1950, Communist North Korean soldiers launched a surprise attack across the thirty-eighth parallel, the dividing line between North Korea and the Republic of South Korea. Within three days, the Communists had advanced to Seoul, the South Korean capital, and the U.S. ambassador requested the immediate evacuation of all American civilians in the city. Three days after the invasion, the United Nations declared war on the North because it had violated the U.N. Charter, which outlawed wars of aggression. U.N. forces, composed primarily of American and South Korean forces, went to war the next day.

The U.S. Air Force soon employed new jet fighters, such as the F-86 Sabre, to gain control of the skies. It also helped protect U.N. ground forces with close support and successful raids to destroy North Korean reinforcements and supplies. U.S. Air Force B-29's were first used in August, 1950, for the purpose of knocking out North Korea's ability to build guns and tanks, a goal that was accomplished by the end of September. By late October, the U.N. troops had advanced far into North Korea, almost reaching the Yalu River, which forms North Korea's northern boundary with China. The first appearance of a Russian-built MiG-15 fighter on November 1 showed that China was about to enter the war to prevent the collapse of North Korea. When the Chinese attacked late in November, the U.N. forces retreated to South Korea under the protection of the U.S. Air Force.

The battle for air superiority continued to escalate until July, 1953, when an armistice was signed. In air-to-air combat, U.S. Air Force fighters had shot down 792 MiGs, losing only 78 American craft. After the war ended, the Air Force kept a large number of units in the Pacific to defend against any future Communist invasions in Asia.

The Cold War and the Arms Race

In the 1950's, the invention of the hydrogen bomb, 100,000 times more powerful than the atomic bombs used against Japan, inaugurated an arms race between the United States and the Soviet Union. By the middle of the decade, both nations had developed long-range rockets and were working on missiles that could reach halfway around the world in about thirty minutes. Under the command of General Curtis LeMay, the Air Force's Strategic Air Command (SAC) became the key instrument of American defense strategy. SAC planes were in the air twenty-four hours a day, always flying along the Russian border within thirty minutes of Moscow. Another major part of the Air Force's fleet was the long-range B-52 Stratofortress, which would remain the principal bomber in the U.S. Air Force for more than forty years.

In the 1960's, intercontinental ballistic missiles (ICBMs), such as the Atlas, Titan, and Minuteman, were added to the U.S. arsenal. With the development of satellites, the Air Force also expanded its mission into space. Together with the Navy's missile-launching submarines, bombers and land-based ICBMs made up the triad of the U.S. nuclear deterrent force. With nuclear weapons in the air, on the land, and under the sea, the United States felt assured that the Russians would never be able to destroy America's entire nuclear force. At least one arm of the triad would remain, in the event of a devastating nuclear attack, to launch a nuclear attack against the initial aggressor.

In October, 1962, a U.S. Air Force U-2 reconnaissance plane took photographs of Russian missile bases being built in Cuba. The missiles launched from these sites would be within striking distance of Washington, D.C., New York City, and other targets along the Atlantic Coast. President John F. Kennedy ordered the armed forces on alert for the possibility of nuclear war. On October 22, the president declared a strict quarantine of all offensive military equipment under shipment to Cuba. The U.S. Air Force kept the island of Cuba under constant surveillance, providing the Navy with constant information on Russian ships at sea apparently on their way to Cuba. On October 28, only minutes before American and Soviet ships prepared to fire on each other, Soviet premier Nikita S. Khrushchev agreed to remove the missiles as well as a unit of Russian bombers from the island. In the event that shooting had begun, President Kennedy had been ready to launch nuclear missiles toward the Soviet Union and to order SAC planes to attack Russian military bases. The Cuban Missile Crisis represented the closest the world had yet come to a nuclear war.

The U.S. Air Force in Vietnam

Communist expansion in Southeast Asia created new challenges in the mid-1960's. In 1964, the United States became directly involved in a war in the former French colony of Vietnam. The war began when the Communist North invaded South Vietnam. In 1965, after two deadly Communist attacks on American military advisers in South Vietnam, President Lyndon B. Johnson authorized Operation Rolling Thunder, which called for continuous bombing of the North's main cities and military bases.

U.S. Air Force and U.S. Navy airplanes supported more than 500,000 American ground troops in a difficult and unpopular war. The F-4 Phantom II provided close air support for Army and Marine units in the fields and jungles, while the F-105 Thunderchief led hundreds of bombing raids against North Vietnam. SAC B-52 bombers dropped millions of tons of bombs on remote strongholds of the North Vietnamese Army and were refueled by KC-135 Stratotankers.

In 1972, the U.S. Air Force launched Operation Linebacker, which produced the heaviest bombing of the entire war. This intense campaign forced the North to sign a peace treaty in January, 1973. U.S. land forces were withdrawn a few months later and were no longer available to help South Vietnam when the North launched another invasion in 1975. This time, the Communist forces were successful, and South Vietnam was absorbed into the North.

In the 1970's, despite budget reductions, the U.S. Air Force spent as much as it could to modernize its aircraft and missiles while also becoming more heavily involved in space exploration. Meanwhile, the Soviet Union continued to produce new weapons at a faster rate than the United States and built up its ground forces in Europe and the Far East to great levels. After the Soviet Union's disastrous war in Afghanistan (1979-1989), however, the military balance shifted back to the United States.

The U.S. defense buildup of the 1980's allowed the U.S. Air Force to expand its arsenal of aircraft and to deploy a wide range of new weapons systems, including the Lockheed F-117A stealth fighter, which was developed in response to the need for an aircraft capable of attacking targets without being detected by radar. The F-117A was first used in the 1989 U.S. invasion of Panama, known as Operation Just Cause, in which Manuel Noriega, the self-appointed president of Panama, who had been engaged in drug smuggling, was arrested and brought to the United States for trial.

New American technologies, such as radar-proof bombers and space-based weapons systems, helped bring an end to the Cold War. The leaders of the Soviet Union realized that they could no longer compete with American military advances. The tearing down of the Berlin Wall in 1989 marked the final days of the long Cold War and a few years later the Soviet Union itself began to break apart.

U.S. Air Force Actions in the 1990's

The 1990-1991 conflict in the Persian Gulf was in many ways the test case for modern air power in the precision-

Image Not Available

weapons era. After Iraqi armies invaded the neighboring state of Kuwait on August 2, 1990, President George Bush imposed an immediate economic embargo against Iraq and its leader, Saddam Hussein. On August 7, Bush ordered the launch of Operation Desert Shield to free Kuwait and drive out the Iraqi invaders. A coalition of Allied forces under the command of General H. Norman Schwarzkopf was mobilized to carry out the effort against Iraq. When Hussein refused to leave Kuwait peacefully, Operation Desert Storm was begun on January 16, 1991.

After ten days of continuous bombing by coalition air forces against Iraqi military targets, the ground war began. Within two days, the Iraqi army had been crushed, and a cease-fire went into effect. The Gulf War demonstrated the dominance of air power, a key factor in the Allied victory. The Iraqis had been defeated by air strikes that totally destroyed their ability to fight.

In the early 1990's, during conflicts in the former republic of Yugoslavia, U.N. peacekeeping forces undertook an air campaign in an attempt to stabilize the region. The campaign in Bosnia included U.S. Air Force planes and offered more evidence that precise attacks were possible and could shatter air defenses and land forces. In 1995, after eleven days of air attacks brought the Serbian government to the peace table in Dayton, Ohio, the Dayton Accords were signed, helping to bring the promise of peace to the region. Once again, it was proven that air power could make the major difference in victory or defeat.

Humanitarian Aid

Since 1947, the U.S. Air Force has participated in almost six hundred humanitarian relief efforts in response to floods, fires, hurricanes, and earthquakes. Nearly one hundred of these relief efforts have taken place since 1987. Immediately after the Gulf War, the U.S. Air Force used its capabilities to provide critically needed food supplies to the people of the Soviet Union. This effort was called Operation Provide Hope. A few years later, Operation Provide Promise brought humanitarian aid to Bosnia and Serbia. With the ending of the Cold War, the need for the Air Force to respond to humanitarian crises has become a major part of its mission.

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See also: Air Force bases; Antiaircraft fire; Dogfights; Gulf War; Korean War; Military flight; Royal Air Force; Strategic Air Command; Tactical Air Command; Vietnam War; World War I; World War II

Air Force bases

Definition: A U.S. Air Force facility that serves as a base of operations for military aircraft.

Significance: Air Force bases are an important strategic component of the U.S. military

The U.S. Air Force maintains bases in the United States and overseas. Within the continental United States, Texas holds the greatest number of bases with eight, followed by California with six and Florida with five. Overseas, Japan ranks first with three bases, followed by Germany, the United Kingdom, and South Korea, each with two.

Overseas, the bases are operated under bilateral agreements and Status of Forces agreements that reflect the United States' rights and use.

The total worldwide cost of government investment in the bases (original acquisition plus improvements as of September 30, 2000) was $50,483,479,441. The oldest active Air Force base is the Francis E. Warren Air Force Base (AFB) in Laramie County near Cheyenne, Wyoming, which was established in 1867 by the U.S. Army as Fort D. A. Russell. The name of the 5,866-acre facility was changed by presidential degree to Fort Francis E. Warren in 1930. Warren, a former senator and governor, won the Medal of Honor in the Civil War. The Army relinquished jurisdiction of the facility to the Air Force in 1947. It now serves as home to the Ninetieth Space Wing, part of the Air Force Space Command, Peterson Air Force Base, Colorado.

The second oldest installation is Offutt Air Force Base, Nebraska, which was activated as Ft. Crook in 1896. Dating from 1916, Kelly Air Force Base, Texas, was the oldest continuously active air base in the United States. Some other longstanding Air Force bases are Scott Air Force Base, Illinois, established in June, 1917; Bolling Air Force Base, Washington, D.C., established in October, 1917; Brooks Air Force Base, Texas, established in December, 1917; and Pope Air Force Base, North Carolina, established in 1919.

A recent "designated" base is Buckley Air Force Base, Denver, Colorado, in October, 2000. A recent "established" base is Schriever Air Force Base (formerly Falcon Air Force Base), Colorado Springs, Colorado, named for General Bernard A. Schriever, which was activated in September, 1985, and renamed in June, 1998.

The largest Air Force bases in terms of acreage are Eglin Air Force Base, Florida, located on Choctahatchee Bay a few miles from the Gulf of Mexico near the towns of Fort Walton Beach and Destin. Eglin is the sprawling home of the Air Warfare Center, which covers 463,452 acres. It was activated in 1940 and is named for Lieutenant Colonel Frederick Eglin, who was killed in an air crash near Anniston, Alabama, in 1937.

The largest base in terms of personnel is Lackland Air Force Base, in San Antonio, Texas, with approximately 23,500 military, Department of Defense civilians, and students.

The air bases are controlled by eight different Air Force commands. Two bases, the Air Force Academy in Colorado Springs, Colorado, and Bolling Air Force Base, in the District of Columbia, are considered Direct Reporting Units (DRUs).

Twenty-six Air Force installations were closed and six were realigned as a result of the disposal authorities contained in the Base Closure and Realignment Acts of 1988, 1991, 1993 and 1995, following action by the Defense Base Closure and Realignment Commissions (BRAC).

Air Guard and Reserve

In addition, there is the Air Force Reserve Command (AFRC) at Robins Air Force Base, in Macon, Georgia. The AFRC was established on February 17, 1997, and is staffed by 173,725 personnel. The Air National Guard, established on September 18, 1947, and composed of

Major Active-Duty Domestic Air Force Bases, 1998

State	*Air Force Base*	*Command*	*Major Units*
Alaska	Eielson AFB	PACAF	354th Fighter Wing
	Elmendorf AFB	PACAF	Headquarters, 11th Air Force; 3d Wing
Alabama	Maxwell AFB	AETC	Air University
Arizona	Davis-Monthan AFB	ACC	Headquarters, 12th Air Force
	Luke AFB	AETC	56th Fighter Wing
Arkansas	Little Rock AFB	AETC	314th Airlift Wing
California	Beale AFB	ACC	9th Reconnaissance Wing
	Edwards AFB	AFMC	Air Force Flight Test Center
	Los Angeles AFB	AFMC	
	McClellan AFB	AFMC	Sacramento Logistics Center
	Travis AFB	AMC	Headquarters, 15th Air Force
	Vandenberg AFB	AFSPC	Headquarters, 14th Air Force
Colorado	Schreiver AFB	AFSPC	Space Warfare Center
	Peterson AFB	AFSPC	Headquarters, Air Force Space Command; 21st Space Wing
	USAF Academy	DRU	
District of Columbia	Bolling AFB	DRU	11th Wing
Delaware	Dover AFB	AMC	436th Airlift Wing
Florida	Eglin AFB	AFMC	Air Armament Center
	Hurlburt Field	AFSOC	Headquarters, Air Force Special Operations Command; 16th Special Operations Wing
	MacDill AFB	AMC	6th Air Refueling Wing
	Patrick AFB	AFSPC	45th Space Wing
	Tyndall AFB	AETC	Headquarters, 1st Air Force (Air National Guard); 325th Fighter Wing
Georgia	Moody AFB	ACC	347th Wing
	Robins AFB	AFMC	Headquarters, Air Force Reserve Command; Warner-Robins Air Logistics Center
Hawaii	Hickam AFB	PACAF	Headquarters, Pacific Air Forces; 15th Air Base Wing
Idaho	Mountain Home AFB	ACC	366th Wing
Illinois	Scott AFB	AMC	Headquarters, Air Mobility Command; Tanker Airlift Control Center
Kansas	McConnell AFB	AMC	22d Air Refueling Wing
Louisiana	Barksdale AFB	ACC	8th Air Force
Maryland	Andrews AFB	AMC	89th Airlift Wing
Massachusetts	Hanscom AFB	AFMC	Electronics Systems Center
Mississippi	Columbus AFB	AETC	14th Flying Training Wing
	Keesler AFB	AETC	2d Air Force
Missouri	Whiteman AFB	ACC	509th Bomb Wing
Montana	Malmstrom AFB	ACC	341st Space Wing, 819th Red Horse Squadron
Nebraska	Offutt AFB	ACC	55th Wing

State	*Air Force Base*	*Command*	*Major Units*
New Jersey	McGuire AFB	AMC	Headquarters, 21st Air Force; 305th Air Mobility Wing
Nevada	Nellis AFB	ACC	Air Warfare Center
New Mexico	Cannon AFB		
	Holloman AFB		
	Kirtland AFB		58th Special Operations Wing
North Carolina	Pope AFB		
	Seymour Johnson AFB		
North Dakota	Grand Forks AFB		
	Minot AFB	ACC	5th Bomb Wing
Ohio	Wright-Patterson AFB	AFMC	Headquarters, Air Force Materiél Command; Aeronautical Systems Center
Oklahoma	Altus AFB	AETC	97th Air Mobility Wing
	Tinker AFB	AFMC	Oklahoma Air Logistics Center
	Vance AFB	AETC	71st Flying Training Wing
South Carolina	Charleston AFB	AMC	437th Airlift Wing
	Shaw AFB	ACC	Headquarters, 9th Air Force
South Dakota	Ellsworth AFB	ACC	28th Bomb Wing
Tennessee	Arnold AFB	AFMC	Arnold Engineering Development Center
Texas	Brooks AFB	AFMC	Human Systems Center
	Dyess AFB	ACC	7th Bomb Wing
	Goodfellow AFB	AETC	17th Training Wing
	Kelly AFB	AFMC	San Antonio Air Logistics Center
	Lackland AFB	AETC	369th Recruiting Group
	Laughlin AFB	AETC	47th Flying Training Wing
	Randolph AFB	AETC	Headquarters, Air Education and Training Command; Headquarters, 19th Air Force; Air Force Recruiting Office
	Sheppard AFB	AETC	80th Flying Training Wing
Utah	Hill AFB	AFMC	Ogden Air Logistics Center
Virginia	Langley AFB	ACC	Headquarters, Air Combat Command
Washington	Fairchild AFB	AMC	92d Air Refueling Wing
	McChord AFB	AMC	62d Airlift Wing
Wyoming	Francis E. Warren AFB	AFSPC	Headquarters, 20th Air Force; 90th Space Wing

111,633 personnel, is overseen by the National Guard Bureau in the Pentagon but is commanded by the governor in each state or territory and by the commanding general in the District of Columbia. Guard and Reserve units operate from active Air Force bases as well as from commercial airport facilities.

Because those two elements of the nation's total military force play such an active part in fulfilling day-to-day as well as short- and long-term active duty requirements for the active Air Force, their more than eighty locations also might well be considered bases. For example, the Air Guard provides 100 percent of the Air Force interceptor force, 9 percent of the B-1B bomber force, 43 percent of the tactical airlift, 27 percent of the air-rescue capability, 30 percent of the tactical fighters, 25 percent of the tactical air support, 41 percent of the KC-135 refueling capability, and 9 percent of the strategic airlift capability, plus provides six aircraft for the Air Force's special operations missions. On any given day, 95 percent of the reserve units are rated ready for combat. Of its unit-owned aircraft, in times of war or other special needs, 98 percent would be gained by the Air Combat Command or Air Mobility Command.

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Air Force One

Date: Beginning in 1933

Definition: Any one of several different aircraft on which the president of the United States is traveling.

Significance: One of the most recognizable and functional symbols of the American presidency, the planes that serve as *Air Force One* are equipped to support a wide range of missions. They function as command and communications centers, flying White Houses, and a secure and efficient means of transportation for the U.S. president, the commander in chief of the U.S. armed forces.

The Origins of a Presidential Plane

The first presidential plane was not called *Air Force One*, because an independent air force did not exist until 1947. Had the first presidential plane, delivered to the U.S. Navy on June 6, 1933, to transport President Franklin D. Roosevelt, been similarly named in 1933, it might have been called *Navy One*. This plane, a Douglas Dolphin Amphibian accommodating five passengers, served as the presidential plane until December 4, 1939.

Although Roosevelt often flew on commercial aircraft, the U.S. Army Air Force contracted with Douglas Aircraft to build a C-54 Skymaster to serve as the presidential plane. With a C-54A fuselage and C-54B wings, this VC-54C became known as the *Sacred Cow* and was equipped with a secret elevator extending from the aircraft's belly to lift the wheelchair-bound Roosevelt into the plane.

The First *Air Force One*

The *Sacred Cow* served President Harry S. Truman for the first two years of his administration. In 1947, on board the *Sacred Cow*, Truman signed an act creating an independent U.S. Air Force. After the *Sacred Cow* was retired in 1961, it was obtained by the U.S. Air Force Museum in 1985. Following a ten-year restoration effort, it was put on display at the U.S. Air Force Museum at Wright-Patterson Air Force Base near Dayton, Ohio, along with several of its successors.

The Second *Air Force One*

Douglas Aircraft also built the next *Air Force One*, a VC-118, commissioned into service on July 4, 1947. The aircraft was also known as the *Independence*, after Truman's Missouri hometown. At a cost of more than $1 million, the VC-118 was a military version of a Douglas DC-6. It carried Truman to Wake Island to discuss with General Douglas MacArthur the escalating problems in Korea. The VC-118 was retired from presidential service in 1953 and from Air Force duty in 1965.

Subsequent *Air Force One* Planes

President Dwight D. Eisenhower's aircraft was the C-121 military version of the Lockheed Constellation, affectionately known as the "Connie" in commercial transport. This presidential plane, named the *Columbine III*, was Eisenhower's third Connie. He had flown two C-121's as the Supreme Allied Commander in Europe. The *Columbine III* left presidential service when Eisenhower left office in 1961 and was retired to the Air Force Museum in 1966.

President John F. Kennedy's first presidential plane, a Douglas C-118, was the first plane to display the distinctive presidential paint scheme. It was followed by Special Air Missions (SAM) 26000, the first plane actually to use the call sign *Air Force One* when the president was on board. SAM 26000, a Boeing VC-137C, the military version of a 707, was the first jet designed exclusively for presidential use. Purchased in 1962 at a cost of $36.6 million, with its distinctive blue-and-white color scheme, the airplane became a symbol of American power.

SAM 26000 served as the presidential plane during some of the most important events in twentieth century American history. It carried Kennedy to Berlin for his famous speech at the Berlin Wall, to Dallas on November 22, 1963, and then home again, for the last time, only a few hours later. Before the plane could take off on the day of Kennedy's assassination, Lyndon B. Johnson was sworn in as president.

Johnson reconfigured SAM 26000 to suit his preferences. Because he wanted to see what others were doing, he jettisoned wooden cabin partitions in favor of clear plastic. He also required a chair and desk that could be raised or lowered by pushing a button. SAM 26000 carried Johnson to Vietnam at the height of the war, a destination shared by President Richard M. Nixon on his first SAM 26000 trip.

Soon after Nixon took office, SAM 26000 went back to Boeing for a complete overhaul, which included the removal of the taping system that recorded all incoming and outgoing calls on the flying White House. Beginning in 1970, SAM 26000 was used on thirteen secret missions to meet with North Vietnamese officials. In 1972, Nixon flew the plane on his historic mission to normalize relations with China. In 1971, Nixon renamed SAM 26000 *The Spirit of 1976*. In December, 1972, a similar 707, with a cost of $36.2 million and the tail number 27000, took over as the presidential plane. SAM 26000 served as the backup presidential aircraft for five more presidents: Gerald R. Ford, Jimmy Carter, Ronald Reagan, George Bush, and Bill Clinton. When, in January, 1998, Clinton's 747 *Air Force One* 28000 ran off a runway in Champaign, Illinois, SAM 26000 was sent to fetch the president, once again becoming *Air Force One*. SAM 26000 served for thirty-six years and retired to the U.S. Air Force Museum in 1998 with its last flight on May 19.

Other Presidential Aircraft

Because the call sign *Air Force One* is used to identify whatever plane is carrying the president, many less well-known aircraft have served as *Air Force One*. A Beech VC-6A turboprop transported Johnson from Austin, Texas, to his family ranch. Eisenhower used an Aero Commander U-4B twin prop, the smallest *Air Force One*. Johnson used a T-39A Sabreliner in Texas. A VC-140B Jetstar carried presidents Nixon, Ford, Carter, and Reagan. All have retired to the U.S. Air Force Museum. Other aircraft available for use by the president can serve as *Air Force One*, should the president be on board. The fleet includes five 707's, several C-9's and Gulfstreams, all based at Andrews Air Force Base in Maryland. *Marine One* is the name of the Marine helicopter that lands on the White House lawn to ferry the president literally from the doorstep.

The Modern *Air Force One*

The modern primary presidential plane, a VC-25A, is not one, but two, Boeing 747's, with the tail numbers 28000 and 29000. Deployed on September 6, 1990, and March 26, 1991, at an ultimate cost of $626 million for the two planes, spare parts, and a hangar, the planes are marvels of modern technology and comfort. The VC-25A has self-contained baggage loaders and front and back stairs. It has a range of 9,600 statute miles, or 8,348 nautical miles, but is capable of being refueled in flight. With a wingspan of 195.7 feet, it has a maximum takeoff weight of 833,000 pounds. It can operate at altitudes as high as 45,100 feet and attain speeds of 701 miles per hour. Four General Electric jet engines provide the thrust for the 231.8-foot-long aircraft. The VC-25A has armor that protects it from nuclear explosions and the ensuing electromagnetic pulses. It has jamming systems to deflect antiaircraft missile attacks and can make evasive maneuvers to avoid enemy aircraft. It has at least eighty-seven telephones and sixteen video monitors and can carry two thousand meals. It can stay aloft for a week. It has seven bathrooms, a bedroom suite for the president, and full office facilities. It has a total capacity of 102, with 26 crew.

The presidential seal is emblazoned on many items, such as the door, seats, blankets, glasses, silverware, notepads, and boxes of cigarettes, before these were banned during the Reagan administration. Guests aboard *Air Force One* are presented with a certificate upon deplaning attesting to the fact they were passengers on the presidential plane.

Current *Air Force One* Specifications

Builder: Boeing
Power Plant: 4 General Electric CF6-80C2B1 jet engines
Thrust: 56,700 pounds per engine
Length: 231 feet, 10 inches
Height: 63 feet, 5 inches
Wingspan: 195 feet, 8 inches
Speed: 630 miles per hour
Ceiling: 45,100 feet
Maximum Takeoff Weight: 833,000 pounds
Range: 6,800 nautical miles
Passenger/Crew Capacity: 102 (26 crew)
Introduction Date: December 8, 1990 (No. 28000); December 23, 1990 (No. 29000)
Date Deployed: September 6, 1990 (No. 28000); March 26, 1991 (No. 29000)
Inventory: Active force, 2; ANG, 0; Reserve, 0

Source: Data taken from (www.af.mil/news/factsheets/VC_25A_Air_Force_One.html), June 6, 2001.

Extraordinary Plane, Ordinary Problems

For all its modern marvels and protections against attack, *Air Force One* must fly in crowded airspace and deal with commonplace aviation problems. On May 27, 1997, *Air Force One* and a United Parcel Service 747 had a near-midair collision, coming within 500 vertical feet of each other when mandatory ATC separations were not maintained. In 1995, an investigation by the Inspector General of the U.S. Department of Transportation into bogus parts on commercial jetliners led to the conviction of emergency-oxygen and fire-suppression equipment suppliers for *Air Force One*. In 1997, *Air Force One* was inspected for center-wing tank problems after the explosion of TWA 800, an earlier model 747. In 1998, *Air Force One* repeatedly disappeared from the Federal Aviation Administration's air traffic control radar screens.

As *Air Force One* is not safe from aviation problems, neither is it immune from bad press. When, on May 18, 1993, Clinton idled *Air Force One* on a Los Angeles International Airport tarmac while receiving a haircut from a Hollywood hairstylist, the negative publicity about the misuse of *Air Force One* was blistering.

Air Force One in Film

In 1997, *Air Force One* won a better place in Hollywood with the release of the blockbuster action film of the same name, filmed in cooperation with the U.S. Air Force and starring actor and real-life pilot Harrison Ford as the U.S. president. Audiences were treated to a glimpse inside the world's most famous aircraft. The filmmakers improved upon reality by adding a presidential escape pod, an oversized conference room, and a virtual arsenal of weaponry that does not actually exist on the real *Air Force One*. The weapons and vehicles that the Secret Service uses to protect the president are actually carried on support aircraft, one of which arrives well in advance of *Air Force One* to complete security arrangements.

Mary Fackler Schiavo

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See also: Air Force, U.S.; Airplanes; Military flight

Air France

Also known as: Compagnie Nationale Air France
Date: Founded in 1933
Definition: The major international airline of France.
Significance: Based in Paris, Air France serves thousands of people every year in international flights to the United States, Canada, and all major European points. Air France serves China as well, a particularly important service in terms of the globalization of world business.

History

Air France was founded in 1933 through the merger of five companies originally founded between 1919 and 1929, Société Centrale pour l'Exploitation de Lignes Aériennes, Compagnie Internationale de Navigation, Air Union, Air Orient, and Compagnie Générale Aéropostale. The new company negotiated with the French government to become the country's national air carrier. World War II nearly destroyed the company, but on October 11, 1945, Paris-to-London service was resumed. In 1948, the new Compagnie Nationale Air France was reincorporated, with 70 percent of the company owned by the government. On January 12, 1990, all four of France's government-owned airlines, Air France, Air Inter, Air Charter, and UTA, were merged into the Air France Group.

Transatlantic flight was initiated in 1946 with a Paris-to-New York route, and thirty years later, Air France inaugurated supersonic transatlantic flight with the Concorde. The first Concorde flight was between Paris and Rio de Janeiro, but ultimately the only profitable supersonic route was between Paris and New York, and in 1982 the company made that its only Concorde route.

In the realm of subsonic flight, however, Air France, by the end of the twentieth century, served more than 230 cities in 88 countries. Its fleet is composed of Boeing 737's, 747-200's, 747-300's, and 747-400's, 767's and 777's, and Airbus A310's, A320's, and A340's.

Corporate Divisions

Air France is a major employer within the airline industry. In the United States alone, it employs nine hundred people

Events in Air France History

1933: A group of airlines collectively named the Société Centrale pour l'Exploitation des Lignes Aériennes (S.C.E.L.A.) is renamed Air France.
1938: Air France becomes the world's third-largest airline network, with one hundred aircraft. Its expansion is subsequently interrupted by World War II.
1946: The airline inaugurates Paris-to-New York service.
1947: Air France cooperates with the French Postal Service to establish night-mail service, giving the airline the largest network in the world.
1959-1960: Air France begins implementing Caravelle and Boeing 707 jet aircraft, cutting flight times in half.
1966: Air France's last remaining long-haul, propeller-driven aircraft are removed from service.
1968: Air France adopts the medium-haul Boeing 727 and, two years later, the long-haul Boeing 747, which carries approximately five hundred passengers.
1974: Air France flies the first Airbus A300 aircraft.
1976: Air France introduces the Concorde for supersonic travel along the airline's Paris-Dakar-Rio de Janeiro route.
1978: The airline establishes a cargo division.
1981: The airline introduces business-class service.
1990: Responding to increasing competition in the airline industry, Air France merges with UTA and Air Inter to become the Air France Group, one of the world's largest air transport groups.
1995: Air France launches the Airbus A340 wide-body aircraft.
2000: Air France enters into a global alliance with Aeromexico, Delta Air Lines, and Korean Air. An Air France Concorde jet crashes shortly after takeoff from Paris's Charles de Gaulle Airport, killing all on board and four on the ground.

to serve Air France customers. The Air France Industries Division is responsible for complex maintenance activities that include full checks on all equipment, and required major overhaul operations. The Air France Maintenance Division, operating from two main bases, at the Paris-Charles de Gaulle and Orly airports, is the hands-on and online maintenance service. They handle preflight checks, random daily inspection checks, and the entire range of minor to major repairs, up to and including all overhaul work to the Concorde fleet. The Industrial Logistics Division combines all of the Air France groups' industrial and repair activities.

Air France has developed a customized fleet service, which offers a range of services tailored to individual needs. This service is particularly directed to young airlines or others unwilling or unable to develop their own customized aeronautical maintenance structure. Air France markets all its industrial and aircraft maintenance services under the Air France Industries brand, which ranks as the second worldwide carrier in terms of aircraft maintenance and employs approximately nine thousand staff members. Air France Industries also offers an extensive range of skills and available training, particularly in Boeing fleets powered by General Electric and CFM International engines, as well as in various components used in Boeing fleets and the Airbus. Because of extensive experience with the Boeing 747, Air France is considered a world leader in that aircraft's overhaul, completing more than three hundred B-747 overhaul checks a year. Combining this skill with the handling of more than 300 engines and 62,000 components, Air France is considered the major service-oriented airline. Developing a concept of customized fleet service and having developed a global quality approach, Air France generated a 29.8 percent increase in operating revenues between 1999 and 2000, amounting to approximately 3.3 billion francs, or 497 million euros.

In 2000, Air France launched a very special globalized service called SkyTeam with three partners—Aeromexico, Delta Air Lines, and Korean Air—which focuses entirely on customer service. Air France retains leadership in the French market, Europe's largest domestic air-transport market, as well as leadership of world tourism.

Safety Record

Given their global network of flights, Air France's safety record is good. Two hijackings, on June 27, 1976, in Entebbe, Uganda, and on December 24, 1994, in Algiers, Algeria, resulted in passenger deaths, and crashes in 1988 and 1992 in France, and 1998 in Columbia also had fatalities.

However, Air France's most dramatic disaster was the crash of the Concorde on Tuesday, July 25, 2000. The Concorde's first fatal accident occurred when Concorde Flight 203, bound from Paris to New York, crashed within sixty seconds of takeoff, killing all 109 persons on board. Another four people were killed in a local hotel on the ground. Both Air France and British Airways Concorde flights were temporarily grounded. Air France suffered some very negative publicity as a result of the crash.

According to the official version presented by a French accident investigation, the crash occurred when a tire hit debris on the runway and burst. This, in turn, caused chunks of tire rubber to puncture under-wing fuel tanks and led to a loss of thrust from an engine on the left wing, which veered the Concorde to the edge of the runway. Proceeding too quickly to abort, the pilot apparently took off with engines not functioning properly, thereby losing control and crashing into the Paris suburb of Gonesse. Air France mechanics are charged to have disassembled the undercarriage for service, reassembling it without the part that keeps the wheels in correct alignment. The missing spacer was found on the original part in the workshop, according to the *Paris Observer.* Thus, it was not a loss of power that caused the fatal accident. The theory of the missing spacer has been controversial, discussed, refuted, and validated. While Concorde compensation settlements were reached in Germany for families of seventy-five passengers, it was unclear whether the settlement ultimately included Continental Airlines, which investigators believe may have been the source of a metal strip on the runway that may have caused the accident.

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See also: Air carriers; British Airways; Concorde; Hijacking; Supersonic flight

Air rage

Definition: Uncontrolled verbal abuse or physical violence caused by frustration connected to problems related to commercial flying.

Significance: During the late 1900's and early 2000's, airline passengers and crews were sometimes put at risk by violent passengers who acted out their frustrations when the airlines did not deliver the service they anticipated and demanded. Ground rage, related to air rage, has also become a problem affecting airline employees who deal with the flying public on the ground.

Manifestations of Air Rage

Air rage takes a number of forms. Frequently it results in unpleasant, abusive verbal exchanges between passengers and airline personnel. Even when the manifestations of air rage are merely verbal, they create problems by distracting airline employees from the jobs they should be doing and leaving them unnerved as they go about serving other passengers. Verbal exchanges also occasionally escalate into physical assaults, so once passengers show signs of acute frustration through shouting or speaking rudely, those who deal with them must be vigilant to ensure that the situation does not escalate into greater violence. Most air rage occurs in the confined space of an aircraft that is often flying 5 or more miles above the earth at speeds of just under 10 miles a minute. These factors imbue such situations with the potential for extreme danger.

Air rage is usually verbal rather than physical. This type of anger may attract considerable attention because it frequently involves raised voices, loud shouting, acrimonious outbursts against the airline and its personnel, and the unbridled use of vulgar language. It may be accompanied by intoxication, a condition heightened when people drink in the controlled environment of an airliner. Most people get drunk more quickly at an altitude of 30,000 feet than they would at sea level.

Although air rage is usually directed at airline employees, particularly flight attendants, it may also be directed at fellow passengers. When this is the case, flight attendants become involved quite quickly. They can often control the situation by moving unruly passengers to seats away from the object of their anger, although this is not consistently a fail-safe solution.

Some Causes of Air Rage

During 2000, 615 million ticketed passengers flew on the airlines of the United States. Airport facilities have become so overtaxed by the dramatic increase in air travel that the once-friendly skies are perceived by many travelers as being quite unfriendly. Among the major complaints voiced by those who fly are late departures and arrivals, the cancellation of scheduled flights because of bad weather or mechanical problems, overbooking, substantial differences in air fares on the same flight, and lost luggage.

Crowded on-board conditions, especially when flights are full, adds to the frustration of fliers, particularly if they have been flying uninterruptedly for many hours as long-distance travelers are sometimes forced to do. Many airlines attempt to avoid serving in-flight meals, which are expensive. Passengers who drink and do not eat become intoxicated quickly, particularly in the controlled atmosphere of an airplane and particularly if they have been without sleep for extended periods. Intoxication can cause some drinkers to become hostile and aggressive.

Flying, especially on flights lasting more than three hours, causes many people to become disoriented, a condition that drinking can intensify dramatically. Another factor in some incidents of air rage is the airlines' prohibition of in-flight smoking. People who are dependent on nicotine are forced to undergo extended periods without it from the time they enter an airport until the time, often as much as ten hours later, when they leave it. This deprivation can lead to irritability in otherwise serene people.

Air rage is not new. In 1969, rock musician Jim Morrison, of the band The Doors, and a traveling companion were ejected from a flight because they were drunk, smoking cigars, and making very loud obscene statements. The Federal Bureau of Investigation (FBI) investigated the behavior of the "long-haired hippies," thereby inaugurating what became a rather substantial FBI file on the singer. Air rage is, however, on the increase and increasing attention has been focused on it and on such related issues as road rage and ground rage.

Ground rage is usually directed against those who check passengers in for their flights. Often passengers become frustrated by long check-in lines. If, after waiting thirty minutes, passengers are told that flights on which they have reservations have been canceled or oversold, so they cannot be accommodated, they may be pushed beyond the limits of their endurance and may direct their anger toward the ticket agent, even though this person had nothing to do with creating the situation that understandably frustrates the passenger.

Other situations can provoke violent behavior, as was the case when the small child of one passenger wandered from the boarding area onto the boarding platform. The child's father tried to push past the ticket kiosk to retrieve his errant child, but was restrained. He struck out at the airline personnel who were trying to hold him back. Eventually, he pushed one of them with such vigor that the agent's neck was broken.

In this case, the angry father was arrested and brought to trial, an outcome that most airlines

Image Not Available

prefer to avoid. The court found against the plaintiffs, Continental Airlines and the injured agent, and acquitted the defendant of the charges against him, citing extenuating circumstances.

The Extent of Air Rage

Statistics on air rage vary considerably. U.S. senator Dianne Feinstein of California estimated that some five thousand cases occur annually, whereas airline officials estimated the number at about three thousand. In contrast, flight attendants, who must deal with it frequently, suggest that nine thousand is a more accurate number.

The Federal Aviation Administration (FAA) officially recorded 314 cases in 2000, and 592 cases in 1998 and 1999 combined. However, United Air Lines alone reported 1,075 cases during those two years. The incidents of air rage reported by United dropped from 310 in 1999 to 266 the following year, probably because of a dramatic increase in the legal penalties that air rage can incur.

The Legal Consequences of Air Rage

In October, 2000, a notable air rage incident occurred on American Airlines Flight 67 from London to Chicago. Jorgen Kragh, a fifty-three-year-old Danish businessman, became incensed when the passenger in front of him reclined her seat. He pushed the seat forward and banged on it to the point that its occupant had to get up. A flight attendant attempted to control the situation, but Kragh became irrational and threatening.

The flight captain, informed of the situation, radioed ahead to the Bangor International Airport in Maine, where he subsequently landed. A specially trained team of police officers boarded the plane and arrested Kragh. Bangor's airport, which has eight to twelve such emergency landings in a typical year, maintains a special team to deal with them. It handles the necessary paperwork expeditiously, so that the landing planes may continue without undue delays. In this case, the plane was en route to Chicago in less than an hour and a half.

Kragh, confined to jail, the next day entered a no-contest plea upon arraignment in Bangor. He was sentenced to twenty-one days in prison and ordered to pay a $5,000 fine. Legally, he might have been jailed for a considerably longer time and fined $25,000 for each incident of violence.

Jeff Russell, the marketing manager for Bangor's airport, notes that during the peak summer season, between four hundred and seven hundred international flights a day pass over Bangor, so that the percentage of flights diverted to Bangor because of air rage is minuscule. In one five-week period in the summer of 2000, three flights landed because of air rage incidents.

Ways to Deal with Air Rage

As air rage became an increasing concern in the last half of the 1990's, it grew increasingly apparent that measures had to be taken to control it. In April, 2000, the U.S. Congress passed legislation that increased the civil fine from $1,100 to $25,000 for each violation. A single incident can involve several violations, each punishable by a separate fine. To this can be added $10,000 in civil penalties and the possibility of up to twenty years in prison.

This legislation apparently has restrained some impassioned air travelers, although air rage is not under complete control. Frank Del Gandio, manager of the FAA's Recommendation and Safety Analysis Division, fears that if the matter is left unchecked, air rage will eventually result in the loss of one or more commercial aircraft. Brian Poole, head of the Safety Analysis branch of the FAA's Office of Accident Investigation, cautions, however, that in dealing with air rage, one must differentiate between what is rude and what is dangerous.

Alarmed at the danger air rage poses, Senator Feinstein in July, 2000, urged airline officials to limit the number of drinks flight attendants could serve to each passenger on a single flight. She suggested a two-drink limit, although those on flights that require a change of planes might still drink enough to become intoxicated and abusive under Feinstein's plan. Some people have urged the airlines to ban all alcoholic beverages from planes just as they banned smoking in the 1990's. Airline officials fear that if this is done, passengers will bring their own liquor onto the plane and drink more than they would have, had they been able to order drinks from the flight attendants.

Certainly alcohol has been a contributing factor in more than one case of air rage. In April, 2001, a twenty-two-year-old woman on United Air Lines' Flight 857 from San Francisco to Shanghai drank too much. When the flight attendant refused to serve her additional drinks, adhering to the practice among bartenders who observe their customers becoming drunk, the young woman punched the flight attendant in the face. The flight was diverted to Anchorage, Alaska, where the assailant and her twin sister were arrested. The U.S. District Attorney in Anchorage sought over $50,000 in damages from the two sisters and recommended jail time for each of them.

The diversion of this flight greatly inconvenienced over two hundred passengers, causing one passenger to miss her brother's funeral, and causing countless others to miss appointments, connections, and events dependent on their timely arrival. Certainly any penalties exacted from those whose air rage causes flights to be diverted can in no way compensate the scores of passengers whose plans are compromised by such a diversion.

The FAA has prepared a brochure that defines air rage and outlines the penalties for those who engage in it. The fifty-thousand-member Association of Flight Attendants urges better training of airline personnel to deal with air rage. It also has asked that the penalties for air rage be posted in airport bars and restaurants.

Statistically, the incidents of air rage are small compared with the large numbers of people who fly every year. Nevertheless, air rage is a present and real danger to all who fly and must be dealt with effectively if the skies are to be safe.

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See also: Air carriers; Airline industry, U.S.; Commercial flight; Flight attendants; Passenger regulations; Safety issues

Air shows

Definition: Events featuring the exhibition of aircraft and the demonstration of aviation skills.

Significance: Early air shows helped to promote aviation and increase public awareness about the excitement of flying. Air shows continue to display the latest in aviation techniques and development.

History

The first airplanes had more value as curiosity pieces than as means of transportation. For ten years after the Wright brothers' flight of 1903, aviation was kept alive by devotees who toured the country while performing at circuses, fairs, and anywhere else people would pay to see them. These daredevils performed aerobatic feats, walked on airplane wings, made parachute jumps, and took paying customers for joyrides. Many of these pioneer pilots died in pursuit of their aerial adventures, but they lent an air of romance and danger to the new field of aviation.

World War I-era pilots often had little or no training, flying instead by instinct and sheer courage. During the war, these daring pilots flew into combat zones with courage and determination.

After World War I, the U.S. government offered thousands of surplus airplanes, most of them Curtiss Jennys, for sale at bargain prices. Although these airplanes were stronger than those that had been built before the war, they were not always safe. Made mostly of wood and cloth, they also lacked satisfactory navigational equipment. However, many former military pilots bought these airplanes and used them for an exciting and dangerous type of flying called barnstorming.

Barnstormers toured the United States in the 1920's and put on daring air shows at county fairs and other events. Audiences were thrilled to watch. The pilots flew the airplanes in wild aerobatics and daring stunts. Performers, called wing-walkers, stepped from wingtip to wingtip in midair or leaped from the wing of one flying airplane to another. There were many accidents, some fatal.

Highly skilled World War II pilots were used to faster, more technically advanced airplanes than those of World War I. Although World War I dogfights had spurred aviators to postwar displays of courage and craziness with aerobatics, barnstorming, and cow-pasture thrill shows, post-World War II pilots had more venues in which to display their skills, including air races, air shows, carnivals of the sky, and precision flying. The air shows of the 1940's and 1950's were also showcases for new and sometimes customized aircraft. Parachuting and mock dogfights remained popular parts of air show activities.

Aerobatics

The first recorded aerial stunt was performed in 1913 by French aviator Adolphe Pégoud. Pégoud flew his Blériot monoplane upward in an ascending arc until he was flying upside-down and then dove to close the circle. He had, unwittingly, invented the loop. When American daredevil Lincoln Beachley heard of Pégoud's stunt, he jumped into his Curtiss biplane and completed three loops. In a final gesture of victory, he landed his airplane inside San Francisco, California's immense Machinery Palace.

In 1915, Ruth Law was the first woman to loop-the-loop. She made her first exhibition of this stunt in Daytona Beach, Florida. After World War I, Law and her husband and business manager, Charles Oliver, formed Ruth Law's Flying Circus. The circus toured Asia performing aerobatic exhibitions. Law was famous for racing her airplane against cars on a racetrack and for making car-to-plane transfers in which a stuntperson would leap off the car and grab a rope ladder hanging from the moving airplane. This stunt was dangerous, full of risks and excitement. The audiences at the air shows responded in amazement. In another dangerous trick, Law would fly with a copilot, climb out of the open cockpit, and stand on the wing while the copilot looped-the-loop as many as three times. This stunt terrified and thrilled audiences.

On October 1, 1910, Blanche Stuart Scott made her public debut as part of the Curtiss Exhibition Team at an air meet in Chicago, Illinois. She was given the nickname "Tomboy of the Air" for performing daring stunts, such as flying upside-down and under low bridges. In her most famous stunt, the Death Dive, Scott would dramatically climb to a height of approximately 4,000 feet, level the airplane for a moment, and then nose-dive. Audiences screamed and waited breathlessly, while the airplane plunged straight down to a level of 200 feet above the ground before snapping out of the dive and landing to thunderous applause.

Barnstorming

When highly skilled military pilots returned to the United States after World War I, they found hundreds of surplus airplanes, but few available flying jobs. Not wanting to give up flying, many of them turned to exhibitions, air shows, crop dusting, fire spotting, air racing, or any aerial activity that would attract a crowd.

Barnstorming—so named because some ex-war pilots and flying pioneers actually flew through barns, in one door and out the other—became an American craze. These skilled aviators were able to display at home the skills they had acquired flying over hostile German terrain, now winning income and applause. Barnstormers took the loops and stunts of earlier pilots and added even riskier tricks. Some of the tricks required more than one person aloft. One pilot would fly the airplane, while the other would walk on its wings or hang beneath the airplane, holding on to a rope by the teeth. Pilots captivated crowds when they crawled from the wing of one airplane to another in midflight. These daredevils of the air, in their Jenny aircraft, continuously worked to develop newer and more daring exploits.

Many women also found post-World War I opportunities in barnstorming. After years of struggling to be recognized as serious pilots, they discovered a chance to become involved in flying, even if in a more theatrical and unusually dangerous way. Many women entering aviation through the air show or barnstorming circuit were seen as renegades and breakers of tradition. Women found this entry into aviation was not only a chance to earn money but also a possible way to prove themselves as pilots. Many began as wing-walkers or parachutists, working their way up to the airplane controls. In October, 1928, Florence "Pancho" Barnes opened Pancho Barnes' Mystery Circus of the Air, a stunt barnstorming troupe.

In 1923, Emerson Lockhart, an American aviator, bought a Jenny for $175. Determined to create the best aerial thrill show, he made a sign that said simply, "Aero Thrill Show, A Stupendous Exhibition of Flying Skill." His airplane attracted the curious but it was the sign that hooked them. Lockhart eventually got permission to use a local farmer's pasture alongside the highway. He parked the airplane and, as expected, began to draw a large crowd. It was estimated that there were about two hundred people along the highway when he took off. He dazzled his audience doing loops and buzzed the parked cars many times. His grand finale was a dive from 3,000 feet, pulling out about 100 feet above the pasture, after which Lockhart did a sharp bank, a roll, and brought the airplane down in the pasture.

Lockhart finally realized his dream when he arrived in California ready to be an air-show star. After his arrival, he found out that California was loaded with air shows but overloaded with barnstormers. He adjusted his act into actual aerial stunt flying and joined a show-business-oriented flying team. He was paid the then-generous sum of twenty-five dollars per week.

Motion Pictures

The burgeoning motion-picture industry was a magnet for many former military pilots, recreating the glorious days of battle and providing new career opportunities. Even pilots who had neither seen combat nor been in the military took to the air in the numerous postwar films then being made in Hollywood. A special group of cinematic war aces was created, perhaps the best-known of whom was Art Scholl.

When Scholl performed in his Pennzoil Chipmunk, a small aircraft that he had designed himself, he became an accomplished aerobatic pilot who represented the United States in competitions around the world. He became highly sought after in the choreography of aerial stunts for film productions and, later, television commercials.

Scholl did not start out to be a stunt pilot. After graduating from high school in Brown Deer, Wisconsin, he moved to California to enroll as a student of engineering at the Northrop Institute. He later left Northrop and enrolled at Mount San Antonio College, from which he earned his degree in aeronautics.

Air Derbies

With performing pilots across the United States, there became a need for public competition and a platform for pilots to display their skills, abilities, and showmanship. Cross-country racing became the event that fired the imagination of the public and fueled the imagination of pilots.

The 1929 Women's Air Derby was a cross-country race that included such high-profile pilots as Amelia Earhart, Ruth Elder, and Bobbi Trout. The first race did more than display women's ability to compete as pilots, it allowed women to realize that they were not alone in their dreams of careers and accomplishments as pilots.

Marvel Crosson was a veteran commercial pilot from Alaska; she and her brother, Joe Crosson, had taught themselves to fly after piecing together an airplane using surplus parts from World War I airplanes. Favored to win the 1929 Women's Air Derby, Marvel experienced engine trouble over the mountains near the Gila River in Arizona. She bailed out too low for her parachute to open properly and was killed, thus becoming the first casualty of the Women's Air Derby. The winner of the flight, Louise Thaden, dedicated her Symbol of Flight trophy to Crosson and sent it to Crosson's mother. Crosson's death created a rash of editorials against women air racers and even against women fliers, but Women's Air Derby continued until 1976.

Pilots of both genders thrived in their competitive race to professional recognition and eventually competed against each other. It was not long before air-show performers, racers, and record setters were recognized for their skills regardless of their gender.

Modern air races and air shows, organized by branches of the military or by independent event sponsors, continue to be held throughout the year across the United States. These events usually incorporate past, present, and future aircraft and continue to feature exciting exhibitions of pilots' flying skills.

Lori Kaye and Maureen Kamph

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See also: Aerobatics; Barnstorming; Amelia Earhart; Jenny; Military flight; Ninety-nines; Wing-walking; Women and flight

Air traffic control

Definition: Air traffic control (ATC) uses technology and trained staff to assure safe movement of aircraft in airspace and at airports.

Significance: ATC continually monitors every instrument flight rules (IFR) flight from takeoff to landing, as well as visual flight rules (VFR) flights upon pilot request and controller availability, enabling reliable, efficient transportation of people and goods by airlines.

History and Evolution

Air transportation is essential to modern life, and it requires that passengers feel safe during air travel. The features of aviation that distinguish it from other transportation forms are its high speed and vertical operation. Crashes are devastating because of their intense impact, created by the heights from which aircraft can fall and the speeds at which they may be traveling. The potential danger is alarming to consumers, especially because the frequently high death tolls from single crashes make a strong impression in public awareness, while many people are unaware of the great overall safety of air transportation compared to other forms of travel.

The potential for severe injury or death to aircraft passengers has led to air traffic control (ATC) systems that have evolved from early traffic control with signal flags in the 1920's to the sophisticated systems using advanced technology and specially trained staff of the twenty-first century. Current ATC assures the safe movement of virtually all aircraft operating in airspace and at airports. Its objectives include giving pilots all the data and control ser-

Image Not Available

vices needed to maximize safe, efficient aircraft operation; maximizing safe air traffic at airports; and minimizing unavoidable flight arrival and departure delays. It is ATC, a product of the National Airspace System, that makes air transportation the safest means of mass transportation in the United States.

Commercial airplanes generally travel airways, which are analogous to roads, although they are not physical structures. Airways have fixed widths and defined altitudes, which separate traffic moving in opposite directions. Vertical separation of aircraft allows some flights to pass over airports while other processes occur below. Air travel usually covers long distances, with short periods of intense pilot activity at takeoff and landing and long periods of lower pilot activity while in the air, the portion of the flight known colloquially as the "long haul." During the long-haul portion of a flight, pilots spend more time assessing aircraft status than searching out nearby planes. This is because collisions between aircraft usually occur in the vicinity of airports, while crashes due to aircraft malfunction tend to occur during long-haul flight.

Flying Rules

The main rule systems governing flights are instrument flight rules (IFR) and visual flight rules (VFR). The minimum instruments needed for VFR are an airspeed indicator, an altimeter, and a magnetic direction indicator. In VFR, pilots fly using visual ground references and a "see and be seen" rule. The minimum requirements for VFR vary, but often include cloud ceilings of 1,000 feet and visibility of three miles.

IFR are used if aircraft operate above 18,000 feet, an area known as Class A airspace. Outside this airspace, any aircraft may use VFR, although only slow-moving, low-flying aircraft or small jets on short flights routinely do so. In some conditions, such as congested airspace around medium and large airports (Class B, C, and D airspace), in poor visibility, and at night, pilots must obtain permission from ATC controllers to fly by VFR and usually are only granted that permission if they are instrument rated and there is at least one mile visibility.

At airports with control towers, all air and ground movements are subject to permission from and instruction by ATC. This is because major airport peak traffic may involve three to four landings or takeoffs per minute. With dense aircraft concentration around airports, maintaining acceptable collision risk is not possible without strict adherence to procedures set out and monitored by ATC.

All pilots wishing to utilize IFR must demonstrate their ability through detailed testing, and all aircraft must have adequate flight instruments. For each flight, a detailed flight plan must be filed with the Flight Service Station, part of the Federal Aviation Administration (FAA); flight clearance must be received from Clearance Delivery or Ground Control (or from Approach Control if the pilot files while in the air); and ATC directions must be followed throughout the flight. Such directions usually depend upon radar surveillance, including the use of airborne radar beacon transponders that allow ATC facilities to identify each aircraft in flight.

Airspace is divided into classes designated A through E. Class A airspace is all airspace above 18,000 feet; Classes B, C, and D are designated around specific airports rated by their size and amount of traffic, and Class E covers all other airspace between 14,500 and 17,999 feet. In addition to vertical airway spacing, horizontal spacing is important. This is created by planned time intervals (often ten minutes) between aircraft on the same track, with lateral spacing of ten miles.

Landing, Takeoff, and En Route Procedures

Air terminal ATC, the element of air traffic control that is most familiar to the public, involves aircraft departures and arrivals. Its procedures include issuing instrument flight rules route clearances and communicating departure runways, taxi instructions, and definition of climb and altitude routes. These operations assure passengers of safe, speedy air traffic patterns.

A departing aircraft enters the taxiway as instructed by the ground controller and the pilot awaits being fitted into the pattern of incoming and outgoing flights. ATC controllers allocate available departure runways to enable safe aircraft separation. Once the aircraft climbs to its initial altitude on an ATC-instructed heading, departure control makes sure that radio contact with the departing pilot is established before allowing a new takeoff. More instructions clear the aircraft for its final climb to the en route segment of the flight and for transferring the pilot to the next control facility.

Air traffic controllers relay descent instructions to incoming aircraft to keep them separated by five-mile intervals. As the aircraft approaches an airport, its speed is adjusted and its flight path altered to maintain an aircraft separation of over three miles within airport boundaries. ATC controllers determine aircraft landing sequences, stacking plans, and takeoff adjustments to handle aircraft flow. To simplify this flow, all commercial aircraft remain at their origin airport until it is confirmed that a landing site will be available at their destination airport at the planned arrival time. Travelers often become frustrated when a pilot cannot obtain a landing slot after leaving the gate at the origin airport, but the practice maximizes safety since flight delays are safer when spent on the ground than in the air.

The last part of descent control transfers the aircraft to the approach controller. Data from radar surveillance determine the final landing directions. Radar monitors optimize landing, and once on a runway, the pilot and the ground controller interact to prevent aircraft movement conflicts on the field. This controller also tells the pilot how to reach the craft's apron or parking position at the airport.

En route ATC includes monitoring the routes between terminals granted to individual pilots. A flight follows a predetermined path in a defined airway corridor. Effective en route ATC instructs pilots when and how to avoid nearby aircraft. During most flights, a given ATC facility periodically transfers control of each flight within its jurisdiction to the next facility on a flight plan. For this reason, ATC gives pilots radio-frequency changes that occur as they are passed on to the next controller along their flight paths.

The availability of inertial navigation units for commercial aircraft has reduced the need for this communication. In an inertial navigation unit, a computer and gyroscope are oriented to true north, while speed sensors track the aircraft's direction and the distance to its destination. Although inertial navigational units can fly virtually automatically until the aircraft reaches an airport, en route information is provided for safety and to warn of impending delays or other dangers. As a result, all IFR aircraft are monitored continuously throughout each flight. In addition, pilots must get ATC approval before making any flight path alterations. Required en route progress reports are tracked on air route surveillance radar, which monitors aircraft in each sector of the air route ATC system.

Craft-to-Ground Communication

Navigation within a designated—and desired—airspace requires pilots to identify the exact position of their aircraft and assure that they are in the airway assigned in their flight plan. This depends upon ground beacons and electronic equipment in airplanes. The most widely used ground system is the very high frequency omnidirectional range beacon (VOR). VOR stations operate on noise-free radio frequencies and provide fine accuracy. On airplanes, visual displays indicate the course needed to travel directly to a VOR station.

Most stations have distance-measuring equipment, which gives pilots the distance to VOR stations. VOR and distance-measuring equipment service all aircraft. Other methods used for navigation are Doppler navigators and inertial navigation systems, which do not require ground stations or radio beams. Another navigational tool is the Global Positioning System (GPS). It is composed of GPS satellites and provides worldwide position ability accurate to 350 feet horizontally and 500 feet vertically. GPS is available for all phases of flight.

Pilots and ATC controllers communicate by radio en route and at airports. This helps ATC to make continuous updates of the positions of all planes in its operation area and provides an unambiguous means of instant flight instruction communication. All ATC surveillance of aircraft uses radar. Each radar system possesses a primary beacon that sweeps its coverage area and transmits images of all objects encountered back to a radarscope. The primary beacons are synchronized with a secondary radar system that uses automatic aircraft transponders to identify each flight in a given jurisdiction. Such radar systems are found in many air route traffic control centers and air terminal radar control facilities, providing sophisticated ATC.

The operation of the ATC system utilizes computer-assimilated flight information such as the position, course, airspeed, and transponder number of all craft in a jurisdiction. This enables controllers to determine the safest, most direct flight plan for each aircraft and to make continual updates. ATC also incorporates traffic alert and collision avoidance systems in aircraft. ATC technology in the United States is located at a national air traffic control command center at about twenty-four regional control centers, nearly six hundred terminal control facilities, and 250 flight service stations. All facilities interact to provide a nationwide weather profile, data on all airborne flight positions, and information on airport flight acceptance. Data are analyzed by a national computer and automatically circulated to regional facilities and airports. Regional air traffic control facilities are also computerized and automated.

Recognition of aircraft under IFR is essential at all points in a flight, especially when aircraft enter an airport terminal control area. Recognition is achieved through cross talk between aircraft flight transponders and surveillance radar beacons. For this reason, the FAA requires that all aircraft flight transponders are kept on from takeoff until landing is complete. A flight transponder provides several levels of information to ATC. When turned on, it continually transmits a radar symbol showing the geographic position of the aircraft relative to ATC facilities. The level of information transmitted is determined by a pilot's responses to queries from ATC facilities. Most flight transponders also alert ATC facilities of radio failure, skyjacking, and other emergencies by pilot input to transmit specific code numbers.

Terminal Control

Terminal ATC is found in most public airports. Control facilities are divided into two parts, an ATC tower (ATCT) and approach and departure control. The tower controls approaching or departing aircraft in the five-mile radius of the airport traffic area around the airport. Approach and departure control covers a radius between five and thirty-five miles from the airport, beginning where tower control stops.

ATC controllers identify and sequence all aircraft in the airport traffic area, expedite aircraft arrivals into and departures from the airport traffic area, control all ground aircraft movement, cancel flight plans, and provide other use-

Top Ten FAA-Operated Air Traffic Control Towers, 1996

Tower	*Rank*	*Annual Operations*
Chicago O'Hare International, Illinois	1	909,186
Dallas/Ft. Worth International, Texas	2	869,831
Atlanta International, Georgia	3	772,597
Los Angeles International, California	4	764,002
Miami International, Florida	5	546,487
Phoenix Sky Harbor International, Arizona	6	544,363
Van Nuys, California	7	532,221
Detroit Metro Wayne County, Michigan	8	531,098
St. Louis International, Missouri	9	517,352
Oakland International, California	10	516,498

Source: Federal Aviation Administration, *Statistical Handbook of Aviation*, 1996.

ful information. In both landing and takeoff control, IFR aircraft may be provided with horizontal and vertical path guidance. In contrast to ATCT control, which regulates the flow of traffic within the airport itself, approach and departure control regulates the safe and efficient flow of air traffic around airports.

This regulation begins as soon as an aircraft reaches the perimeter of the area under approach and departure facility control. At that time air traffic controllers begin to fit the aircraft into the pattern of current air traffic. They define the course, altitude, and speed changes that each aircraft needs for a safe landing within the framework of existing arrivals and departures.

Terminal ATC is based mostly on data obtained from ATC radar beacon systems. Major air terminals are equipped with computerized automated radar terminal systems (ARTS), which accept radar inputs from all surveillance systems. They automatically show individual aircraft on ATC video displays, where a plane is seen as a radar screen data block in front of the controller. The block shows a symbol for each aircraft, along with its identifying call sign, speed, and altitude. The systems also warn of possible collisions or instances where aircraft approach minimum safe altitudes.

Using ARTS, all flights are kept at specific distances, horizontally and vertically, from one another. Flight plans are fed into computers and updated as flights progress. ATC controllers watch carefully to prevent collisions. As aircraft converge on an airport to descend for landing, congestion may occur. In this situation, IFR planes are instructed to circle a specific location designated by an IFR intersection. As more planes arrive, they are held increasingly farther out from the airport.

For instrument landings, pilots use an instrument landing system (ILS) similar to VOR. Cockpit instruments indicate deviations to either side of a localizer beam leading to the runway, and guidance information from a glide slope beam warns if the plane is too high or low on the approach.

The State of Flux in ATC

Air safety is created by the efficient operation and continued updating of ATC. ATC operation modes change quickly and extensively, since the system operates at near capacity, while the total number of operating aircraft is increasing. As a result, the FAA is continuing an automation and modernization program addressing aspects of en route air navigation methods, weather identification and dissemination, flight service stations, and facets of airport terminal ATC. Goals of this National Airspace System Plan include meeting continued increased airspace demands, reducing operational errors, collision risk, and weather-related accidents, and minimizing escalating ATC operation and maintenance costs. ATC's main need is to increase its efficiency, because while industry demand will grow, major airports do not have the ability to significantly expand, due to physical or environmental constraints. The prospect for construction of new large airports is also dim.

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Airbus

Definition: One of the two largest global manufacturers of heavy commercial aircraft.

Significance: The Airbus consortium of European aircraft manufacturers is a successful example of regional and global economic cooperation in the production of a highly valuable, strategically significant, and high-technology product.

Corporate Information

Airbus, headquartered in Toulouse, France, is owned by two leading European aerospace companies. One is the European Aeronautic Defense and Space Company (EADS), born of the merger between Airbus consortium partner companies Aerospatiale-Matra of France, Daimler Chrysler Aerospace of Germany, and CASA of Spain; the other is BAE Systems of the United Kingdom. In June, 2000, EADS and BAE Systems announced the creation of Airbus Integrated Company, intended to consolidate Airbus Industrie resources and practical knowledge in existing locations around Europe into a single entity. As a result, all Airbus-related design, engineering, and manufacturing assets located in France, Germany, Spain, and the United Kingdom became part of a new Airbus company under the day-to-day control of a single management team. As of 2001, the company employed some forty thousand people throughout Europe. The consortium members are both industrial participants and shareholders. Their role is to carry out most aircraft design and all manufacturing under Airbus's management.

Each partner company operates under the laws of the country in which it is incorporated. The partners are responsible for their own financing of the research, development, and production phases of the aircraft programs. Airbus Industrie's production system is flexible and appears to be quite effective and efficient, as evidenced by the fact that approximately 96 percent of all aircraft work is performed in plants operated by the partner companies. Fully equipped sections of Airbus Industrie aircraft are produced in factories throughout Europe and transported to Toulouse, France, or Hamburg, Germany, for the final assembly. The production network is set up in an innovative way that uses the specialized skills of each partner and associate.

Airbus Industrie has more than 1,500 suppliers in twenty-seven countries and cooperative agreements with aerospace industries in nineteen countries. More than 35 percent of the components for the company's aircraft are supplied by over five hundred United States companies. Numerous suppliers are also located in the Asia-Pacific region, such as Singapore Technologies Aerospace, which produces wing ribs and passenger doors for the A320, A321, A319, and A318 and engine mounts and thrust reverser doors for the A340 and A330; and the Indian company Hindustan Aeronautics, which also builds A320 passenger doors.

One of the keys to Airbus's sales success has been the flight operational commonality that exists among all the company's fly-by-wire, or fully automated and computerized, aircraft. The Airbus philosophy has been to develop families of fly-by-wire controlled aircraft with similar cockpits and flight handling characteristics and common systems and hardware. As a result, pilots trained to fly any Airbus fly-by-wire aircraft feel equally at home in any of the single-aisle models in the A320 family, such as the A318, A319, A320 and A321, and the wide-body A330 and A340 models. This commonality may result in millions of dollars of savings for airlines. It reduces training costs, increases crew productivity, and provides pilots with the flexibility of flying a wide range of routes, from short-haul to ultra long-haul.

Organizational Structure

Airbus Industrie was created on May 29, 1970, and was formed as a public interest group on December 18, 1970. The company was formed under French law, in the absence of a functional legal framework accepted throughout the European Union, then known as the European Economic Community. The public interest group is a form of business organization that permits participating firms to integrate their activities in certain domains while preserving their individual identities. The French public-interest law was used as an appropriate legal framework for the company as it was beneficial to Airbus Industrie's goals in establishing itself in the market and managing its risk, at least initially. Originally, two partners, Aerospatiale and Deutsche Airbus, had equal ownership of the company. Each partner assumed equal unlimited liability relative to the project. Because the company was a public interest group, new members could be admitted with the consent of both partners. To provide oversight of the entire project, an organizational structure was formed in December, 1970. This department dealt directly with third parties to sell aircraft and provide pilot and crew training. There were two representatives from each industrial partner in the assembly of members. A supervisory council was organized to administer the assembly. This structure was intended to act as a true multinational collaboration.

Airbus is an outstanding example of successful multinational cooperation in the large commercial aircraft sector of the aerospace industry. Airbus was developed with the support and cooperation of the governments of the European Union member states with companies in the consortium (France, Germany, Spain, and the United Kingdom).

Airbus Development

Model	*Program Launch*	*First Flight*	*In Service*
A300	May, 1969	October, 1972	May, 1974
A310	July, 1978	April, 1982	April, 1983
A300-600	December, 1980	July, 1983	June, 1984
A310-300	August, 1983	July, 1985	December, 1985
A320	March, 1984	February, 1987	March, 1988
A300-600R	March, 1987	December, 1987	May, 1988
A330-300	June, 1987	November, 1992	December, 1993
A340-200/300	June, 1987	April, 1992/October, 1991	March, 1993
A321	November, 1989	March, 1993	January, 1994
A300-600ST	November, 1991	September, 1994	January, 1996
A319	May, 1993	August, 1995	April, 1996
A330-200	November, 1995	August, 1997	April, 1998
A340-500/600	December, 1997	May, 2001	2002
A318	April, 1999	2001	2002
A380	December, 2000	2004 (projected)	2006 (projected)

This cooperation greatly contributed to Airbus's success. Even though cooperation within the consortium took place among technical experts, it was the governments' willingness to create a large producer of commercial aircraft that provided the impetus for such cooperation to occur. Airbus's strategy was to develop large civil aircraft that were both distinguished and economically attractive.

The explicit and systematic arrangement of the Airbus project began with the structure of its management. True collaboration, the goal of the new European industry, required joint financing, marketing, and work-sharing agreements, and thus some sort of transportation decision-making and administrative structure. To define the mutual rights and responsibilities to which the collaborative agreement would be subjected, Deutsche Airbus (now Daimler Chrysler Aerospace Airbus, a member of EADS) had a limited liability of DM 100 million (approximately 55 million U.S. dollars), while both the Spanish and French members were liable for the entirety of their resources. Deutsche Airbus was privately owned and consisted of independent firms. In contrast, Aerospatiale, the French participant, could rely on the assistance of the state for its liability.

Aircraft Projects

Airbus's first project was the development of the A300, envisioned as a short- and medium-range aircraft. By 1971, two basic designs had been decided upon, the A300B2 and the A300B4. Both were wide-body, twin-aisle, two-engine aircraft having a capacity of 220 to 270 passengers for air travel over 1,200 nautical miles. The first fuselage was completed in September, 1971. In November, 1971, the first two wings were shipped from Britain to Toulouse. The landing gear was attached in January, 1972, engines were mounted in April, 1972, and the systems testing progressed throughout the year. On September 28, 1972, the aircraft was rolled out and one month later, on October 28, 1972, it flew its first flight.

In July, 1978, the A310, a shortened version of the A300 seating 218 passengers in a standard two-class configuration, was launched. Airbus was set to expand from a sound base and to create a complete range of airliners with a common theme. Following the A310 project, British Aerospace, which had taken over Hawker-Siddley, became a full partner on January 1, 1979.

Airbus brought the new A320, a single-aisle, 130- to 170-seat aircraft, into the family during the same year. The launch of the A320 filled out the product line. The A320 was revolutionary, incorporating the very latest technology and, as a result, providing better operating efficiency and better performance. The flight deck set the standard for all subsequent Airbus cockpits, with obvious advantages to pilots and operators. Among the innovations installed were fly-by-wire controls, which removed cumbersome mechanical controls.

The A320 itself was followed in 1989 by the A321, a lengthened version seating from 180 to 200 passengers, and in 1992 by the A319, a 120-seat version. The family was completed in 1999 with the introduction of the 107-seat A318.

In 1987, Airbus launched two larger aircraft in a single program: the A330, a 235-seat, twinjet, medium-haul aircraft, and the A340, an ultralong, four-engine, 295-seat jetliner. The two new airliners shared the same airframe, the same wing design, and the same popular twin-aisle cross-section of the A300/A310. The proven fly-by-wire controls of the A320 were extended to both the new aircraft. The A340 entered service in 1993 and the A330 joined it one year later, the first commercial transport jointly certificated by European and U.S. aviation authorities. The twin-engine A330-200 and A330-300 carry 253 passengers and 335 passengers respectively, with the A330-200 capable of a 12,000-kilometer range.

Funding and Trade

Airbus as a consortium had a unique funding mechanism compared to those of other commercial producers in the market. The supervisory council approved Airbus Industrie's routine payments for the purchase of major equipment items and overhead expenses. The partners incurred nonrecurring costs resulting from the development process as well as production funding expenses. Each partner was responsible for financing research, development, and production. The industrial firms involved in the Airbus program have historically looked to their respective governments to secure this money. Usually this has been accomplished through low-interest loans repaid through sales proceeds.

The manner in which the Airbus consortium secured its money through government subsidies and loans, especially during its first years, has been a major issue of friction between Airbus and its competitors, particularly the Boeing Company of the United States. Airbus's competitors argued that the company's project financing practices were in direct violation of fair trade rules set by the General Agreement on Tariffs and Trade (GATT), specifically as they applied to fair trade in the commercial aircraft manufacturing industry. These rules were later more formally institutionalized by the World Trade Organization (WTO).

In 1985, the GATT agreements were updated, further limiting the ability of governments to provide financial assistance by requiring governments to lend money to companies such as Airbus at the same rates that would be charged to consumers taking out bank loans, thus preventing such companies from having their loans subsidized through lower interest rates. Airbus was accused of receiving over $13 billion of subsidies from European Union governments between its inception and 1990. European Union governments were also accused of providing loans to Airbus at much lower than market rates, and in some instances at free rates. It has been estimated that the subsidy amount, if compounded at commercial rates, would amount to over $25 billion.

Significance and Position

Airbus is an example of regional and global economic cooperation to produce a valuable high-technology product. By practicing cost diversification, Airbus has engaged in prudent risk management. They have hedged against downturns in the financial cycle and in the long selling cycles that prevail in the industry. Airbus was successful because it was able to develop a unique corporate structure and culture, which were to a large extent independent from the influence of politicians and were developed based on business principles and economic planning, rather than political necessities.

On its World Wide Web page, Airbus states its corporate philosophy: "Setting the standards' means anticipating the market, offering innovation and greater value, focusing on greater passenger comfort, and creating a true family of aircraft." Airbus also claims that "Real competition always creates a better product," and Airbus's two aircraft manufacturing partners brought European competition to the forefront of the world market. At the start of 2001, when its turnover reached $17.2 billion, Airbus had received more than 4,200 orders in total and had over 2,400 aircraft in service with 176 operators.

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See also: Aeronautical engineering; Airline industry, U.S.; Airplanes; Boeing; Manufacturers

Aircraft carriers

Also known as: Carriers, flattops

Definition: Large naval warships whose purpose is to project a nation's air force by sea into virtually any other part of the world. To that purpose, carriers are distinguished by their flat landing and takeoff decks and their complement, carried on deck and in internal hangar spaces, of fighter, attack, reconnaissance, antisubmarine, electronic warfare, and other aircraft essential to the mission of the carrier.

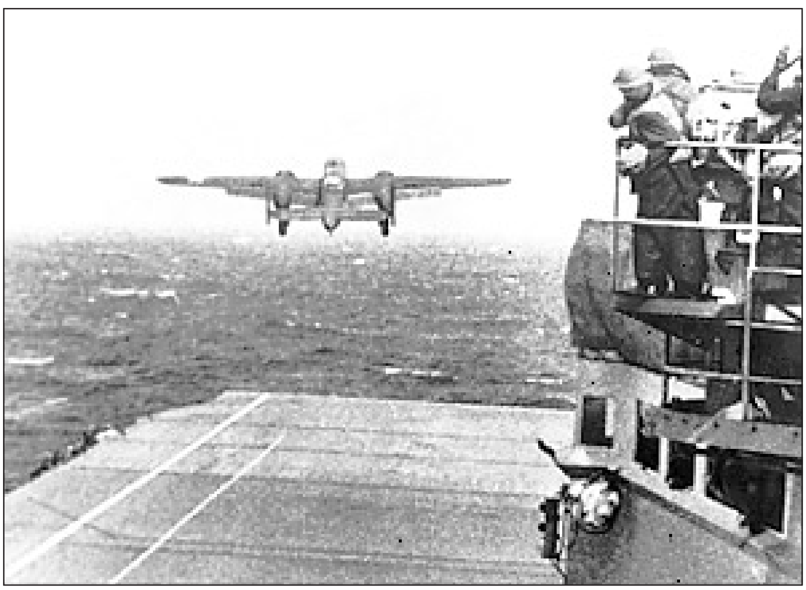
Significance: Aircraft carriers are the most important and complex ships in a modern navy. Their air power allows them to project a nation's presence, influence, and power almost anywhere in the world. Aircraft carriers are powerful instruments of technology, combat, and diplomacy around the world. A carrier sent to a trouble spot in the world focuses attention and power on that spot.

Description

The first prototype aircraft carriers entered the British navy during World War I, but were first used significantly in battle in World War II by the British, American, and Japanese navies. Aircraft carriers have essentially two components: the ship and its systems, and the air wing, or complement of aircraft it carries. Aircraft carriers are the largest military ships in the world; a modern U.S. carrier displaces more than 97,000 tons of water, travels at a speed in excess of 30 knots, and carries a complement of more than 5,000 Navy and Marine personnel. A navy captain usually commands the ship; another captain on board commands the air wing.

Aircraft carriers are extremely expensive, large, and potentially vulnerable to attack. They operate at sea as part of a carrier battle group, which also includes guided missile cruisers, guided missile destroyers, frigates, attack submarines, and replenishment/resupply ships. These combatant ships have antisubmarine, antiair, and antiship roles. The carrier, when on active patrol, also operates a combat air patrol of its own fighter aircraft. The carrier's only other armaments are missile launchers and Phalanx radar-guided 20-millimeter cannon for antiaircraft and antimissile defense. It carries a wide array of sophisticated intelligence-gathering equipment, radar, sonar, countermeasures, and other electronic systems.

The aircraft of a modern carrier are many and diverse. A U.S. carrier in 2001 carried one-half dozen different types of aircraft, including the supersonic swept-wing F-14 Tomcat, an air superiority, strike, and fleet defense fighter aircraft that carries both missiles and cannon. The F/A-18 Hornet (C/D models) and F/A-18 Super Hornet (E/F models) are all-weather fighter and attack aircraft. These supersonic aircraft carry both missiles and cannon. The EA-



Aircraft carriers provide mobile platforms from which military aircraft can take off and land for air raids or reconnaissance. (Digital Stock)

General Characteristics of U.S. Aircraft Carriers

	Nimitz Class	*Enterprise*	*John F. Kennedy*	*Kitty Hawk* Class
Builder(s)	Newport News Shipbuilding Company	Newport News Shipbuilding Company	Newport News Shipbuilding Company	New York Ship Building Corporation; New York Naval Shipyard
Power Plant	2 nuclear reactors, 4 shafts	8 nuclear reactors, 4 shafts	8 boilers, 4 shafts	8 boilers, 4 geared steam turbines, 4 shafts
Overall Length (feet)	1,092	1,101	1,052	1,062.5
Flight Deck Width (feet)	252	252	252	252
Beam (feet)	134	133	130	130
Displacement, fully loaded (tons)	97,000 (approximate)	89,600	82,000	80,800 (approximate)
Speed (miles per hour)	34.5+	34.5+	34.5+	34.5+
Aircraft	85	85	85	85
Ship(s)	USS *Nimitz*, USS *Dwight D. Eisenhower*, USS *Carl Vinson*, USS *Theodore Roosevelt*, USS *Abraham Lincoln*, USS *George Washington*, USS *John C. Stennis*, USS *Harry S. Truman*, *Ronald Reagan* (under construction)	USS *Enterprise*	USS *John F. Kennedy*	USS *Kitty Hawk*, USS *Constellation*
Crew (Ship's Company/ Air Wing)	3,200/2,480	3,350/2,480	3,117/2,480	3,150/2,480
Armament	2-3 NATO Sea Sparrow launchers, 3-4 20-millimeter Phalanx CIWS mounts	2 Sea Sparrow missile launchers, 3 20-millimeter Phalanx CIWS mounts	Sea Sparrow missiles with box launchers, 3 20-millimeter Phalanx CIWS mounts	Sea Sparrow launchers, 3 20-millimeter Phalanx CIWS mounts
Date Class First Deployed	May 3, 1975	November 25, 1961	September 7, 1968	April 29, 1961

Source: (www.chinfo.navy.mil/navpalib/factfile/ships/ship-cv.html), June 6, 2001.

6B electronic warfare and countermeasures aircraft are subsonic, achieving speeds of more than 500 knots per hour. They carry countermeasures equipment and antiradar missiles. The subsonic S-3 Viking antisubmarine plane carries missiles, rockets, mines, torpedoes, and depth charges. The propeller-driven E-2C Hawkeye airborne early warning and command plane is unarmed. The SH-60 Seahawk antisubmarine, search-and-rescue, and special operations helicopter carries machine guns, missiles, and torpedoes. All but three U.S. carriers have nuclear propulsion. The ships' reactor plants are capable of carrying them many times around the world without refueling.

Carriers of other countries carry different aircraft. Several nations' carriers embark the British Aerospace Harrier, capable of vertical and short takeoffs and vertical landings (V/STOL). The Royal Navy currently flies the Sea Harrier FA2, which carries bombs, missiles, and cannon, and flies at about Mach 0.9. France's carrier carries the Super Etendard attack and reconnaissance aircraft. France also operates the Rafale M multirole fighter aircraft, capable of Mach 2, which carries missiles and cannon.

Early History

The first instance of a heavier-than-air craft taking off from a warship was the flight of a Curtiss airplane from a ramp mounted on the U.S. cruiser *Birmingham* in 1910. The first landing on a warship was on the USS *Pennsylvania* in 1911. Several other experiments of this type continued in the United States and Great Britain around this time. Seaplane carriers, which simply carried seaplanes in their hulls, launched them on catapults, and then winched them aboard after they had made a water landing, were developed in the first twenty years of the 1900's as well. The first true aircraft carrier, which enabled aircraft to take off and land, was the HMS *Furious* in 1917.

World War II

During the interwar years, the United States, Japan, France, and Great Britain built large fleet aircraft carriers. Earlier carriers were built on the hulls of former cruisers, battleships, or battlecruisers; later ships were built from the keel up as aircraft carriers. In World War II, these aircraft carriers came into their own and proved their worth as offensive and defensive strike weapons, primarily with the navies of the United States, Great Britain, and Japan. Germany had begun the construction of at least two aircraft carriers before World War II. Only one came near completion; named the *Graf Zeppelin*, it was never finished, scuttled at the end of the war, and later sunk. Fleet aircraft carriers effectively spelled the end of then-conventional surface warfare, wherein capital ships attempted to destroy each other with long-range gunnery, in World War II. The British Royal Navy carrier raids on the Italian port of Taranto and the 1941 Japanese carrier attack on Pearl Harbor, based in part on the Taranto raid, showed conclusively that carrier-based aircraft could, under the right conditions, destroy capital ships in port. The battles of the Coral Sea and Midway, in May and June, 1942, definitively demonstrated that carrier battle groups were capable of searching out and sinking each other while hundreds of miles apart. At Coral Sea, the American carrier force, though losing a carrier, stopped the Japanese approach to Australia; at Midway, some weeks later, the American force destroyed all four Japanese carriers and effectively turned the tide of the Pacific war. In the 1944 battle known as the Marianas Turkey Shoot, American fighter planes destroyed most of what was left of the Japanese carrier air component.

In addition, smaller carriers, called escort carriers, or jeep carriers, did important service in the war by performing much-needed convoy escort protection in the Atlantic Ocean, as well as performing antisubmarine duty and support of amphibious landings, as well as strikes against land targets.

Modern Carriers

After World War II, the aircraft carrier moved from a largely battlefleet role to a variety of roles in both peacetime and war. Technical innovations in carriers included the embarcation of jet aircraft; nuclear weapons capability; steam catapults, which made jet operations possible; and angled flight decks, which allowed the simultaneous takeoff and recovery of multiple airplanes. In Korea, navy planes launched from carriers flew combat sorties and search-and-rescue missions; the same was true for carriers positioned in "Yankee Station" in the South China Sea during the Vietnam conflict. Carriers were used to retrieve the Mercury, Gemini, and Apollo astronauts from their space missions in the 1960's and 1970's.

After the war, the United States embarked on the idea of the "supercarrier," a ship which would be larger and more powerful than previous ships. The original supercarrier, the *United States*, was canceled before being built. However, subsequent carriers incorporated supercarrier designs, such as increased space for aircraft, fuel, and munitions.

Modern Supercarriers

Currently, the United States Navy is by far the largest operator of aircraft carriers in the world, with thirteen in service: *Ronald Reagan* (under construction), *Harry S. Truman*, *John C. Stennis*, *George Washington*, *Abraham Lincoln*, *Theodore Roosevelt*, *Carl Vinson*, *Dwight D. Eisenhower*, *Nimitz*, *Enterprise*, *John F. Kennedy*, *Constellation*, and *Kitty Hawk*. Other nations operating carriers as of 2001 included Great Britain (*Invincible*, *Illustrious*, and *Ark Royal*); France (*Charles de Gaulle*); India (*Viraat*); Thailand (*Chakri Nareubet*); Italy (*Giuseppe Garibaldi*); Spain (*Principe de Asturias*); Brazil (*São Paulo* and *Minas Gerais*); and the Russian Republic (*Kuznetsov*). Of the U.S. carriers, only the *Kennedy*, the *Constellation*, and the *Kitty Hawk* are conventionally powered; the remaining ten have nuclear propulsion. France's *Charles de Gaulle* is nuclear powered. The carriers of India, Great Britain, Spain, Italy, and Thailand are designed to operate helicopters and the Harrier V/STOL fighter/attack aircraft.

In addition to aircraft carriers, several other types of warships conduct air operations, largely with helicopters; these are used by several nations. The U.S. Navy operates several amphibious warfare ships, sometimes called helicopter carriers, whose flat decks are for the purpose of embarking and debarking troop concentrations, such as Marine Expeditionary Units (MEUs).

American aircraft carriers are ships with multiple roles in the twenty-first century. Apart from their immediately obvious tactical military role, they are often used as strategic tools of diplomacy and national will when needed. American carriers have been sent to "show the flag" and project American power in world trouble spots since the 1950's. American carriers were sent to the Persian Gulf to safeguard shipping during the Iran-Iraq War of the 1980's, and during the Desert Shield campaign of 1990 and 1991.

Future

The future of the aircraft carrier in the short and middle term seems assured. Despite comments from critics that aircraft carriers are too expensive (costing billions of dollars) and too vulnerable to either military or terrorist attack, the navy's newest carriers are being built with an expected useful service life of over thirty years (taking into account service life extension programs to update structures and systems). In addition, the commitment of the United States to thirteen active aircraft carriers (though not all are at sea at the same time) indicates America's commitment to the concept of anytime, anywhere naval carrier operations for some time to come.

Several aircraft carriers of World War II and later eras have been permanently docked and serve as museums, including the *Hornet* in Alameda, California, *Intrepid* in the New York City harbor, *Lexington* in Corpus Christi, Texas, and the carrier *Yorktown* in Charleston, South Carolina. Many active carriers have their own World Wide Web sites.

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See also: Gulf War; Harrier jets; Hornet; Landing procedures; Military flight; Navy pilots, U.S.; Takeoff procedures; Tomcat; Vertical takeoff and landing; World War II

Airfoils

Definition: A two-dimensional, front-to-back section or slice of a wing.

Significance: The shape of a wing's airfoil section or sections determines the amount of lift, drag, and pitching movement the wing will produce over a range of angles of attack and also determines the wing's stall behavior.

The shape revealed if a wing were to be sliced from its leading edge to its trailing edge is called the wing's airfoil section. Although airfoils come in many different shapes, all are designed to accomplish the same goal: forcing the air to move faster over the top of the wing than it does over the bottom. The higher-speed air on the top of the airfoil produces a lower pressure than the flow over the bottom, resulting in lift. The shape of the upper and lower surfaces of the airfoil and the angle that it makes with the oncoming airflow, or angle of attack, determines the way the flow will accelerate and decelerate around the airfoil and, thus, determines its ability to provide lift.

Flow around the airfoil also causes drag, and an airfoil should be designed to get as much lift as possible while at the same time minimizing drag. The shape of the airfoil then determines the balance of lift and drag at various angles of attack. An airplane designer tries to select an airfoil shape that will give the best possible lift-to-drag ratio at some desired optimum flight condition, such as cruise or climb, depending on the type of aircraft. The amount of pitching movement, or tendency for the airfoil to rotate nose up or down, is also a function of the airfoil's shape and the way lift is produced. Pitch must be evaluated along with the forces of lift and drag.

Camber and Thickness

Early airfoil shapes were thin, essentially cloth stretched over a wood frame, a type of airfoil sometimes seen today in the wings of ultralight or hang glider-type aircraft. Usually the frame for such an airfoil was curved, or cambered. The camber line, or mean line, of an airfoil is a curved line running halfway between its upper and lower surfaces. If the airfoil is symmetrical, in other words, if its upper surface is exactly the inverse of its lower surface, then the camber line is coincident with its chord line, a straight line from the leading edge to the trailing edge of the airfoil. A symmetrical airfoil is said to have zero camber. The amount of camber possessed by an airfoil is defined by the maximum distance between the chord and camber lines expressed as a percentage of the chord. In other words, an airfoil has 6 percent camber if the maximum distance between its chord and camber lines is 0.06 times its chord length.

Experimenters in the late 1800's tried wings built with airfoils with different amounts of camber and different positions of maximum. They found that the location of maximum camber affected both the amount of lift generated at given angles of attack and the airfoil's stall behavior and that too much camber can give high drag. Later researchers learned to create temporary increases in camber by using flaps.

Later aircraft used thicker airfoils with both upper and lower surfaces covered first with fabric and then with metal. The thicker airfoils allowed a stronger wing structure as well as a place to store fuel. They also proved able to provide good aerodynamic behavior over a wider range of angle of attack as well as better stall characteristics, but excessive thickness made for increased drag.

NACA Airfoils

In the 1920's, the National Advisory Committee for Aeronautics (NACA) began an exhaustive study of airfoil aerodynamics, examining in detail the effects of variations in camber and thickness distributions on the behavior of wings. This systematic study of variations in the amount and position of maximum camber and thickness resulted in the wind-tunnel tests of hundreds of airfoil shapes. NACA also developed a numbering system, or code, to describe the shapes. In the first series of tests, each of the numbers in a four-digit code was used in a prescribed set of equations to draw the airfoil shape. For example, the NACA 2412 airfoil had a maximum camber of 2 percent of its chord with the maximum camber point at 40 percent of the chord from the airfoil leading edge, and the maximum thickness was 12 percent of the chord.

Many other series of NACA airfoils were developed and tested. The 6-series airfoils were designed to provide very low drag over a set range of angle of attack by encouraging a low-friction laminar flow over part of the surface. Other series of airfoils were developed for use on propeller blades. NACA's successor, the National Aeronautics and Space Administration (NASA), has continued to test and develop airfoils including a series of supercritical shapes that give lower drag near the speed of sound, as compared to older designs.

Modern Airfoil Design

Throughout the twentieth century, airfoil design was essentially a matter of creating a shape based on desired camber and thickness distributions, testing it in wind tunnels and then in flight. Today, airfoils can be selected from hundreds of past designs or custom-developed by specifying a desired distribution of pressure around the surface and using computers to solve for the shape that will give those pressures. Then wind-tunnel tests are done to validate the computer solution. The result is that every airplane can have a wing with a unique distribution of airfoil shapes along its span, all designed for optimum performance. The basic idea is the same as it has always been, to find the combination of camber and thickness which will give the best available mix of lift, drag, and pitching movement for the task at hand.

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See also: Aerodynamics; Forces of flight; Hang gliding and paragliding; National Advisory Committee for Aeronautics; National Aeronautics and Space Administration; Roll and pitch; Ultralight aircraft; Wing designs

Airline Deregulation Act

Date: October 30, 1978

Definition: A federal law passed in order to eliminate the U.S. government's control of airline regulations, routing, fares, and schedules.

Significance: In an effort to create a freely competitive airline industry, the Airline Deregulation Act revolutionized the way airlines were allowed to do business.

History

The freedom of flight must have been one of humankind's earliest dreams. It must have been wondrous to watch birds soar, swoop, and land at will, and then lift off again to fly. When humans finally began to take to the skies in flying machines, they little dreamt the skies would one day need controlling, scheduling, and regulating. The idea of free and open skies for anyone who could fly became unrealistic in the increasingly commercial world of aviation, where business and safety were primary concerns.

World War I, which began in 1914, helped to educate the public about aviation and its possibilities. Warring nations began manufacturing war planes with metal bodies, which had previously been made of wood, and developed more powerful engines to increase speed and flying distance. After the war, organized air service developed rapidly in Europe.

By 1921, government subsidies for the development of new aircraft were in place, and most of Europe's major cities were linked by air service. In 1926, the U.S. government began awarding airmail delivery contracts to private air carriers and subsidizing private air carriers to transport the mail. This development helped to spawn the airline industry. As passenger travel on these early airlines increased, the government quickly became involved with enforcing economic and air safety regulations, as well as awarding mail contracts.

Civil Aeronautics Act

The Civil Aeronautics Act of 1938 established federal control over airline regulation. This influential legislation strengthened the government's power and led to the creation of the Civil Aeronautics Board (CAB) and the Air Safety Board, a forerunner of the Federal Aviation Administration (FAA).

The CAB took on a role of responsibility and importance. Its four main points of control were to review route requests and grant authorizations; to establish a uniform system of rates and fares; to approve airline mergers, acquisitions, and new entrants; and to rule on unfair competition. The CAB also awarded Certificates of Convenience and Necessity to domestic airlines and assigned carriers to specific routes. Airlines were required to request permission from the CAB, a complicated procedure, for any route expansion or airfare increase. The CAB simplified the fare system and regulated airfares, so that all carriers flying between the same cities had the same fares. Any requests for changes were processed, reviewed, debated, and, in many cases, eventually denied.

The CAB was originally established to ensure orderly competition and growth within the airline industry. Many policymakers believed that if the U.S. airline industry were permitted to operate unregulated, then unprofessional and perhaps unethical competition might develop, leading to the survival of only a few large airlines. If airlines were allowed to choose their own routes, they would avoid servicing small, less profitable communities and cities. Until 1978, the federal government—through the CAB and the Air Traffic Conference, a nongovernmental airline group—controlled all U.S. airline transportation. There was little or no competition among commercial airlines.

Airline Deregulation Act

On October 30, 1978, President Jimmy Carter signed the Airline Deregulation Act, which scheduled the shutdown of the CAB for January 1, 1985. Between 1978 and 1985, the CAB assisted in the transition process. With the impending elimination of the CAB, the domestic airline industry began its own restructuring for the future.

Deregulation of the airlines had many goals, some of which were to allow airlines to set their own fares, thus stimulating competition and lowering fares; to allow airlines to determine their own routing, thereby expanding flight options available to passengers; to allow airlines to discontinue unprofitable routes; and to stimulate growth within the industry by allowing for the establishment of new carriers.

Deregulation led to changes for the entire travel industry as well as the traveling public. Thousands of fares change daily in response to changing competitive conditions, in stark contrast to the fare stability that prevailed prior to deregulation. Deregulation has also given the airlines the freedom to fly wherever they wish. This freedom has spurred the creation of new route structures.

Travelers have benefited from deregulation because of the greater number of lower discount fares available. These new lower fares, fare wars, and promotional airfares have enabled more people to use air transportation than ever before. Competition between the airlines has become intense. Deregulation permitted hundreds of new airlines to start. Many new airlines such as People Express threw the industry into turmoil by offering super bargain fares. As had been expected, many of the major carriers lost money trying to compete at that level, leading some airlines to merge while others just faded away. There were bankruptcies and downsizing. Low-cost, no-frills airlines were established to tap into high traffic corridors and regional market segments. Major airlines have made dramatic efforts to increase customer loyalty with such incentives as frequent-flier programs. They have developed aggressively competitive strategies involving promotions, destination, partnering, code sharing, and as always, the special low-fare promotion.

Airlines will continue to compete fiercely for passengers. New categories of budget airfares with numerous travel restrictions are constantly being developed. Although passengers benefit from reduced prices, travel and ticketing agents must work with complex ticketing and reservation situations. Because printed tariffs can become obsolete before reaching a travel agency, travel agents rely on their computer systems to access fares and information regarding their related purchase requirements.

Deregulation allowed airlines to govern aspects of their commercial dealings. Airlines could establish their own routes and airfares. They could create their own packages and fare plans to effectively compete for more passengers. They may now function as tour operators, providing packaged tours directly to the public. In addition, they may own and operate travel agencies. Thus, they have developed new methods of selling tickets outside the existing travel agency system.

Since the dismantling of the CAB on December 31, 1984, the Department of Transportation (DOT), which was created in 1966, has watched over the U.S. airline industry. The powers of the DOT are more limited than those of the CAB. In writing the Airline Deregulation Act of 1978, Congress had intended that the federal government alone would regulate the airline industry. Federal regulations on any airline industry issue take precedence over the rights of the states or individuals to legally challenge any carrier's business practices. The DOT regulates and monitors all transportation industry and safety issues in the United States. Because this large task encompasses so many industries, there are specialized administrations under the DOT whose authority is specific to one type of transportation. One branch of the DOT, the Federal Aviation Administration (FAA), plays an important role in the continued regulation of air safety. The FAA has absolute authority over flights passing through U.S. airways.

Hub-and-Spoke System

One result of deregulation was that airlines were granted the new freedom of choosing their own routing, spurring the creation of new route structures. The airlines have basically abandoned point-to-point route systems, in which cities were connected by nonstop flights, in favor of hub-and-spoke networks. A hub is an airport through which an airline schedules the majority of its flights, like a wheel with many spokes radiating from the center of the hub. An airline schedules most of its flights from various cities, or spokes, to arrive at approximately the same time at a designated hub. The airline then schedules most of its flights to depart one to three hours later to other destinations, or spokes, along its routes. This enables flights from the various spokes to be routed through the central hub, where passengers are combined to fly on to a common destination. Today, passengers can change planes at a hub airport on the way to their eventual destinations.

Hub-and-spoke routings benefit the airlines because they lose fewer of their passengers to other airlines through interline connecting services. The hub system has proven beneficial to passengers because it allows them to remain on line, or on the same carrier, all the way through to their final destination. They can change planes at the hub airport without scrambling to change airline carriers and with less possibility of lost luggage and missed connecting flights.

A hub airport is a major connecting center, as well as the typical location of the airlines' administrative offices. A gateway is a hub for international flights and serves as an arrival and destination point for international travelers.

International Air Transportation Competition Act

In line with deregulation of the domestic airline industry, Congress passed the International Air Transportation Competition Act of 1979. The act, passed in February, 1980, encompassed ten goals. The first was to strengthen the competitive position of U.S. air carriers and to increase profitability. The second was to ensure air carriers the freedom to offer fares and rates that corresponded with consumer demand. The third was to reduce restrictions on charter options. The act also allowed multiple carrier designations for U.S. airlines with permissive route authority so that carriers could respond swiftly to shifts in demand. It eliminated operational and marketing restrictions with respect to capacity and flight frequency. It sought to integrate domestic and international air transportation and to increase the number of nonstop U.S. gateway cities. It provided opportunities for foreign airlines to increase their access to U.S. points if exchanged for benefits of similar magnitude for American carriers with permanent linkage between rights granted and rights given away. It sought to eliminate discrimination and unfair competitive practices against U.S. air carriers in foreign air transportation. Finally, it pledged to promote and develop civil aeronautics and a viable, privately owned U.S. air transport industry.

The passing of the International Air Transportation Competition Act of 1979 reaffirmed the U.S. policy of competition. The established carriers jumped at the chance to expand. They wanted long-haul flights between major cities, where they could attract the most money. What they had not expected was that the introduction of more carriers in the large markets simply meant that the planes were flying without full passenger loads. Because pricing had been placed in the control of the carriers, they did what all businesses do when supply exceeds demand: They lowered their fares. During the fierce price wars of the early 1980's, it was often less expensive to fly to a destination than it was to drive.

In 1997, the U.S. airline industry launched more than 22,348 flights a day, employed more than 586,509 people, carried 1.6 million people each day, and recorded $109.5 billion in revenues. The 1997 survey of air travelers by the Gallup organization revealed that a record 80 percent of the entire adult population of the United States had flown.

Alliances of the Future

Under deregulation, the airline industry has undergone dramatic change, leading to significant consolidation, hub systems, low airfares in competitive situations, and high airfares where competition was lacking.

The future holds alliances that could involve the largest carriers in the United States. Alliances are being negotiated with an overwhelming range, from equity positions, to code sharing, to frequent-flier programs, reciprocity, and other joint marketing arrangements. International alliances have been debated since KLM (Royal Dutch Airline) and Northwest Airlines linked in 1992. United Air Lines established the Star Alliance, which included Lufthansa, Air Canada, Thai Airways, SAS, and Brazil's Yang Airlines.

Authorities in both the United States and the European Union are analyzing how to deal with the many major airline alliances. The decisions they make will shape the future of airlines around the world. It remains to be seen whether these alliances will benefit consumers through greater choice, lower fares, greater convenience, and frequent-flier miles or whether they will create monopolies, higher fares, and new noncompetitive situations. Perhaps government action may be needed to call for reregulation.

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See also: Air carriers; Airline industry, U.S.; Airmail delivery; Airports; Federal Aviation Administration; Frequent-flier miles; KLM; Lufthansa; Mergers; Northwest Airlines; SAS; Ticketing; United Air Lines

Airline industry, U.S.

Definition: The system of airline carriers and aircraft supplying national and international air travel services for passengers in the United States.

Significance: The U.S. airline industry has evolved to become the most highly developed transportation network in the world, comprising more than 5,000 aircraft valued at more than $65 billion. U.S. airlines schedule more than 12,000 domestic and international flights per day, with more than 200,000 available seats. These flights carry a major portion of the world's air commerce.

History

Scheduled air transportation actually began in Germany, where, as early as 1910, zeppelins carried 35,000 passengers per year. The first recognized attempt at establishing a scheduled air passenger service in the United States occurred in 1914, with the short-lived St. Petersburg-Tampa Airboat Line, which consisted of one Benoist Type XIV flying boat. The carrier's 18-mile route across Tampa Bay was covered in twenty minutes at a price of $5.00 for the one passenger per flight. The airline contracted with the city of St. Petersburg for two daily round trips. This endeavor lasted for four months and carried 496 passengers. There would not be another regularly scheduled airline in the United States until well after the end of World War I.

After World War I, Europe again led the way in developing scheduled airlines. With the advances in design and construction, large military aircraft could be converted for civilian uses. Geographic features such as the English Channel made scheduled flights feasible and flights between London and Paris began while the Treaty of Versailles was still being negotiated. Because most of Europe's transportation and communications infrastructure had been destroyed by the war, government assistance was available to fledgling airlines of European countries. These airlines would be used to connect the outlying outposts of the various empires.

In contrast, the U.S. transportation systems within the United States had not been damaged by the war. Indeed, the most highly developed railroad system in the world remained intact. The long distances involved in U.S. travel lent themselves more comfortably to Pullman-type sleeper cars and well-stocked dining cars than to open-cockpit biplanes. At the time, trains were as fast as most of the existing airplanes and could continue to travel throughout the night while passengers slept. Unlike the governments of European nations, the U.S. government displayed little inclination to subsidize the development of air transportation.

The next serious attempt to establish a regularly scheduled air service in the United States had more to do with politics than with aeronautics. In 1919, Congress passed the Volstead Act, which made illegal the selling and consumption of alcoholic beverages. However, the institution of Prohibition did not quench the thirst of the American public. Lying conveniently off the coast of Florida were the independent nations of Cuba and the Bahamas, which were beyond the jurisdiction of U.S. laws. In order to meet the demands of American consumers, Aeromarine Airways developed a route that came to be known as the Highball Express. Using fourteen-passenger flying boats, Aeromarine began a scheduled service from New York City to Havana, Cuba. Aeromarine added flights to Nassau in the Bahamas and expanded its service to Cleveland and Detroit. The airline continued to operate until September, 1923, ultimately carrying 17,000 passengers.

The Role of the U.S. Post Office

Although the U.S. government's official position was that air transportation should be developed without government subsidies or direct government involvement, the U.S. Post Office had begun experimenting with airmail delivery as early as 1911. In 1918, the Post Office began to establish a scheduled airmail delivery system. This activity culminated in the development of a transcontinental route structure with numerous connecting routes. With the passage of the Air Mail Act of 1925, also known as the Kelly Act, the Post Office turned these routes over to private operators through competitive bids. Many, if not most, of the existing airlines in the United States were established with the goal of obtaining a Post Office airmail contract. The airmail contract would ensure that the fledgling airlines could generate enough income to remain in existence. The goal of the contract airmail service was to subsidize the private

Immediate Impact of the Terrorist Attacks of September 11, 2001, on Major U.S. Carriers

Air Carrier	Financial Results	Announced Job Cuts (% of workforce)	Expected Federal Compensation	September, 2001, Traffic	
				Number of Passengers (% decrease from 9/00)	Load Factor (% in 9/00)
Alaska Airlines	2000: $70 million net loss 2001: $3 million net loss through 9/30/01	None	$100 million	805,000 (22.0%)	60.7% (62.7%)
American Airlines	2000: $813 million profit 2001: $964 million net loss through 9/30/01	~20,000 (14%)	~$1 billion	61.3 million (6.9%)	59.6% (69.8%)
Continental Airlines	2000: $342 million net income 2001: $54 million net income through 9/30/01	12,000 (~20%)	$458 million	2.9 million (32.0%)	61.4% (72.4%)
Delta Air Lines	2000: $928 million net income 2001: $482 million net loss through 9/30/01	Up to 13,000 (15%), 11,000 from retirement, voluntary severance	$690 million	5.87 million (35.0%)	56.2% (68.5%)
Northwest Airlines	2000: $256 million net income 2001: $207 million net loss through 9/30/01	10,000 (19%)	$500 million	3.1 million (33.9%)	63.8% (76.5%)
Southwest Airlines	2000: $603 million net income 2001: $47.6 million net income through 9/30/01	None	$280 million	3.6 million (28.7%)	53.4% (65.7%)
United Air Lines	2000: $50 million profit 2001: $1.84 billion net loss through 9/30/01	~20,000 (20%)	$800 million	4.2 million (34.6%)	61.1% (69.9%)
US Airways	2000: $269 million net loss 2001: $960 million net loss through third quarter	11,000 (24%), 2,000 voluntary	$331 million	2.92 million (39.0%)	56.1% (66.9%)

Source: Data taken from “Ailing Airlines: An Industry in Crisis,” MSNBC.com, November 1, 2001 airlines in order eventually to develop a viable passenger service.

By 1927, the Post Office had contracted all the airmail routes to private companies. The original transcontinental route was eventually awarded to what is today United Air Lines. Mergers forced by the postmaster general resulted in the formation of American Airlines. American received the newly established southern transcontinental route. Transcontinental Air Transport, the company that had pioneered the idea of combining aircraft and passenger trains for transcontinental travel, was forced to merge with Western Air Express. The resulting airline, Transcontinental and Western Air, eventually became Trans World Airlines (TWA). Other airlines were awarded routes in support of the transcontinental routes. Eastern Air Lines received a north-south route along the East Coast; Northwest Airlines received a route northward to Minneapolis. Many other smaller airlines also received contracts, although within a few years most of these companies had been absorbed by the larger operators.

The U.S. Post Office also awarded mail contracts for international airmail. Pan American Airways, under the leadership of Juan Trippe, won the vast majority of these contracts. Although there were accusations of favoritism and unfair practices associated with Pan American's unparalleled success, these were never proven. Pan American became the chosen instrument of the U.S. State Department and remained virtually the only international airline in the United States until the advent of World War II. Pan American absorbed any potentially competitive company. By the time the United States entered World War II, Pan American had developed into the largest, most successful airline in the world. Not only did the company fly throughout Central and South America and across the Atlantic Ocean to Europe, but it also covered the Pacific Ocean, with service to exotic destinations such as Hong Kong.

Although the efforts of the U.S. Post Office resulted in a strong network of air carriers, not everyone was pleased with its practices. The methods employed by Postmaster Walter Folger Brown had alienated many of the small operators who had not been awarded airmail contracts. With the election of President Franklin D. Roosevelt in 1932, many complaints surfaced. Roosevelt ordered an investigation that led to the ill-fated cancellation of all domestic airmail contracts in 1934. The president ordered the army to carry the mail, but this arrangement proved to be disastrous, as a number of poorly trained and equipped pilots were killed in accidents. The airmail contracts were returned to the original operators shortly thereafter, but the passage of the Air Mail Act of 1934 placed severe restrictions on the airlines. The provisions of this law resulted in large financial losses, and many airlines were on the brink of bankruptcy when Congress passed the Civil Aeronautics Act of 1938, which saved the airline industry.

Although all the domestic airmail contracts had been canceled, none of the international contracts that had been awarded to Pan American were affected. Pan American, with the cooperation of the U.S. Navy, continued to expand its operations. Rates in the Pacific were actually increased above the maximum allowable rate in the name of national security. Pan American continued to operate successfully and profitably as the country prepared for World War II.

World War II

World War II had a tremendous impact on the U.S. airline industry. The United States assumed the role of supplying the worldwide war effort with supplies, material, and human resources. The aircraft manufacturing industry began to mass-produce large, long-range aircraft, operated by airline-trained crews. These crews flew to every corner of the world, establishing routes, airports, and facilities that would be invaluable at war's end. This effort, which came to be known as airlift, was one of the major military accomplishments of World War II. The experience gained by the airlines and crews, coupled with advancements in aircraft design and technology, catapulted the United States into a dominant position in international air transport. The war destroyed or dispersed the airlines of most of the countries of the world. European aircraft manufacturing was forced to concentrate on building fighters and bombers rather than large transport-type craft. Pilots were engaged in combat flying rather than long-range international flights. U.S. airlines assumed the role of international transportation.

The domestic U.S. transportation system also experienced growth during World War II. Routes were expanded to meet the needs of the government, and the number of passengers exceeded the number of airplane seats available. Although the majority of airlines still utilized the venerable Douglas DC-3 for domestic service, larger and faster airplanes began to appear. Passenger-generated income finally exceeded that generated by airmail delivery, and the structure of a mature industry began to develop. By the end of the war, air travel had become an accepted fact and was no longer considered an unusual extravagance. Industry and government began to rely more heavily on the airplane and its scheduled services.

The war had a significant impact on the structure of international air service. Prior to the war, Pan American had been the so-called chosen instrument of the United States. The demands of war had led to a number of additional airlines being granted international routes. Both American and TWA flew transatlantic routes during the war, and they were allowed to continue with these routes after the war, much to the dismay of Pan American. Political difficulties with the Roosevelt and Truman administrations further weakened Pan American's dominance as airlines such as Eastern, Braniff International, and Northwest were granted international routes, often into the heart of Pan American's territory. While Pan American was losing its international monopoly, the airline was simultaneously barred from establishing a domestic network in order to compete with the new international airlines, a prohibition that was eventually to have disastrous consequences for the once-proud Pan American.

Postwar Industry

As a result of World War II, the U.S. airline industry had evolved into a large worldwide operation. Airlines began to become differentiated into passenger airlines, all-cargo airlines, commuter airlines and air taxis. Airlines were divided into categories. Trunk airlines, such as American, Eastern, TWA, and United, were those that operated between nations and crossed oceans. Later this category was changed to include large domestic airlines, and trunk airlines became reclassified as regional airlines, which did not operate international routes and typically served four or five states. Commuter airlines were scheduled airlines that were restricted to aircraft weighing less than 12,500 pounds. This classification system lasted until the passage of the Airline Deregulation Act in 1978.

Industry Growth

Throughout the 1940's and 1950's, the Civil Aeronautics Board (CAB) continued to award routes to various airlines in an attempt to expand the transportation network and maintain an environment of controlled competition. The airlines, in turn, competed with each other primarily in terms of service and speed. This competition resulted in performance improvements in the various types of commercial aircraft. Airlines such as American favored the Douglas DC-6/7 series, whereas TWA favored the Lockheed Constellation series. Continual performance increases led to passengers enjoying pressurized comfort while crossing the country in eight hours or less. In addition, pressure from a number of nonscheduled operators charging significantly lower fares forced a number of the domestic trunk airlines to begin offering lower fares. In 1948, Capital Airlines introduced coach-class service and, by 1949, was joined by American and TWA. In May, 1950, United followed suit. The airlines, with the approval of the CAB, agreed to a mutual $99.00 coast-to-coast coach fare in 1952.

In an attempt to guarantee service to smaller communities, the CAB established the classification known as feeder airlines in 1944. Feeder airlines, such as Pioneer, Allegheny, North Central, Piedmont Airlines, and Mohawk Airlines, were heavily subsidized to supply air service to small communities. In 1955, this airline classification was renamed local service carriers. Most of these airlines relied on Douglas DC-3 aircraft that had been retired by the larger trunk carriers. Eventually, local service carriers replaced the DC-3 with more modern aircraft and introduced turboprop aircraft, such as the F-27 Friendship. By the 1960's, the CAB was coming under increasing pressure to do away with the subsidies and allow the free market to determine success. However, with shorter routes serving small cities, it would be more difficult for these smaller airlines to make a profit.

Recognizing this fact, in 1959, the CAB instigated the so-called "use-it-or-lose-it" policy. Cities were informed that if they did not have a minimum of 1,800 passengers a year, their air service would be terminated.

At the same time, the local service carriers began to pressure the CAB for the right to expand their route structures. They purchased larger aircraft, including jets such as the Douglas DC-9. Airlines such as Frontier grew to challenge the existing trunk airlines. As the expansion of the local service carriers continued, a number of mergers began to occur, with the stronger airlines devouring the weaker ones. The original thirteen local service carriers had been reduced to nine by 1968. At this time, the name of the local service carrier classification was changed to that of regional carrier. Mergers between the regionals continued, with Allegheny, the largest, merging with Mohawk, the third largest, to form what was eventually renamed USAir in 1979. North Central and Southern Airlines also merged to form Republic Airlines. These so-called regionals were now as large as the trunk airlines. As the regionals abandoned their short-haul markets, the third-tier airlines, calling themselves commuters, expanded to fill the void.

The CAB recognized this discrepancy and in 1980 established a new airline classification system. All airlines in the United States were now to be classified based on their revenues as majors, nationals, or regionals. Majors were required to generate $1 billion in annual revenues, and nationals were required to generate $75 million. Regionals were divided into two subclassifications: large, which

Large Air Carrier Classifications, 1995-1996

MAJORS

Alaska	Continental	Northwest	United
America West	Delta	Southwest	United Parcel Service
American	Federal Express	TWA	USAir

NATIONALS

Air Transport International	Business Express	Hawaiian	Rich International
Air Wisconsin Airlines	Carnival	Horizon Air	Simmons
Aloha	Contintental Express	Kiwi	Southern Air
American International	Continental Micronesia	Markair	Sun Country
American Trans Air	DHL Airways	Mesa	Tower
Arrow	Emery	Midwest Express	Trans States
Atlantic Southeast	Evergreen	Polar Air Cargo	USAir Shuttle
Atlas	Executive	Reno	ValuJet
			World

LARGE REGIONALS

Air South	Express One	Midway	Spirit
Amerijet	Fine	North American	Sun Jet
AV Atlantic	Frontier	Northern Air	UFS
Buffalo	Grand American	Pan Am	Viscount
Challenge	Kitty Hawk	Reeve	Western Pacific
Champion	Miami Air	Ryan International	Zantop

MEDIUM REGIONALS

Air 21	Florida West	Pacific International	Trans Continental
Airtran	Grand Airways	Prestige	Transmeridian
Capitol Cargo	Laker Airways	Renown	Tristar
Casino Express	Milton	Sierra Pacific	USA Jet
Custom Air	Nations Air	Sun Pacific	Vanguard
Eastwind	Omni	Sun World	
Falcon	Pace	Tatonduk	

Source: Federal Aviation Adminstration, *Statistical Handbook of Aviation*, 1996.

earned $10 to 75 million in annual revenues, and medium, which earned less than $10 million. Under this new system, former local service carriers Republic and USAir received major airline status.

The Jet Age

Perhaps the one event that had the greatest impact on air transportation was the development of the jet engine. From its inauguration in the De Havilland Comet, it was clear that the jet engine would alter the entire industry. U.S. airlines entered the jet age in October, 1958, when Pan American scheduled the first Atlantic jetliner crossing by an American airline. With the establishment of this jet service, Pan American dominated the transatlantic service for

American airline. With the establishment of this jet service, Pan American dominated the transatlantic service for a number of years. Other airlines quickly followed Pan American's lead and introduced jet service. National Airlines was, in 1958, the first airline to introduce domestic jet service. This event marked the eclipse of the large, multiengine, piston-powered airliners that had been developed since World War II. Aircraft manufacturers continued to manufacture jet-powered aircraft in different sizes to meet the needs of the evolving market. Today, many turboprop commuter aircraft have been replaced with small, fifty- to seventy-seat jet aircraft. A number of commuter airlines plan a transition to all-jet fleets just as their larger counterparts have done.

Deregulation

Claimed by some analysts to be the most important event in air transportation history, the Airline Deregulation Act was passed in 1978. Through this act, the U.S. government reduced its role in the regulation of most of the business and financial aspects of airline operations. The CAB no longer approved a new airline's entry into the industry. Neither would the CAB approve routes or set fare structures. The airlines entered into an era of virtually unrestrained competition. The immediate effect of deregulation was the appearance of a number of new airlines. Many of these new entrants to the industry were low-cost, no-frills operations. The largest of these airlines was People Express, which rapidly expanded to compete with a number of the major airlines. These new entrants typically had significantly lower operating costs than did existing airlines, due to lower employee seniority, nonunion labor, and older aircraft. Although many of these new airlines were initially very successful, the major airlines reacted to the threat by lowering fares, purchasing the competing operators, and increasing frequency of flights. The major airlines also formed what came to be known as hub-and-spoke route structures, which led to the domination of various geographical markets. Code sharing with, or the outright purchase of, commuter airlines supplied a continuous flow of passengers to the hub airports. Computer reservations systems and complex revenue-management systems allowed the largest airlines to further dominate the market. Of the large number of new airlines that entered interstate or international service immediately after deregulation, only two remain.

Deregulation also had a devastating effect on some of the oldest and largest airlines, a number of which were unable to adjust to the changing demands of a deregulated environment. Giants such as Pan American, Braniff, and Eastern ceased to exist. Others, such as Republic, were forced to merge and ceased to exist.

By 1990, 60 percent of the airline business was concentrated in the hands of the big three: American, United, and Delta. Airlines such as TWA, America West, and Continental were forced into Chapter 11 bankruptcy and reorganization. The early 1990's, in particular, were a disastrous time for the airline industry. All airlines except Southwest lost large amounts of money; some were unable to recover and return to profitability, leading to additional consolidation within the industry.

In response to the crisis of the 1990's, Northwest and US Airways looked for relief to European partnerships. While the partnership between US Airways and British Airways was less than a complete success, a similar partnership between Northwest and KLM led to a return to profitability for Northwest. Other partnerships, such as United's Star Alliance have been successful and have strengthened the competitive positions of those airlines involved. Even with such successes, the fact remains that the U.S. airline industry is subject to the fluctuations of the economy. It performs strongly in a strong economy and suffers in a weak economy. It is also very probable that the strong will continue to devour the weak and that the number of major airlines will decrease in the future. For example, in 2001, American Airlines made a proposal to buy TWA; the merger was accepted by the federal government.

September 11

The sudden, tragic events of September 11, 2001—four commercial jets hijacked by Islamic fundamentalists and then crashed, three flown into the World Trade Center's Twin Towers and the Pentagon, resulting in more than three thousand deaths—had an enormous impact on the U.S. airline industry. The government ordered an immediate national ground stop that morning until the situation could be assessed. Commercial flights resumed a few days later, but passengers and crews alike were understandably reluctant to board airplanes, given the threat of further terrorist acts.

The loss of revenue over the following weeks forced major air carriers and airports to lay off tens of thousands of employees. The longer-term picture was also grim. Tourism and business travel were curtailed. Moreover, the already fragile U.S. economy was placed firmly into recession. A federal bailout plan for the industry was devised. President George W. Bush signed into law an emergency aid package providing five billion dollars in direct federal aid and ten billion dollars in loan guarantees. The measure also offered federal help with rising insurance costs in the dustry sought ways to make flying safer and to reassure the public, but many predicted that the consequences of September 11 would be evident for years to come.

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See also: Air carriers; Airmail delivery; Airports; American Airlines; Continental Airlines; Delta Air Lines; Federal Aviation Administration; Flight attendants; Food service; Frequent flier miles; Mergers; Northwest Airlines; Pan Am World Airways; Pilots and copilots; PSA; Southwest Airlines; Ticketing; Trans World Airlines; Transatlantic flight; Transcontinental flight; Transglobal flight; United Air Lines; US Airways

Airmail delivery

Definition: The distribution of intercity and international first-class mail by aircraft rather than surface transport.

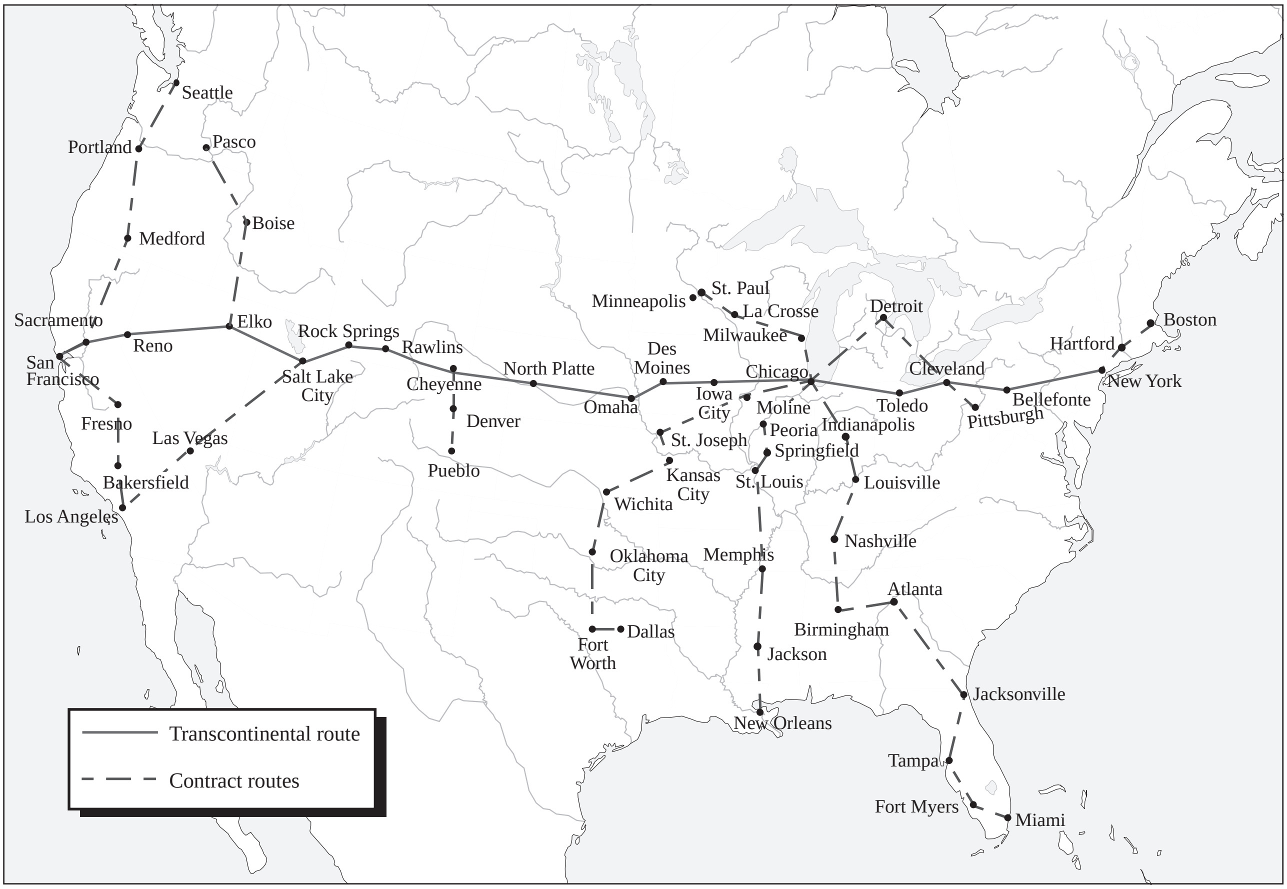
Significance: The U.S. Post Office tradition of guaranteeing the fastest possible mail delivery continued with the initiation of airmail service in 1918, when scheduled air service remained an untried and unproven concept. The airmail efforts of the U.S. Post Office also resulted in the development of the modern air transportation system, as most modern major airlines began operation as contracted airmail carriers.

Early Experiments

The earliest U.S. airmail experiment took place in 1858, when balloonist John Wise was contracted by Thomas Wood, the postmaster of Lafayette, Indiana, to carry a packet of mail to New York by air. This trip was advertised as the world's first official airmail delivery. However, the winds did not cooperate, and Wise was blown south rather than east. After a short flight, he landed a mere 30 miles from his point of departure.

Image Not Available

Early U.S. Airmail Routes



Although this first attempt was less than successful, the U.S. Post Office continued to support airmail experiments. As early as 1910, aviation pioneer Glenn H. Curtiss had unofficially carried mail in an aircraft. The first official mail to be carried in a heavier-than-air craft was carried by pilot Earle Ovington at the International Aviation Meet at Garden City, New York, in September, 1911. During the weeklong air meet, Ovington carried more than 40,000 pieces of mail by air to nearby Mineola, New York. Postmaster Frank Hitchcock was so impressed by the feat that he authorized the carriage of airmail from New York to Los Angeles. Given the state of aviation at this time, however, it would be many years before this plan became a reality.

The Air Mail Service

As early as 1912, the U.S. Post Office had requested funding to establish an experimental airmail service. The request, for a congressional appropriation of $50,000 for the establishment of the experimental program, was denied. Nevertheless, the postmaster continued to support the demonstration flights that were taking place at various air meets and renewed the request for funding each year.

In 1916, an appropriation was finally approved. The U.S. Post Office requested bids to operate experimental routes in Alaska and Massachusetts. Because the state of aircraft design at the time was such that there were no aircraft capable of successfully meeting the terms of the contract, there were no bidders.

The U.S. Post Office began negotiations with various aircraft manufacturers to design aircraft capable of meeting the demands of a scheduled airmail service. However, in 1917, the United States entered World War I, and the efforts of the Post Office were curtailed. World War I would have one effect that would later benefit the efforts of the Post Office. In response to the demands of the war, the design and performance of aircraft underwent significant improvement. By war's end, aircraft were available that could meet the demands of the postal service.

On June 30, 1918, the U.S. Post Office finally received an appropriation of $100,000 to initiate an experimental airmail service. The problem now was that the Post Office had no pilots or aircraft. U.S. Army captain Benjamin Lipsner was appointed to run the experiment, and Army pilots were assigned to fly the initial flights. The Post Office ordered six modified Curtiss aircraft to support the effort. On May 15, 1918, the first airmail flight was conducted, connecting Washington, D.C., Philadelphia, and New York. The effort was a success, even though one of the pilots from Washington, D.C., became lost and landed in Maryland, causing the mail to be put on a train for delivery. When, on August 12, 1918, the Post Office officially took over from the Army and began flying the mail with its own pilots and aircraft, the U.S. Air Mail Service was officially launched.

The original mail route between Washington, D.C., and New York was steadily expanded. The intent was to establish a transcontinental route from New York to San Francisco with feeder routes running north and south that connected with the transcontinental route. The original transcontinental route was completed on September 8, 1920. Using a combination of aircraft during the daylight hours and trains at night, airmail arrived twenty-two hours faster than the fastest train then in service. On February 22, 1921, an attempt was made to demonstrate day and night flying along the route. This day-night transcontinental demonstration was successful, and continuous flight was authorized. In addition, Congress appropriated $1,250,000 for the expansion of the service. In conjunction with this effort, portions of the airway were lighted with beacons, emergency airfields were established, and radio stations reported weather. As a result of these developments, the time for transcontinental mail delivery was reduced to twenty-six hours and fourteen minutes for eastbound travel and to twenty-nine hours and thirty-eight minutes westbound. This effort proved to be very popular, and the Post Office ordered fifty-one specially designed Douglas mail planes to replace the World War I surplus airplanes that had been operating since 1918. The arrival of these new aircraft further reduced the time required for transcontinental mail delivery. On July 1, 1924, airmail postage was set at eight cents per ounce, and regular night mail service began.

During the period from 1918 to 1927, when the U.S. Post Office operated the airmail service, the route structure increased from the original 218 miles to more than 2,700 miles. Air Mail Service planes experienced more than two hundred crashes, and more than eighty pilots were killed or injured. Of the original forty pilots hired by the Post Office, thirty-one were killed. Air Mail Service pilots flew more than 13,000,000 miles and carried 301,000,000 letters. They completed more than 93 percent of their scheduled flights. The total government expenditure for the entire period was $17,411,534. Income from the service totaled approximately $3,000,000.

The Air Mail Act of 1925

Even though the U.S. Post Office had demonstrated the feasibility of transcontinental airmail service, the ultimate goal was to turn the system over to private companies. Congress passed the Air Mail Act of 1925, known as the Kelly Act, which authorized the Post Office to solicit competitive bids for various airmail routes, culminating with the award of the transcontinental route to private companies. The first contracted airmail flights began in 1926. The last flight of the U.S. Post Office Air Mail Service took place on August 31, 1927.

The passage of the Kelly Act initiated the era of contract airmail. As the postal routes were turned over to private companies, the award of the contracts was used as a tool to encourage, and in some cases to force, operators to begin carrying passengers, as well as mail. Many modern carriers that continue to operate began as contract airmail carriers. In 1925, the initial five contracts were awarded. The awarding of routes continued, with the transcontinental route being awarded in two parts in 1927. The volume of mail increased substantially in 1928, when the airmail postage rate was lowered to five cents per ounce.

In 1929, Walter Folger Brown was appointed postmaster general under the administration of President Herbert Hoover. Brown had a vision for the air transportation system that would make it the most efficient system in the world. To support his goal, he arranged the passage of the Air Mail Act of 1930, also known as the McNary-Watres Act. This act gave the postmaster virtually total control of the contract airmail bidding process. Brown proceeded to implement a system favoring larger, more well-financed operators at the expense of the smaller operators, forcing a number of airlines to merge in the name of efficiency. He invited only the large operators to attend conferences in Washington, D.C., where contracts were awarded. These conferences became known as the spoils conferences and resulted in a scandal that led to the cancellation of all airmail contracts in 1934. Brown's actions resulted in the large airlines, such as United Air Lines, Trans World Airlines (TWA), American Airlines, Eastern Air Lines, and Northwest Airlines, receiving lucrative contracts at the expense of smaller operators. By July, 1933, twenty-three airmail routes had been established, covering 27,735 miles.

With the election of President Franklin D. Roosevelt in 1932, there were charges of collusion and graft, and the contracts came under investigation. Although no evidence was uncovered indicating illegal activity, Roosevelt canceled all existing airmail contracts and turned the airmail over to the U.S. Army, which began flying the mail on February 19, 1934. The Army was, however, ill-equipped and ill-trained to fly the mail. They were only able to service twelve of the existing routes. Immediately tragedy struck. By the end of the first week, five pilots had been killed, and a total of twelve army pilots would perish. The press blamed the Roosevelt administration for the deaths, and there was a public outcry. By June 1, the airmail contracts had been returned to the civilian operators. However, the controversy was far from over.

The Air Mail Act of 1934

In response to the allegations of corruption, Congress passed the Air Mail Act of 1934, known as the Black-McKellar Act. This act revised the airmail contract awarding process, redefined the eligibility requirements for companies bidding on contracts, and forced airlines holding airmail contracts to be independent of any other companies involved in aviation. It also separated the airlines from the cartels, or parent companies, that furnished the airlines their financial backing and, in so doing, imposed a major burden on the companies that were awarded airmail contracts. The airlines lost large amounts of money because of these restrictions, and they would continue to do so until the Civil Aeronautics Act of 1938 was passed and the United States prepared to enter World War II.

One of the original goals of the contract airmail system had been to subsidize the fledgling airlines while they developed a profitable passenger transport system. While the rates paid to the airlines for the carriage of mail varied over the years, the cost to the U.S. Post Office had been steadily decreasing. The average cost of the contracts in 1929 was $1.10 per mile, which had decreased to $.54 per mile by the time the contracts were canceled in 1934. From 1938 to 1953, the airmail rates were set by the Civil Aeronautics Board (CAB). After 1953, the CAB paid the subsidies directly to the airlines in the form of what was called a fair charge for the services rendered, rather than a fixed amount based on weight.

Beginning in 1953, the U.S. Post Office began shipping first-class mail by air on a space-available basis on regularly scheduled airline flights. This, in effect, meant that some letters were being shipped by airmail while being charged the cheaper ground rate. By the mid-1970's, the Post Office had begun exploring the feasibility of removing the additional airmail charges. After this was done, the airmail officially ended, with all first-class mail being delivered by the fastest means available. Through the utilization of regional as well as major airlines, the bulk of the intercity first-class mail now travels by air in the cargo compartments of most airline flights. The revenue provided by the mail has been reduced to a relatively minor percentage of airlines' total revenues.

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Airplanes

Definition: A means of air transportation that is propelled by an internal combustion, turboprop, or jet engine.

Significance: The invention and use of airplanes defined the twentieth century, during which the world witnessed two world wars and the development of aircraft from propeller-driven airplanes to supersonic jets. Each year, airplanes are used around the world for transportation, commerce, and recreation.

Nature and Use

Airplanes fly with the help of the laws of physics and engineering. They come in all shapes and sizes and serve different purposes. Some aircraft are used for training; others are used for transporting goods and freight. Military aircraft are used in waging warfare. Passenger airliners are used for the daily transportation of travelers.

Although airplanes have different designs and functions, all airplanes share common traits. The fuselage, or body of the aircraft, carries people, cargo, and baggage. Attached to the fuselage are the wings, which provide the lift to carry the aircraft and its payload. To balance the airplane in flight, the tail, or empennage, is very important. The landing gear allows the airplane to operate on the earth's surface. The flight controls are used to maneuver the aircraft in flight. Flaps provide additional lift and drag for takeoffs and landings.

Fuselage

The primary job of the fuselage is to provide space for the flight crew and passengers. The attachment of the wings and other load-bearing structures is also an important function of the fuselage.

Depending on the size and function of the aircraft, the fuselage provides a safe haven for those inside the craft. For large airplanes that fly at high altitudes, these compartments are pressurized and air-conditioned. In smaller general aviation airplanes, the cockpits can be drafty, noisy, and either cold or hot, depending on the time of the year.

In airliners, seats are arranged to allow the greatest number of paying passengers to ride inside the fuselage. In older airliners that have been converted to cargo carriers, the fuselage is a cavernous hold without seats in the cabin.

Wings

Wings are as varied as other parts of the airplane. They come in different shapes and sizes, depending on the aircraft's speed and weight requirements. A slower airplane may have a rectangular wing or a tapered wing. A rectangular wing is one in which the chord line, or cross section, of the wing, remains constant from the root of the wing near the body of the aircraft to the wingtip. A tapered wing is one that becomes narrower toward the tip. High-speed aircraft, such as jet transports, airliners, or fighter aircraft, have swept-wing designs. The purpose of the swept wing is to allow the airplane to fly at higher airspeeds.

The size of an airplane's wing in relation to the airplane's size is important. The larger the airplane, the bigger the wing must be to support it in flight. Many factors determine how the wings work in lifting an airplane.

The first factor is that of the wingspan. This is the distance from one wingtip to the other. Small general aviation airplanes typically have wingspans from 35 to 40 feet. Larger airplanes, such as the Boeing 747, have wingspans that easily exceed 100 feet.

The second factor is that of chord. The wing chord is the distance as measured from the leading edge of the wing, or front, to the trailing edge. In a rectangular wing, the chord is constant and, as such, is a constant-chord wing. On tapered, elliptical, or other odd-shaped wings, the chord is not constant. On these wings, the average chord, or mean aerodynamic chord (MAC), is required in equations dealing with the wing.

One important equation in aircraft wing design involves the load the wing will bear while in flight. Wing loading directly relates to the size, or the wing area, of the airplane wing. The first mathematical step in determining wing loading is to determine the wing area by multiplying the wingspan by the chord, or MAC.

After the wing area has been determined, the wing loading can be determined, using the weight of the airplane. The gross weight, or GW, is the operational weight of the airplane. To determine the wing loading of a particular aircraft, the weight of the airplane is divided by wing area. For the lightest of civilian airplanes, wing loading may reach values as low as 6 pounds per square foot, whereas a tactical jet bomber will have a wing loading of more than 375 pounds per square foot.

As the wing flies through the air, it does so at a particular angle. This angle, measured by the relationship between the relative wind and the chord line of the wing, is directly related to the speed of the aircraft. An airplane flying at high airspeeds will have a small angle of attack, whereas one flying slowly will have a large angle of attack.

The lift equation aptly expresses the relationship between the speed, angle of attack, and weight of the aircraft. An airplane's lift must equal its weight in order for the airplane to remain in flight. Pilots are unable to change either the density of the air or the area of the wing. However, they are in control of the other two variables, the airplane's speed and angle of attack.

Because lift must always equal weight in level flight, if the airplane slows down, the angle of attack must increase. Accordingly, an increase in speed will require a decrease in the angle of attack.

Empennage

The empennage is the tail structure of the aircraft, which includes the vertical stabilizer and rudder, along with the horizontal stabilizers and elevator. These essential components provide stability for the airplane in flight.

The vertical stabilizer stands straight up, like a fin, from the aft portion of the airplane's fuselage. It is important to the stability of the aircraft in that it helps the airplane track a straight path. The larger the vertical fin is in area, the more stable the aircraft is around the vertical axis.

Attached to the trailing edge of the vertical stabilizer is the rudder. By way of the pedals at the pilot's feet, the rudder controls movement about the vertical axis of the airplane.

Acting in concert with the vertical stabilizer are the horizontal stabilizers. Located on each side of the fuselage and near the vertical stabilizer, they provide longitudinal stability to the airplane about the craft's lateral axis. The combination of the horizontal stabilizers and elevators re-

Acting in concert with the vertical stabilizer are the horizontal stabilizers. Located on each side of the fuselage and near the vertical stabilizer, they provide longitudinal stability to the airplane about the craft's lateral axis. The combination of the horizontal stabilizers and elevators resembles the main wing in shape. However, the function of the horizontal stabilizers and elevators is totally different from that of the wing. Whereas the wing lifts up in force, the horizontal stabilizer provides a downward force that provides longitudinal stability to the airplane.

Landing Gear

In order to move around on the earth's surface, all aircraft have landing gear. The most common arrangement of the landing gear is the tricycle landing gear, in which the aircraft has two main wheels that extend from either the wing or the fuselage and a third wheel that extends from the nose of the aircraft. The brakes are located on the main wheels, or mains, whereas the steering is the function of the nose gear. Depending on the size and model of the aircraft, nose-gear steering maneuvers the airplane on the ground. The nose wheel can be freewheeling, with the maneuvering done by differential braking. Aircraft steering can be actuated by rods, cables, or hydraulics systems.

Another arrangement of the landing gear is the conventional landing gear, typically seen on older aircraft. In the conventional arrangement, there are two main wheels in the front of the fuselage, with a smaller tailwheel located on the aft end. Conventional gear was the norm in the early period of aviation, but it fell out of fashion in the 1950's and 1960's, because the tricycle landing gear is inherently more stable.

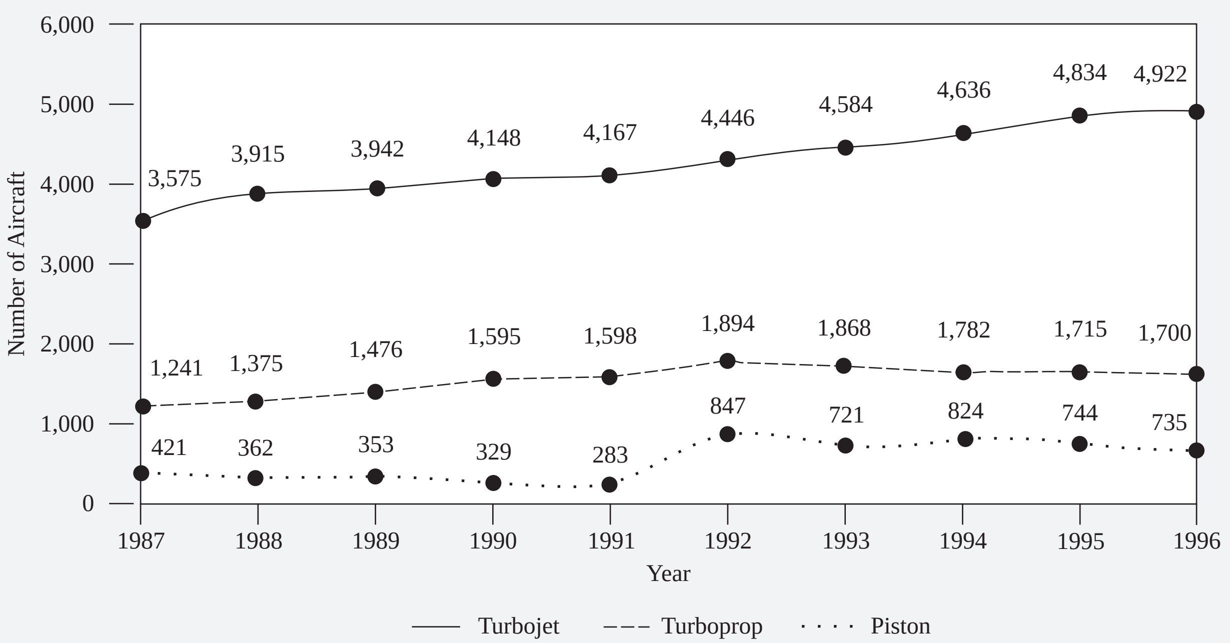
Another type of arrangement, found on the B-52, is the bicycle landing gear, which has two sets of main landing gear centered on the fuselage, one behind the other along the centerline of the fuselage. Because there are no supporting landing gear outside the body of the craft, devices known as outriggers keep the wingtips from striking the ground.

Flight Controls

The flight control system controls the aircraft in flight and comprises the devices that command movement of the aircraft around all three axes: longitudinal, lateral, and vertical.

The elevator controls the airplane's longitudinal movement about its lateral axis. In other words, it causes the airplane's nose to go up or down. In this manner, combined with the power output of the engine, the elevator adjusts

Total Fixed-Wing Aircraft Reported in Operation by Type of Aircraft, 1987-1996



Source: Federal Aviation Administration, *Statistical Handbook of Aviation*, 1996.

opposite aileron spoils the lift on the opposite wing. This starts a rolling movement about the longitudinal axis.

Finally, the rudder controls the airplane about the vertical axis. Actuated by the pedals at the pilot's feet, the trailing edge of the vertical stabilizer moves the airplane's nose either left or right, depending on which pedal is depressed.

Flaps

Airplanes have flaps for both takeoffs and landings. Located on the inboard portion of the wing at the rear, flaps change the shape of the wing in a way that creates both lift and drag. The first half of travel, after takeoff, creates more lift than drag, whereas the last half of travel, before landing, creates more drag without a noticeable increase in lift. With the flaps partially extended for takeoff, the wing will generate more lift at lower airspeeds, allowing for shorter and safer takeoffs. On the other end of the spectrum, an aircraft approaching a landing with full flaps extended is generating more drag. This will allow the pilot to fly a steeper approach, land more slowly, and stop in a shorter distance.

There are four types of flaps: plain flaps, split flaps, slotted flaps, and Fowler flaps. Each has its own characteristics, with the first three found typically on general aviation airplanes. The fourth type, the Fowler flap, is typically found on larger air transports. The Fowler flap system is heavier and more complex than the other three types of flap, necessitating a larger aircraft.

The Power Plant

The internal combustion engine powers many of today's light airplanes. The most popular arrangement of the engine is in the horizontally opposed configuration. The engine is air-cooled and typically arranged in a flat four- or six-cylinder configuration, allowing the best cooling for all of the cylinders.

Unlike the aircraft engines built before World War II, the modern aircraft engine is highly engineered and very reliable. Although modern engines may still fail, the likelihood of complete power loss is minimal.

Most aircraft engines are four-stroke engines, which means each cylinder has an intake stroke, a compression stroke, a power stroke, and, finally, an exhaust stroke. The amount of power the engine puts out depends on the engine's size. Essentially, an engine's power increases with its size.

Aircraft engines come in all sizes, from one of the smallest, the 65-horsepower Continental A-65, to the 350-horsepower TSIO-540. As horsepower requirements reach higher than 350, many aircraft manufacturers opt to equip their high-end models with turboprop engines.

The advantages of a turboprop engine over an internal combustion engine are increased power output, smoother operation, and the ability to operate at higher altitudes. At higher altitudes, a pilot can take advantage of winds that are more favorable and realize better specific fuel consumption. Typical cruise speeds for airplanes equipped with turboprops are in the 230-knot to 350-knot range. For faster cruise speeds, a jet engine is required.

Jet engines are very simple devices. The thrust of a jet engine is determined in pounds of force rather than in horsepower, as are reciprocating engines and turboprop power plants.

The heart of the jet engine is the compressor and turbine. Linked together by a common shaft, the turbine and compressor spin at rates as high as 20,000 revolutions per minute. As the fuel and air mixture burns in the combustion chamber, the exhaust gases escape through the turbine, spinning it at high speeds. The turbine, by way of the common shaft, spins the compressor, ingesting more air into the engine. The potential power available from a jet engine is phenomenal.

More phenomenal than jet engines are future engine possibilities. Presently under development, the Stirling engine may be the most significant innovation for aviation in the near future. The Stirling engine, an external combustion engine originally invented in 1896, is on the verge of becoming the power plant of choice not only for airplanes but also for cars, boats, and many other applications.

Types of Airplanes

There are as many airplanes as there are reasons for their existence. Small, privately owned aircraft such as Cessna, Beechcraft, and Piper aircraft are used for transportation and recreation. Most privately owned airplanes are single-engine, one- or two-seaters that have a range of about 400 miles and a speed of 100 miles per hour. Higher-end privately owned airplanes are turboprops and jets that are rather expensive to acquire and maintain. Powered by two engines, these more complex airplanes require more training and certification for their operation than do smaller craft. The turboprops are capable of 230- to 275-miles-per-hour cruise speeds, whereas some privately owned jet aircraft can reach a speed of 600 miles per hour.

The cost of the privately owned aircraft varies. In 2001, small two-seaters in flying condition could be purchased by bargain hunters for less than $12,000. Such airplanes are rudimentary but capable of flight and cost effective for flight training.

At the same time, the cost of a typical four-seater family airplane began at $25,000 for an older, used craft and could reach as high as $150,000 for a new model. Still more sophisticated models could cost as much as $500,000. The smaller light twin-engine craft cost $50,000 to $75,000, on the low end of the market for used craft. On the high side, a newer aircraft cost as much as $750,000.

In 2001, the cost of turboprop aircraft and small corporate jets started at well over the $1 million mark. Depending on the make and model of the corporate jet, the cost can reach as high as $40 or $50 million. Typically used in commercial endeavors, these aircraft are a strain for one or two individual owners to manage financially.

The airliner, the type of airplane with which most passengers are familiar, flies at high speeds and altitudes. Smaller commuter airliners carry an average of fifty passengers and a crew of five or six, including the two pilots. As the airline industry moves into the twenty-first century, there is a desire to move away from the turboprop aircraft of the 1980's and 1990's, as passengers prefer the smoother, higher, and seemingly safer ride of jet aircraft.

The final category of aircraft is military aircraft. The armed forces use different types of airplanes for different jobs. The task of protecting the nation from intruders falls to fighter planes, jets that can fly at almost twice the speed of sound. Fighters carry one or two crew members, and their mission is to stop any unannounced intruder into national airspace. The military branches also operate airline-type aircraft to move personnel and cargo throughout the world.

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Airport security

Definition: The use of technology and well-trained staff to protect aircraft, aircrews, and passengers from terrorist attacks, to prevent cargo theft, and to solve illegal ticket problems.

Significance: Airport security seeks to protect aircraft, carrier personnel, and passengers from acts of terrorism, prevent cargo theft, and solve ticket-associated problems such as theft and black (or gray) market sale.

Airport security includes the protection of aircraft and the people on board from terrorist attacks, the prevention of cargo theft, and ticket-associated problems such as theft and black (or gray) market sale. The most visible aspect of this security operation is the protection of aircraft from hijackings and bombings perpetrated by the world's international terrorists. In the United States, all airport security activities are overseen by the Federal Aviation Administration (FAA).

In the late 1960's, a series of aircraft hijackings alerted the U.S. government to the need for the active implementation of airport security methods and an enumeration of security requirements for U.S. air carriers. The FAA initiated an anti-hijacking program in late 1970. At that time, President Richard M. Nixon ordered air carriers to use surveillance equipment in all U.S. airports. He also instructed the Departments of Defense and of Transportation to collaborate with air carriers in identifying the utility of metal detectors and X-ray equipment—already used by U.S. armed forces—in prevention of hijackings.

Basics of Passenger Screening

By early 1972, with the utility of tested detection technology deemed probable, the FAA ruled that all air carriers must use an FAA-approved passenger-screen system to check all aircraft passengers through behavior profiles, metal and other detection methods, physical searches, and identification checks. In late 1972, in the face of continued hijackings, the FAA required the screening of all passengers and their carry-on baggage entering commercial aircraft. Hijacking and sabotage of U.S. aircraft also led to treaties between nations and regulations that established the current U.S commercial aviation security system. Air carriers, airports, and the FAA each play specific roles in assuring this security. Especially important to continued and expanded passenger screening development was the 1988 bombing of Pan American Flight 103 over Lockerbie, Scotland. This led to the creation of a Presidential Commission on Airline Security and Terrorism in 1989 and the enactment of the Aviation Security Improvement Act of 1990.

Air carriers, airports, and the FAA participate in the passenger-screen system. The air carriers provide secure travel conditions; maintain security programs; screen passengers, cargo, and carry-on and other baggage; and protect their aircraft. In turn, the airports provide safe aircraft-operating environments, develop and maintain sound security programs, and provide airport law-enforcement personnel. The FAA, for its part, is expected to furnish both the administrative and procedural guidance to identify and analyze threats, establish requirements for the activities of air carriers and airports, coordinate all crisis situations, enforce regulations, and supply any needed technical assistance.

Ensuring the safe commercial air travel, not only of domestic carriers within the United States but also of U.S. and foreign carriers leaving and entering the country, is a huge task. Currently, about two million passengers and all of their luggage are screened daily for metal weapons and other dangerous materials. The anti-hijacking and screening program currently used requires each air carrier to have a passenger-screen system capable of preventing entry of weapons, explosives, and other threat objects into the passenger compartments of its aircraft. Since this effort began in 1972, X-ray and metal-detection systems as well as the selection, training, and testing of security personnel have improved. It could be argued that the mere presence of screening systems increases aircraft security by acting as a deterrent to crime and terrorism.

The FAA continually investigates new means to enhance screening technology that detects metal weapons and other dangers, such as plastic explosives. The ideal passenger screen would quickly detect these threats with high sensitivity and very few false alarms. It would also expose, prior to their boarding aircraft, any passengers carrying weapons or explosive devices that might be used to frighten flight crews into changing the aircraft's destination.

X Ray Origins and Uses

X rays are forms of penetrating electromagnetic radiation with shorter wavelengths and higher energy than visible light. X rays were discovered in 1895 by the German physicist Wilhelm Conrad Röntgen, who was studying cathode rays in a gas-discharge tube. Röntgen noticed that, although the tube was inside a black box, a nearby barium-platinocyanide screen emitted fluorescent light whenever the tube was in operation. He found that the observed fluorescence was due to an invisible radiation, more penetrating than ultraviolet light.

The first X-ray tube was the Crookes tube, a partially evacuated glass bulb holding two electrodes. When electric current is passed through the tube, the gas inside is ionized; the positive ions thus produced strike the cathode, causing ejection of fast-moving electrons. The electrons bombard the glass walls of the Crookes tube and produce low-energy X rays. Improvements culminated with the development of Coolidge tubes, commonly used in a variety of X-ray detectors.

These detectors began with photographic emulsions, which are affected by X rays in the same way they are affected by visible light. A substance's absorption of X rays depends upon its density and atomic weight. The lower a material's atomic weight, the more transparent it is to X rays of given wavelengths. Thus, when a human body is X-rayed, the bones, at a higher atomic weight than flesh, absorb X rays more effectively and cast darker shadows on photographic plates. X rays also cause fluorescence in materials such as barium platinocyanide and zinc sulfide. When a screen coated with such material is substituted for photographic film in a technique known as fluoroscopy, the structures of opaque objects, such as flesh, bones, and tumors, or guns and explosives, may be directly observed.

Such detectors, which vary in their ability to discriminate between screened objects, can be interfaced with computers to produce the X-ray scanners used by hospitals, customs inspectors, and airport security. The danger involved in using X rays to screen living beings arises from radiation's potential to cause cancer. To minimize such health risks, the X-ray scanners used in airports utilize low-energy (soft) X rays and exposures of just a few seconds.

However, the acceptance or rejection of a given screen item by airport operators, air carriers, and passengers and flight crews is just as important as is screen performance. Judgments must be made as to whether a screen harms, injures, or otherwise endangers people; violates Fourth Amendment rights; allows air carriers to screen passengers quickly enough to maintain flight schedules; or makes people believe that their privacy is being invaded or reveals too much personal information. A considerable effort is being exercised to address these problems while introducing items that optimize passenger-screen systems.

Screening Procedures

Carry-on baggage and other luggage is analyzed by X-ray analysis, a process called active screening. This procedure is routinely performed on baggage that is not carried in an aircraft's passenger compartment. In contrast, routine preboarding screens occur in two concurrent phases. First, all passengers place their carry-on baggage onto a conveyor belt for inspection by X-ray equipment. Then, they walk through a portal that detects metal objects. If the portal alarm sounds, the passengers involved are searched more completely to ensure that they are not carrying any threatening object. Alarm-clearing searches use handheld metal detectors and physical pat-downs. However, these procedures do not detect all possible nonmetal weapons, explosives, and other threat objects.

Few airports have routine passenger screens that can operate at the highest possible level of technology for the detection of threatening objects, where imaging shows both the body and objects carried beneath clothing. Even the most advanced systems do not produce images of photograph quality. Screen operators must view and interpret the images, and when they perceive threats, they can, together with airport police, body-search passengers. Sound operator judgment and decision-making ability are crucial to screening success, as inaccuracy can cause the passenger-screen system to fail either by missing threatening objects or by excessive numbers of false alarms.

Even assuming the best screening possible, the imaging of passengers is a complex process. Legitimately, passengers may fear health risks from X rays and also may be unwilling to have others view their bodies. An alternative process, less-often used and more expensive, is called passive screening, which analyzes natural body radiation. Both kinds of body screening produce interpretable images of threat objects, including metal and nonmetal weapons and explosives. It is important that at any screen site, people who object to a procedure, such as one displaying an image of the naked body, should be given the option of another method, such as hand-wand screening. Such options may be costly, but will alleviate legitimate concerns based on nationality, religion, and personal beliefs.

In addition to physical screening, other screening occurs behind the scenes. The FAA integrates data from intelligence agencies, air carriers, and airport surveillance crews to identify immediate threats to given aircraft. Whenever hijackers or terrorist targets are identified, a higher alert level is invoked and screening imposes additional procedures to assure timely terrorist detection and detention. Included are much more stringent baggage inspection, passenger questioning, and identification checks. The routine screen alone is used only where the probability of bombing or hijacking is deemed to be minimal.

A security system must be both effective and suitable. Effectiveness is measured by the ability to detect threat objects and depends upon system technology capability. Suitability is measured by system operation without undesired characteristics, such as excessive radiation. Performance is evaluated continually to provide feedback that will allow both the air carriers and equipment manufacturers to improve the systems. The minimum acceptable performance level is compliance with the standards set by the FAA. Evaluations test the system's ability to detect and react to a terrorist threat or action, often by using federal teams carrying mock threat items into the field.

Passenger Screen Operators

The importance of passenger-screen system personnel and the quality of their performance cannot be overemphasized. These individuals are responsible for accurately determining potential passenger-related danger to aircraft, aircrews, and passengers. The FAA has formulated criteria for their selection, training, and motivation. Many critics frequently assume that poor passenger-screen system performance is due to low wages and that higher wages alone would improve performance levels.

Although it may be argued that wage increases are always useful, other factors are more responsible for imperfect personnel performance. These relate to finding more valid modes of selecting operators, better training methods, monitoring and analyzing effectiveness of passenger-screen systems and personnel, and providing feedback to the individuals involved. Training is increasingly important as screening systems evolve, because personnel performance involves very complex tasks. Accelerated human factors programs are suggested as one overall means to aid personnel choice, training, motivation, and provide data on ergonomics of screening equipment.

Lapses in Security

On September 11, 2001, the importance of airport security became tragically apparent. On that morning, four commercial planes—two 767's out of Boston's Logan Airport and 757's out of Washington's Dulles International Airport and Newark, New Jersey—were hijacked by teams of terrorists armed with box cutters. The hijackers gained access to the cockpits, either killed or incapacitated the flight crews, switched off the transponders, and took over the controls. American Airlines Flight 11 and United Air Lines Flight 175 were each flown into the Twin Towers of the World Trade Center in New York City, causing both buildings to collapse a short time later. American Flight 77 was crashed into the Pentagon in Washington, D.C. The cess to the cockpits, either killed or incapacitated the flight crews, switched off the transponders, and took over the controls. American Airlines Flight 11 and United Air Lines Flight 175 were each flown into the Twin Towers of the World Trade Center in New York City, causing both buildings to collapse a short time later. American Flight 77 was crashed into the Pentagon in Washington, D.C. The fourth hijacked plane, United Flight 93, went down in a field near Pittsburgh, Pennsylvania, when passengers in touch with loved ones by phone realized the nature of their situation and stormed the cockpit. In total, more than three thousand people, from the planes and on the ground, died that day.

Investigations in the aftermath of the tragedy revealed many lapses in the security system at U.S. airports. As a result, an aviation security bill was signed into law on November 19, 2001. Within a year, all screening was to be done by federal employees, U.S. citizens having undergone criminal background checks. After three years, airports meeting federal standards could request that private contractors handle screening, based on the findings of pilot programs at five airports of varying size. Airports were given until the end of 2002 to install explosives detection X-ray systems for checked bags. Until then, all checked bags were to be inspected by X rays, passenger matching, or hand checking. The Computer Assisted Passenger Prescreening System (CAPPS) would be used to screen all passengers, and a database would allow cross-checking with government watchlists. Flight deck doors were to be strengthened and kept locked during flights. Pilots and crew would attend training courses on dealing with hijackers, and the Transportation Department could authorize cockpit weapons. Flight schools were to conduct background checks on foreign nationals seeking instruction in operating large aircraft. The bill created a Transportation Department agency called the Transportation Security Administration to supervise security issues.

There was an immediate expansion of the Federal Air Marshal (FAM) program. FAMs respond to criminal incidents and other in-flight emergencies on board U.S. aircraft. They are authorized to carry firearms and to make arrests in order to preserve the safety of aircraft, crew, and passengers. On September 28, 2001, an FAA amendment raised the maximum age requirement from thirty-seven to forty years of age.

Following the attacks, new regulations were put in force. Travelers were advised to allow extra time to check in, to bring government-issued identification, and to board with only one carry-on bag and one personal bag, such as a purse or briefcase. Curbside checking of luggage was banned, and several airports curtailed traffic to and from the terminals.

Air Cargo Theft

Aircraft have carried freight since airmail began in 1918, but it was not until the late 1950's that other air freight exceeded airmail as a revenue source for air carriers. Large air freighters can carry heavy loads, such as automobiles and cattle. However, the fast transportation of packages weighing under fifty pounds is also an important air carrier revenue source. The speed of aircraft makes them ideal for transporting perishable items such as flowers, fruits, and vegetables and enables manufacturers to get merchandise to destinations quickly, thus raising their profits.

A number of unique security problems are associated with carrying air cargo. Cargo often contains more expensive items than those shipped by other freight-carrying methods; hence, the potential for loss is greater. It is also more difficult to identify where losses occur. In other methods of shipment, items are simply picked up, moved, and delivered to loading docks. Air cargo movement is much more complex: cargo is first moved from freight terminals to flight terminals, then loaded onto freight aircraft before shipping, with opportunities for theft all along the way. When freight is placed on a passenger airplane, risk is increased because it must go to a passenger terminal and is exposed to additional handlers. At many airports, carts travel to and from flights along unlit routes, creating still more opportunities for theft. Moreover, 90 percent of air cargo is shipped at night, the time period when most crime occurs. Pilferage, fraudulent pickups, and theft by drivers also occur, as in other freight-carrying operations.

Air cargo theft problems first surfaced in the 1960's in New York, when racketeers infiltrated the pickup and delivery segment of the air freight industry. Eventually, the U.S. Department of Justice indicted the racketeers and corrupt truckers. These occurrences and some spectacular thefts of valuable items led carriers to establish an Airport Security Council in 1968. However, by 1970 it became clear that terminal facilities and carrier cargo handling were inadequate, losses were not reported systematically, and there was no good way of telling where losses occurred. By 1988, airlines and shippers at New York's John F. Kennedy Airport and in Los Angeles together reported $11 million of freight stolen per year and it became clear that air cargo theft was growing.

The FAA, Department of Transportation, the Treasury Department, the air carriers, and airports have taken combined action, along with legislation, to protect air cargo more effectively. Airport security personnel are trained more efforts must be made before it can be completely eradicated.

Ticket Theft and Fraud

Another aspect of airport security concerns airline tickets. Air carriers need to make a profit on the sale of tickets to survive and to subscribe to other aspects of airport security. The prices for equivalent legitimate airline tickets differ by carrier, depending on travel class, payment date, travel day, duration of stay at the destination, and other factors. Often, people sitting next to each other on a plane have paid very different ticket prices for the same flight. Everyone wants the lowest fare possible, so many passengers buy tickets from gray (black) market vendors. The most risky sources of such tickets are personal newspaper ads, because some offer stolen tickets. Furthermore, some travel agencies sell both legitimate and stolen tickets.

Computers contribute greatly to the validation of tickets. For example, the airlines enter into their reservations systems the numbers of all known stolen tickets. Ticket agents can enter the ticket number into a database to check its legitimacy and receive an immediate response. Tickets are also checked by computer after flight departure. If a stolen ticket is discovered, a phone call to the destination allows airline personnel to meet the flight, interview the passenger, and determine where and how the ticket was obtained. Because stolen tickets are so easy to sell, travel agencies are often burglarized and robbed. This causes danger to agency personnel and an average loss of $1,000 to the air carrier for each stolen ticket.

Another source of stolen or fraudulent tickets arises from frequent flier miles, programs begun in the early 1980's to reward airline brand loyalty with free flights in return for miles traveled on a carrier's aircraft. The programs are quite lucrative for air carriers, but they also attract criminals who see frequent flier ticket certificates (coupons) as a way to make dishonest money. It took some time before air carriers began to realize that frequent flier fraud cost them billions of dollars in decreased revenues. To solve the problem, the programs have been modified so that unused mileage expires after a certain date. Seats used for the program have also been reduced in number, so that passengers need to reserve months ahead of time to use the mileage. Although these measures diminish illegal coupon brokerage, it still occurs. Brokers have established prices they will pay for specific frequent flier distance awards. In some cases, employees of firms that handle frequent flier accounting for air carriers have set up fictitious accounts and sold the resultant certificates to brokers. There have also been several federal prosecutions of travel agents for frequent flier fraud. Efforts to prevent this type of illegal operation are an ongoing part of airport security.

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Airports

Also known as: Aerodromes, airfields, landing strips

Definition: An area of land that provides for the taking off, landing, and surface maneuvering of aircraft.

Significance: Although airports mark the beginning and ending points of aircraft flights, they are more than mere runways or grass areas for takeoffs and landings. Airports are facilities that provide for the maintenance and servicing of aircraft, serve as exchange points for passengers and cargo, and host the various navigational aids used by pilots to guide an aircraft in flight.

Nature and Use

An airport is defined by the type of aircraft it serves and by where it is located. Airports range in size from large commercial air carrier airports, such as Chicago's O'Hare International Airport, with enplanements, or paid boardings, of more than 30 million passengers per year, to small, privately owned grass landing strips in rural areas with landings of only a few small aircraft each year. In the United States, there are about 15,000 airport landing facilities, only 5,000 of which are open to the public. Even fewer, about 3,000, are served by commercial air 3carrier service. The other airports are small, general aviation airports in private or public ownership.

An airport serves as the transition and exchange point for passengers and cargo between air and ground transportation. Therefore, an airport's operations include the buildings and facilities that support the transition and exchange of services. Aircraft and passenger facilities often associated with the landing facilities are maintenance, passenger terminal, cargo, fueling, parking, and hangar-storage facilities.

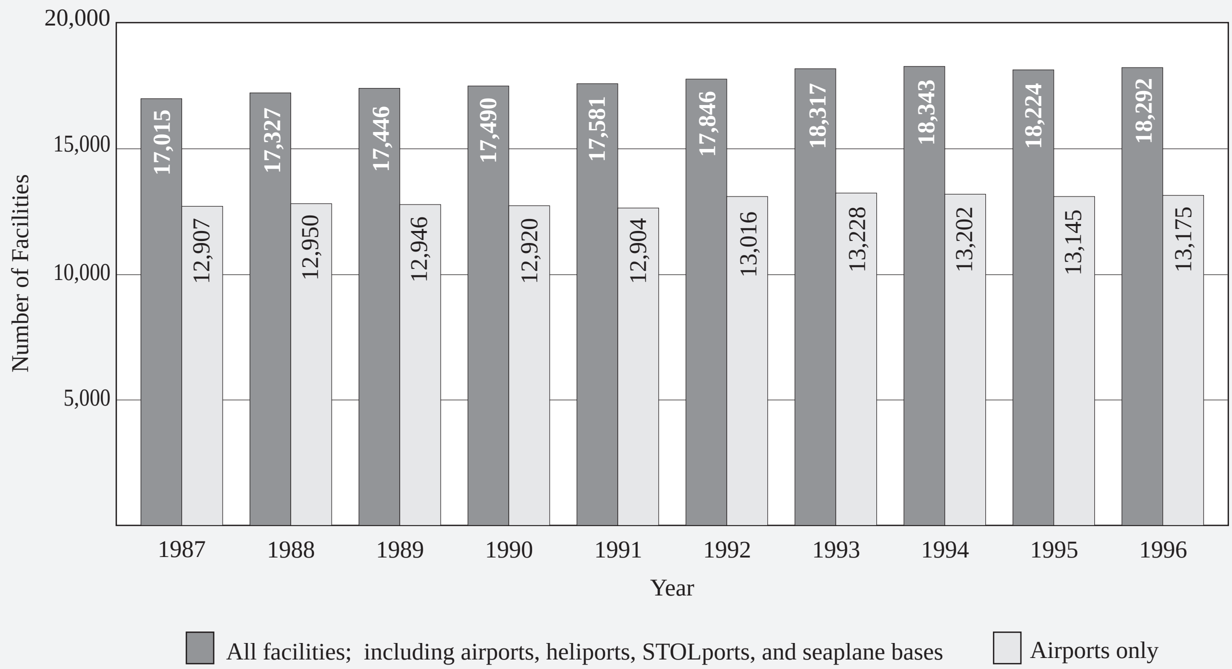
An airport is typically a facility that handles propeller- and jet-driven fixed-wing aircraft. In some countries, the definition for an airport can include landing areas other than on land. Specific areas on rivers and waterways are known as seaports or sealanes. A facility specifically used by helicopters is known as a heliport or helipad. Vertical takeoff and landing (VTOL) aircraft can operate out of special short takeoff and landing (STOL) facilities, heliports, or regular airports. If designed to do so, airports also have the ability to handle helicopters, airships, hot-air balloons, and ultralights.

Types of Airports

Although airports may be classified in a number of different ways, the broadest categories are general aviation and commercial service airports. General aviation airports are those that do not receive regularly scheduled passenger service but rather have a primary purpose of serving the aviation interests and needs of small or outlying communities. General aviation includes such activities as corporate and business transportation, recreational flying, aircraft instruction and rental, aerial application, aerial observation, skydiving activities, and other special uses.

Commercial service airports are those that receive scheduled passenger service. These airports can be further classified into large-hub, medium-hub, small-hub, or nonhub airports. The different classifications reflect the number of enplaned passengers boarding aircraft annually at the airport. A large-hub airport will normally have more than

U.S. Civil and Joint-Use Airports, Heliports, STOLports, and Seaplane Bases, 1987-1996



Source: Federal Aviation Administration, *Statistical Handbook of Aviation,* 1996.

five million enplanements, a medium-hub airport more than one million, a small-hub airport more than one-quarter million, and a nonhub airport fewer than one-quarter million.

The term "hub" has more than one meaning in air transportation. For instance, an air traffic hub refers not to an airport, but to the geographic and demographic characteristics of a community. A large air-traffic-hub airport would be associated with a large city from which many people have access to the air transportation system. A medium air-traffic-hub airport would similarly be associated with a medium-sized city, and so forth.

The term hub is also used to describe an airline route structure. An airline hub operation is one where a large number of an airline's flights converge from distant airports to exchange passengers and then return to those same airports. Because the operation resembles the spokes and the hub of a wheel, it has come to be known as a hub-and-spoke operation. The airports and cities at the end of the spoke served by the main hub airport are commonly known as origination or termination airports, because the majority of those airport's passenger enplanements originate from the local community.

Planning and Design

To ensure that airports are constructed with adequate safety parameters, nations develop their own guidelines in conformance with the International Civil Aviation Organization (ICAO). In the United States, ICAO guidelines are reflected in specific airport design criteria established by the Federal Aviation Administration (FAA). The design criteria are based upon the operational speed and overall size of the aircraft intended to use the airport.

An airport is normally developed according to an airport master plan. A master plan is an overall concept of the long-term development of an airport and serves as a guide for developing the physical facilities of an airport. It takes into account the environmental effects of airport construction and operations, ground-access needs, and economic and financial feasibility. It outlines schedules for the prioritization and phasing of airport improvements. The plan must also conform to the design standards of the federal government. A major product of airport master planning efforts are the airport layout plans and drawings.

Landing Facilities

An airport's landing facilities generally consist of a runway or landing strip along with related taxiways and parking areas. A runway is a graded or paved area suitable for the taking off or landing of aircraft. Although most runways in developed nations serving small to large commercial aircraft are paved, there are still many airports that are either grass or dirt strips. These types of landing strips usually serve small piston- or turbine-engine aircraft in rural or undeveloped areas of a country or in developing nations.

Runways

In the early days of aviation, dirt and grass runways were the norm. They tended to be wide open field areas that allowed pilots to take off and land in whichever direction the wind was blowing. This is because aircraft weighed relatively little and needed only a short distance to take off.

As aircraft and pavement technology developed and the weight of aircraft increased, the need for longer and stronger runway surfaces emerged. The previously open fields were soon developed into graded areas oriented in the direction of the prevailing winds. These graded areas were then paved. If strong winds occasionally blew from a direction different to that of the paved runway, crosswind runways might also be graded and paved.

Aircraft are designed to land into the wind. When winds blow from a different direction than the orientation of the primary runway, some aircraft are unable to handle the side forces of the wind when landing or taking off. A secondary crosswind runway built to accommodate the occasional crosswind is then used instead of the primary runway.

An airport's runway configuration is often based upon one of four basic layouts: single, V-shaped, parallel, and intersecting. The many airports built during World War II were arranged in a triangular pattern to accommodate the various wind directions. They were also built to accommodate aircraft that only needed 5,000 feet of land to take off. The introduction of jet aircraft required runways in excess of 7,000 feet.

Along with jet aircraft and increasing passenger and cargo usage came the demand for larger terminal and service buildings, which had to be built within the old airport fence line. These demands shaped many modern airports, where one or two runways were extended and others were closed down to accommodate building facilities. Additional runways of up to 12,000 feet in length and oriented parallel to the others might be added to accommodate larger and heavier aircraft, such as the Boeing 747.

Parallel runways, preferred in large, newly built airports, allow for the greatest number of aircraft operations. Many airports are constrained in capacity by their runway configuration. The runways cannot handle the demand of the aircraft waiting to use them at any particular time without some delay.

The configuration of runways is primarily determined by the prevailing wind direction and the type and volume of expected aircraft activity. Other considerations also affect the layout, including the availability of airspace around an airport to accommodate safe aircraft approaches, departures, and landing patterns; environmental conditions; weather conditions; topography; and the availability of land.

Any paved runway or landing strip is really two runways in one, because each can be used for landing or takeoff in two different directions. Runways are numbered according to the compass heading of the direction in which they are oriented. The numbers are rounded up or down to the nearest whole number and the last-digit zero is dropped. Taxiways are identified by a letter of the alphabet and spoken using the aeronautical alphabet, such as Taxiway Alpha or Taxiway Bravo.

Landing and takeoff surfaces at an airport fall under two general categories: flexible or rigid. Flexible pavements, such as asphalt, dirt, or grass, tend to compress under an aircraft load, whereas rigid pavement, such as cement or concrete, resists compression. The type of pavement used at an airport is determined by the weight of the aircraft expected to use it, and by other factors, such as the expected useful life, anticipated wear characteristics, cost of construction, and exposure to climatic effects.

Because aircraft are affected by the wind and are subject to human inaccuracies in flight and on the ground, safety areas are established in and around an airport to accommodate the safe passage of aircraft. Safety and protection areas help to ensure that the potential for aircraft collision is minimized. They also help prevent serious damage to an aircraft should it go off a runway or taxiway, by allowing it to come to a safe stop without hitting an obstruction.

Within the vicinity of an airport, construction of buildings or towers may be prohibited or restricted in height. Tree heights are also controlled. This is intended to help ensure the structure does not interfere with aircraft in flight and that adequate margins of safety exist.

Taxiways. Taxiways connect the ends of the runways to the main parking and building areas. They are defined pathways used by aircraft to travel on the surface of the airport from one point to another point. Stub taxiways connect the middle portion of a runway with a primary taxiway or taxi route. Stub taxiways can be set at right angles to the runway or set at other angles, in which case they are known as high-speed turnoff taxiways.

Taxilanes are routes that lead from the main taxiway into a parking or terminal area. The design of taxiways and taxilanes must take into account the wingspan and weight of the expected aircraft, so that collisions do not occur with other aircraft or buildings.

Aprons, Ramps, and Parking Stands. Aircraft parking areas are often called ramps, aprons, parking stands, or tie-downs. The various terms are often interchangeable and depend upon local usage. Technically, a ramp is a transition area from a taxiway to an apron, stand, tie-down area, or hangar. Aprons and parking stands are designed for the parking of aircraft, provide access to airport terminal facilities, and allow for the performance of aircraft services. They also accommodate ground vehicle activity.

A tie-down area designates a parking area for primarily general aviation aircraft. Ropes or chains embedded in the ground or pavement are used to secure the aircraft.

All parking areas are structurally designed to accommodate the parking and maneuvering of aircraft. They accommodate the different kinds of ground services, such as fueling, baggage handling, and deicing, provided to the aircraft. Also considered in the design are such things as provisions for electrical, pneumatic, hydraulic, water and lavatory services, access by emergency vehicles, security restrictions, and protection from jet and propeller blast.

Airfield Marking and Signs

On the airport runways, taxiways, and other areas where aircraft operate, special pavement markings help a pilot navigate properly. Runway markings are painted white, whereas taxiway and parking area markings are painted yellow.

The runway markings differ for the different types of navigational equipment used for landing. The intent behind the different markings is to help increase the visual cues a pilot receives as the weather conditions worsen. Markings on a runway identify whether the runway can be used solely by visual reference or with precision or nonprecision instruments in the aircraft.

The pavement surfaces generally have centerlines painted on them to help guide the pilot. Edge markings may also exist. To prevent pilots from mistakenly entering onto a runway from a taxiway, hold-short or stop lines are painted perpendicularly to the taxiway's centerline. A runway's centerline is dashed, whereas a taxiway's centerline is solid.

To further help guide a pilot to a destination on the airport or to distinguish a critical safety marking, signs to the side of the pavement surface accompany the pavement markings. Most signs are internally lighted for enhanced visibility.

Image Not Available

Airfield Lighting

Runways, taxiways, and parking areas are also identified at night by the color of lights used to outline them. The runway and taxiway lights outline the perimeter of the pavement. A runway will have primarily white lights, although green, amber (yellow), and red lights are found near the ends of a runway to clearly identify for the pilot the runway ends, or thresholds. Taxiway and parking areas are bordered by blue lights. Lights embedded into the pavement, called in-pavement lights, provide an added visual cue to assist a pilot.

Navigational Aids

An airport employs a number of different navigational aids to assist pilots in making successful landings, whether the weather is clear or poor. Some of the navigational aids found on an airport are very high frequency omnirange (VOR), localizer (LOC) and glide slope (GS) transmitters, visual approach slope indicators (VASI), Global Positioning Systems (GPS), wind cones, rotating beacon systems, and approach light systems (ALS).

When instrument meteorological conditions (IMC) require pilots to navigate solely through the use of instruments in the airplane instead of outside visual references, the navigational aids align pilots with the runway and help guide the planes down.

An approach light system assists the pilot in making the transition from the instruments in the cockpit to the runway. Newer technology has advanced such that properly equipped airports and aircraft can land in zero-zero conditions, in which there is no visibility either forward or up or down, and the pilot cannot see the lights or runway markings.

The rotating beacon for a land airport is intended to help a pilot easily identify the general location of an airport. Its alternatingly flashing green and white light helps pilots to locate the airport from among all the other lights found in or near a city. The rotating beacon can also be used to communicate with a pilot who has lost radio contact.

Other Terminal Facilities

Various buildings exist on an airport to serve and accommodate aircraft. The number and type are dependent upon the activity level of the airport, and the kind of aircraft that use it. At a large commercial air carrier airport, the passenger terminal building is the primary structure. The terminal building is designed to serve the needs of the passengers, airlines, and businesses that use it or operate within it. The primary purpose of an airport terminal is to transfer passengers and baggage between surface and air transportation with a minimum of time, confusion, and inconvenience.

The location and design of a terminal is determined by a number of factors, such as the configuration of the runway layout, access to a ground transportation network, future expansion capabilities, design requirements established by the FAA, the surrounding terrain, and environmental impact.

he terminal itself must be able to accommodate the various demands placed upon it by business, international, and leisure travelers and by nonpassengers, such as meeters and greeters, employees, and delivery personnel. All of these people have different needs. International travelers, for instance, are subject to customs, immigration, and security requirements to which local business or leisure travelers are not.

Within a large airport terminal building, there may be all types of businesses, such as car rentals, game rooms, restaurants, and retail stores. Some large airport terminals look like small shopping malls, with stores selling clothing, books, gifts, flowers, and other specialty items.

There are many other buildings situated on an airport. A service center for aircraft is called a fixed-base operator (FBO). An FBO can provide any number of aircraft services, such as fueling, maintenance, avionics, pilot lounges, weather planning, flight training, aircraft and pilot-supply sales, aircraft rental, and sightseeing, charter or air taxi flights.

Also found on airports are hangars and other types of aircraft storage facilities, aviation-related businesses, cargo terminal buildings, fuel storage tanks, airfield maintenance buildings, airport administrative offices, and manufacturing facilities. Many large airports actually resemble small cities, with their own electric power generating plants, wastewater treatment facilities, roadway system, parking facilities, and police and fire rescue buildings.

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Alitalia

Also known as: Alitalia Linee Aeree Italiane S.p.A.

Definition: Italy’s national airline, one of the leading European airlines since the 1940’s.

Significance: Alitalia is the fifth-largest airline in Europe, with service across Europe, North America, Africa, Australia, the Middle East, and Asia.

History

Alitalia was started on May 5, 1947, transporting passengers and cargo from Turin, Italy, to Rome. In 1957, Alitalia merged with Linee Aeree Italiane (LAI), creating Italy’s national airline. In 1960, Alitalia had the honor of being the official carrier for the Rome Olympic Games. The airline expanded its service in 1970 with the addition of an Italy-to-North America route, eventually expanding to include airports in New York, Miami, Boston, Chicago, Los Angeles, San Francisco, and Toronto.

With the opening of the Malpensa International Airport in Milan in 1998, Alitalia increased its service to include passenger flights between Milan and Rome’s Leonardo da Vinci International Airport. As one of Italy’s largest airlines, Alitalia operates in 133 cities in 63 countries across Europe, Africa, Australia, the Middle East, and Asia. It offers three classes, Magnifica, PrimaBusiness, and Economy. Alitalia participates in frequent flier programs with Continental and US Airways. The Italian government owns 53 percent of the airline.

Financial Trouble

In 1997, the European Union authorized three installments of aid by Italian authorities when Alitalia developed financial difficulty. In May, 1999, Alitalia made plans to join the Northwest/KLM Transatlantic Joint Venture. The three signed a commercial cooperation and integration agreement and an alliance coordination agreement.

At the same time, Italy was in the process of building a new airport in Milan: Malpensa International Airport. The new facility was intended for use as an important hub for Northern Italy. The European Commission recommended that Alitalia move from its current site at Linate International Airport to Malpensa. According to a study done by Solomon Smith Barney, the move was critical to Alitalia's operation in order for it to increase its share of the Northern Italian traffic to at least 50 percent.

Several European carriers protested this move, claiming that it would give Alitalia an unfair competitive advantage over the other airlines, as well as creating air traffic control problems. The Italian government temporarily delayed Alitalia's move. Because of these delays, KLM called off the merger in May, 2000. In August, 2000, Alitalia filed suit for compensation for breach of contract.

To further complicate matters, Alitalia was subjected to two strikes. The first was in October, 2000, by flight attendants and ground workers as part of an ongoing pay dispute. The airline was forced to cancel over two hundred flights between Milan and Rome. In March, 2001, the flight attendants and air traffic controllers threatened to strike.

In an attempt to recoup its losses and renew its reputation after the merger disaster with KLM, Alitalia investigated alliances with Sky France and Swissair. Code-share agreements were formed with other airlines, such as Qantas, Japan Airlines, and Malaysian Airlines.

Safety Record

Since 1960, Alitalia has experienced nine crashes. The worst crash was on May 5, 1972, when an aircraft crashed upon approach in Sicily, Italy. All 115 persons aboard were killed. The most recent crash was on December 17, 1991, in Warsaw, Poland. There were no fatalities in this incident. Since its beginning in 1947, there have been 425 fatalities on Alitalia flights.

Other Interests

Alitalia is the parent company of Alitalia Group, which is made up of twelve companies involved in air travel and related operations. The airline has a long-standing tradition of sponsorship and support of the arts. Displays of contemporary art can be seen in Alitalia airport lounges in Rome, Milan, and New York. Alitalia also supports the promotion of Italian traditions, and contributed to the restoration of the Upper Basilica of St. Francis in Assissi in 1998 and 1999.

Ulisse 2000 and *Arrivederci* are publications produced by Alitalia for its passengers. *Ulisse 2000* is published monthly for passengers on international and intercontinental flights and offers articles on fashion, celebrities, science, nature, people and places. *Arrivederci* is also published monthly for passengers on domestic flights and focuses each month on a particular region or town.

Alitalia's business school provides training for its managers. There is also a program for individuals who are reluctant to fly. In an effort to provide continuous improvement and customer satisfaction, Alitalia signed a training service agreement with CAE, Inc. Effective from 2001 to 2011, Alitalia will be able to utilize training devices installed at Flumicino Airport in Rome. The ultimate goal of this training center is to increase penetration into the commercial flight training market. The airline also signed a deal with Sextant In-Flight Systems for video-on-demand systems in five of its 747-400's. In addition, Alitalia signed an agreement with Mercury Air Cargo to provide cargo handling through Los Angeles International Airport.

Events in Alitalia History

1947: Alitalia makes its first flight, from Turin to Rome.

1948: Alitalia makes its first intercontinental flight, flying a thirty-six hour, Milan-to-Rome-to-Dakar-to Natal-to-Rio de Janeiro-to-São Paulo-Buenos Aires route.

1950: The airline begins employing stewardesses, who are dressed in designer uniforms.

1951: The airline begins offering hot meals on its flights.

1957: Alitalia merges with Linee Aeree Italiane (LAI) to form a national Italian airline.

1960: The airline begins jet aircraft flights, with the Caravelle and the Douglas DC-8/43.

1967: Alitalia introduces Arco, a new electronic booking system.

1969: The airline retires its last remaining turboprop aircraft, becoming the first European airline with an all-jet fleet.

1970: Alitalia employs its first B-747 jumbo jet on flights to North America.

1972: An Alitalia DC-8 crashes into a mountain near Palermo, Sicily, killing 115.

1984: The airline employs its first MD-80's for use on medium-length flights.

1998: Alitalia enters into an alliance with KLM Royal Dutch Airlines to expand its service; the alliance is terminated in 2000.

In April, 2000, Alitalia signed a deal with McDonald's in which the airlines sold advertising space on one of its aircraft. Since then, Alitalia has signed similar deals with chocolate maker Perugina, luxury goods brand Bulgari, and auto maker Renault. Alitalia's logo has even been adjusted to fit into the color scheme of the ad. The ads were priced at approximately $460,000 per plane for one year.

Other interests of Alitalia Group include airline travel services, automated ticketing services, air fire-fighting services and repair, maintenance, and overhaul operations.

Maryanne Barsotti

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Altitude

Definition: A measured or calibrated height above the ground or above sea level.

Significance: Pilots use indicated altitude to maintain height separation from other aircraft and from ground obstructions. However, the actual, or true, altitude is usually not the same as the indicated altitude.

Indicated Altitude

The standard aircraft altimeter is an aneroid (without liquid) barometer that measures the ambient or static air pressure outside the airplane. It is calibrated through the use of a Standard Atmosphere model so that it presents this pressure to the pilot as an altitude. Because the air pressure on the ground varies a great deal with the movement of air masses across the country, an offset can be introduced by the pilot to make the indicated altitude equal to the actual altitude of an airport before takeoff and while approaching to land. The offset, if any, is indicated by the reading in a window, known as the Kollsman window, on the face of the altimeter.

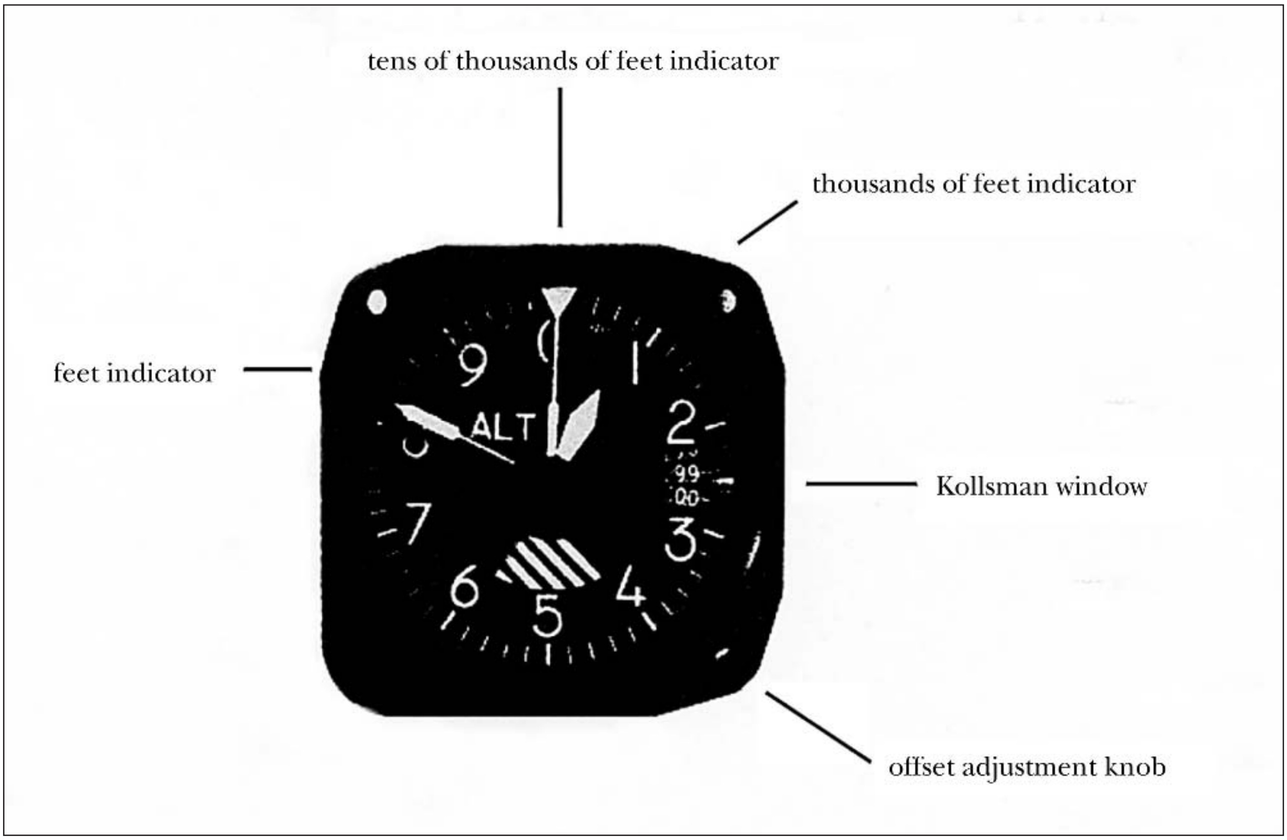
The Standard Atmosphere

The Standard Atmosphere model is based on an arbitrarily chosen, midlatitude, average value for the pressure, temperature, humidity, and density of the air at sea level. It assumes a sea-level pressure of 29.92 inches (76.00 centimeters) of mercury, a sea-level temperature of 59 degrees Fahrenheit (15 degrees Celsius), 0 percent humidity, and an air density calculated from the ideal gas law. It further assumes that the temperature decreases linearly with an increase in altitude at the rate of 3.566 degrees Fahrenheit for every 1,000 feet for the first 36,000 feet, the troposphere, and then is constant, the stratosphere. These assumptions, along with the gravitational and thermodynamic laws, yield the Standard Atmosphere, uniquely defining the "standard" air pressure, density, and temperature at every altitude.

It should be noted that pressures expressed as a height of mercury are not using true pressure units but are reflecting a common way to measure pressures. An accurate mercury thermometer can be made by bending a 6-foot-long glass tube into the shape of an upright "U," filling it half-full of mercury, and attaching a vacuum pump to one end. Atmospheric pressure at the other end then pushes the mercury down, and the difference in mercury heights is a direct measure of the atmospheric pressure. Pressure expressed in inches of mercury can be converted to pressure expressed in units of pounds per square inch (psi) by multiplying by 70.73.

Pressure Altitude

Because the altimeter is calibrated in feet of altitude, or in kilometers in Europe and elsewhere, but is really measuring only atmospheric pressure, the actual air pressure can be obtained by consulting tables of the Standard Atmosphere. This is important because the performance of engines and airplanes depends directly on the air density, and the only way to determine air density is to calculate it from the measured air pressure and temperature, using the ideal gas law. Pilots adjust their altimeters so that 29.92 appears in the Kollsman window—that is, with no offset from the Standard Atmosphere—and the indicated altitude is then called the pressure altitude.



An altimeter measures an aircraft's altitude in feet, thousands of feet, and tens of thousands of feet.

Whenever a pilot is flying above an indicated altitude of 18,000 feet, the altimeter must be set to 29.92 (no offset) to simplify vertical separation of aircraft. All aircraft flying in busy airspace are also required to use transponders that report both position and pressure altitude to air traffic control.

Density Altitude

When the pressure altitude is combined with the outside air temperature through the ideal gas law, the density of the air can be calculated. It is most convenient to express this air density in terms of the altitude in the Standard Atmosphere, which is defined to have this density. This calculation is called the density altitude. The performance of airplanes, in terms of the available engine thrust or power, takeoff distance, climb rate, cruise speeds, and landing distances, depends directly on density altitude, or air density, and is specified as such in aircraft flight manuals. It is very helpful for a pilot to realize intuitively that low pressures (especially due to high elevations) and high temperatures result in very low air density (high-density altitudes) and that in high-density altitudes, aircraft performance will be greatly reduced from sea-level values.

Density altitude is easily calculated from the pressure altitude and the temperature using either an E6-B circular slide rule or an electronic calculator. The current density altitude is also broadcast at many high-altitude airports.

True Altitude

When approaching to land, it is important to enter the appropriate offset, or altimeter setting, into the altimeter, so that it will both give guidance regarding obstacle clearance on the approach and read field elevation after landing. However, usually the variation of pressure with altitude above the airport will not follow the Standard Atmosphere model, and the indicated altitudes of obstructions will still not exactly equal their true altitudes.

Air pressure varies more rapidly with altitude if the air is colder than that assumed by the Standard Atmosphere. Therefore, if a pilot flies into air that is colder than standard, or if the altimeter has not been adjusted en route while flying toward a region of lower pressures, the airplane's true altitude is lower than the indicated altitude, and safety may be compromised, especially in mountainous terrain. Unstable weather conditions and high winds around mountain ranges can also produce locally lower air pressures that result in erroneously high indicated altitudes.

Other Altitude-measuring Instruments

The radar altimeter measures an aircraft's height above the ground by measuring the time it takes a radio wave to return, using the known speed of light. Transport and other complex aircraft find the radar altimeter to be a valuable aid in avoiding obstructions during the landing approach.

Altitude can also be derived by geometry from three or more satellites in the Global Positioning System (GPS) used for navigation. This may become the preferred altimeter for high-altitude, oceanic flight.

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American Airlines

Definition: A large U.S. air carrier of passengers and cargo based in Dallas-Fort Worth, Texas.

Significance: American Airlines is considered to be the largest airline in the world based on total revenue generated in a given year.

Early Years

It is not surprising that an airline with a history going back to the airmail days of Charles A. Lindbergh would become the largest airline in the world. The ride has not always been a smooth one. Like the industry itself, American Airlines has had its ups and downs. Along the way, American Airlines and the people who ran it have helped to change the face of aviation, introducing many of the ideas and innovations that have shaped the way the airline industry does business.

On April 15, 1926, Charles A. Lindbergh, chief pilot for the Robertson Aircraft Corporation of Missouri, flew an airplane containing a bag of mail from Chicago, Illinois, to St. Louis, Missouri. Later that day, he and two other pilots flew three aircraft full of mail from St. Louis back to Chicago. Robertson Aircraft Corporation became the second company to receive a contract to fly U.S. mail and was one of nearly eighty companies that were eventually consolidated to form American Airlines. Lindbergh went on to make aviation history in May, 1927, with the first solo flight across the Atlantic.

In 1929, the Aviation Corporation was formed to begin acquiring newly developing aviation companies in the United States, including Robertson Aircraft Corporation. The airline subsidiary of the Aviation Corporation was called American Airways. The name was changed in 1934 to American Airlines, and Cyrus Rowlett Smith, more commonly known as C. R. Smith, was named president of the company. Smith was largely responsible for molding the dozens of small, poorly financed airlines purchased by the Aviation Corporation into a dominant U.S. carrier. He also became one of the leaders of the aviation industry itself and helped to develop executives who would later manage many other U.S. airlines.

Smith continued as the chief executive of American Airlines until 1968, when he was named secretary of commerce by President Lyndon B. Johnson. Under Smith's leadership, in 1932 American Airlines became the first airline to introduce a coupon program targeted at business travelers. The coupon books were sold to businesses and could be redeemed for discounted ticket purchase. In 1936, American became the first airline to fly the new Douglas DC-3. The introduction of "Admirals Clubs" VIP lounges in airports was another American first, aimed at attracting the frequent-traveling business passenger. By 1940, American Airlines had become the leading domestic air carrier in terms of revenue passenger miles.

Like many of the other large U.S. carriers, American Airlines helped the war effort during World War II by using its fleet to transport men and supplies for the Air Transport Command. Nearly half of American's fleet was eventually placed into action, along with their crews. C. R. Smith also left the airline temporarily to serve during the war. However, the company did not neglect its domestic operation. In 1942, the company established Sky Chefs, an airline catering subsidiary that remains one of the largest airline caterers in the world. It also introduced the first scheduled cargo services in 1944.

After the war, American established another first in 1949 by becoming the only airline in the United States with an entire fleet of pressurized passenger aircraft. These aircraft allowed American Airlines pilots to fly at higher altitudes, improving gas mileage and avoiding inclement weather. In 1952, American introduced the Magnetronic Reservisor to keep track of seats available on its flights. Before introducing the Reservisor, the airline had kept track of available seats through a large display board posted in each reservation office. As passenger volume expanded, this system was simply unable to keep up with demand. The Reservisor used a matrix of relays in which shorting plugs could be manually inserted to indicate a sellout. Agents worked at electrical keypads into which they keyed their requests for seating. If a light began blinking, the request was accepted. This system, designed by Teleregister Corporation, marked the first time any airline had attempted to use an electronic device to handle reservations. The Reservisor was replaced in 1960 by a new electronic system called the Semi-Automated Business Research Environment (SABRE). The SABRE system was developed in conjunction with IBM and ran off two IBM mainframe computers. The system, which cost almost $40 million, was capable of processing 84,000 telephone calls per day. By 1964, the SABRE network extended from coast to coast. Meanwhile, American Airlines introduced the first nonstop, transcontinental service in 1957 and became the first U.S. airline to fly the Lockheed Electra, a U.S.-designed turboprop aircraft, and the Convair 990, a fanjet-powered airplane.

End of an Era

With the retirement of C. R. Smith, George Spater assumed the leadership of American Airlines. Spater, a lawyer and the former general counsel of American Airlines, did not prove to be equal to the challenge of running the airline. The years between 1968 and 1973, when Spater was replaced, are considered one of the low points in American's history. The airline's profits began declining in 1968 and it posted a loss of $48 million in 1973, one of its worst years ever. Part of the problem was that American began receiving the first of its newly ordered Boeing 747's, the largest passenger plane built, at a time when air traffic volume began a sharp decline. For the airline industry as a whole, there were too many seats and not enough passengers. Although the Boeing 747 was ideal for long-haul international flights, it did not suit the shorter domestic routes of American. A second major problem was the oil crisis of the early 1970's, which sent jet fuel prices soaring. To add to American's troubles, several of its executives were charged with taking kickbacks from American suppliers. A final blow came when Spater himself resigned in 1973 after admitting that he had authorized an illegal contribution to the 1972 Committee to Re-Elect the President, Richard M. Nixon.

In February, 1974, Albert V. Casey, a former executive of the Times Mirror Company, was elected president and chief executive officer after receiving the endorsement of C. R. Smith, who had temporarily agreed to run the airline after Spater's resignation. Although Casey had no airline experience, he proved to be an excellent judge of managerial talent and a man willing to make hard choices. Casey went on to sell all of American's Boeing 747's and the Americana chain of hotels owned by the company. These actions, combined with the flight schedule reduction precipitated by the Arab oil embargo of 1973 and the fare increases authorized by the Civil Aeronautics Board, allowed American to post a $20.4 million profit in Casey's first year. However, to keep American profitable, Casey needed a long-term strategic vision for the company. One of the people who helped him shape that vision was Robert L. Crandall. Bob Crandall had left Trans World Airlines (TWA) after being passed over for the job of chief financial officer. Crandall had initially worked in American's finance department but was transferred to marketing, where he moved quickly to revive the SABRE system, which had suffered from underinvestment during the Spater years. American began marketing the SABRE system to travel agents in 1975. By 1976, the system had been installed in 130 locations, including most of the top travel agencies. In 1977, American became the first airline to offer a restricted discount fare, the Super Saver. Other airlines soon adopted this new type of fare, which offered substantial savings to passengers willing to book early and stay over for a specified period of time before returning.

Following the deregulation of the airline industry in 1978, American Airlines began a major expansion of its route structure throughout the United States and the Caribbean. It began to retire its older, less fuel-efficient aircraft. The company headquarters were moved to Dallas-Fort Worth, which became one of American's hubs in 1981. Meanwhile, in 1980 Robert Crandall was elected president and chief operating officer of the company. Crandall then became the chairman and chief executive officer in 1984 on the retirement of Al Casey.

Events in American Airlines History

1930: The Aviation Corporation, a holding company acquiring small aviation companies, is incorporated into American Airways.
1934: American Airways is renamed American Airlines.
1936: American Airlines becomes the first in the nation to fly the Douglas DC-3 for passenger service.
1940: American becomes the first in the nation in revenue passenger miles flown.
1942: Sky Chefs, an American Airlines subsidiary, begins airline catering operations.
1944: American introduces regularly scheduled freight service, the first in the United States.
1949: American becomes the first airline with a fleet consisting entirely of postwar pressurized aircraft.
1959: American becomes the first airline to offer transcontinental jet service, with the Boeing 747.
1960's: With IBM, American develops the Semi-Automated Business Research Environment (SABRE), a real-time data processing system that allows agents to track flight reservations.
1974: American introduces one-stop automated check-in service.
1977: American introduces its popular Super Saver fare on routes from New York and California.
1979: The airline moves its headquarters from New York City to Dallas/Fort Worth, Texas.
1981: American introduces its revolutionary AAAdvantage frequent-flyer award program and establishes its first hub at Dallas/Fort Worth, strengthening its hub-and-spoke network throughout the 1980's.
1984: American introduces its regional American Eagle network and retires its freight fleet.
1994: American institutes nonsmoking transatlantic service.
1999: American joins the oneworld Alliance, a global network of airlines, to greatly expand customer service.
2001: American acquires TWA.
2001: On September 11, in one of the worst acts of terrorism in world history, two American Airlines jetliners are hijacked; one is flown into the World Trade Center in New York City and one into the Pentagon in Washington, D.C. Thousands are killed. On November 12, in an unrelated incident, yet another American Airlines jet crashes, within moments of takeoff from New York's JFK Airport.

The Crandall Years

Under Crandall, a new structure was created for the airline. A holding company, AMR Corporation, was created in 1982 and became the parent of American Airlines. A second subsidiary, AMR Services, was formed in 1983 to provide aviation services to other airlines. The AMR Consulting Group was created in 1992. This group was joined in 1993 by the SABRE Technology Group, which become its own separate company in 2000.

Crandall and American were busy on other fronts as well, creating the American Eagle network and a host of new fares, including the Ultimate Super Saver and the Senior SAAVers Club. The American Eagle network of regional carriers linked small-to-medium-sized cities with the American network, while the new fares appealed to an ever-wider customer base. The American Airlines network of routes was also increasing. By 1994, American Airlines had more flights to London than any other U.S. carrier. Unfortunately, this fact worked against the airline when it announced its plan to form an alliance with British Airways. Crandall, who had once opposed alliances, had decided to bow to the inevitable. If other carriers were going to form alliances, then American would as well. In fact, American would do it better. In 1994, American Airlines reported having eight alliances in *Airline Business* magazine's first yearly alliance survey. Five years later, this number had grown to twenty-eight alliances. American sought antitrust immunity in the United States, which would have allowed American and British Airways to cooperate more closely, particularly in the area of harmonizing price. The fact that the two carriers would control the majority of the transatlantic traffic and the landing slots at London Heathrow caused both the U.S. government and the European Commission to reject the immunity. The carriers have continued in a more limited alliance, called oneworld Alliance, which also includes Japan Airlines and Cathay Pacific.

When Crandall retired in 1998, he left his successor, Donald J. Carty, a much stronger company that he himself had inherited. Carty had joined the company in 1978 to help resolve financial problems with the Americana hotels. After taking over, Carty expanded the American network through two acquisitions. The first occurred in 1998, when Reno Air, a regional carrier based in Reno, Nevada, was added to the American family. Reno Air brought to American an excellent network in the western states, particularly California. It also brought a brief strike from American Airlines pilots concerned with the pay differences between Reno Air and American pilots, as well as the merging of pilot seniority lists. In 2001, American purchased TWA's assets, which included TWA's 180 jets, its St. Louis hub, and its twenty thousand employees.

By 2001, the airline that began as a collection of small, underfunded air carriers in the 1930's was serving over fifty countries with more than 4,100 flights per day. The SABRE system it created had gone on to become a very successful company in its own right, breaking new ground when it introduced Travelocity.com, the first World Wide Web site to offer travel reservations over the Internet. The airline was tested, however, by the terrorist attacks of September 11, 2001, in which two of the hijacked planes were from American's fleet. Like all airlines, American was hurt financially but helped by the emergency aid package signed by President George W. Bush that month.

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Animal flight

Definition: Sustained and powered airborne travel by birds, insects, or mammals through the use of wings.

Significance: Animal flight, particularly that of birds, is important to humans, who first learned and dreamt of flight by studying flying animals. The study of animal flight remains a source of information for understanding and design of flying vehicles.

History

Animals have been flying for millions of years. The first flying animals were insects, which appeared approximately 350 million years ago. From that time, flight evolved separately among three other kinds of animals. There are four types of animals capable of flight: insects, birds, bats, and pterosaurs, the last of which are extinct. Each of these groups developed the ability to fly independently, and, in many cases, different species in each group separately evolved the ability to fly. Additionally, some mammals and birds developed the ability to glide but not to fly.

Unlike aircraft, which gain lift with wings that are either fixed or rotating, animals almost universally accomplish flight by flapping their wings. The flapping motion provides not only lift but also thrust and is referred to as ornithoptic propulsion. Both animals and manufactured aircraft using this method of achieving flight are commonly called ornithopters.

Basis of Animal Flight

The same aerodynamic laws that apply to man-made aircraft also apply to animals, and animal flight is divided into three categories, based on how it is attained. Gliding animals do not fly but trade potential energy (height) for kinetic energy (speed) to remain aloft. Gliding is only useful for small distances. Flying animals use their wings to generate both lift and thrust to remain in the air. Soaring animals, a cross between gliders and fliers, usually use wing movement only for takeoffs and landings, generally relying on subtle changes in wing geometry, thermals, and prevailing winds to gain altitude. Many large birds soar rather than fly. For an animal to remain in level and steady flight, the lift that it generates with its wings must be equal to its weight, whereas the thrust it creates must be equal to its aerodynamic drag. All flying animals generate both lift and thrust by the same method: flapping their wings.

In flapping, or ornithoptic, flight, the wing must produce lift and thrust at the same time. However, lift and thrust does not have to be produced constantly. During a single wing beat, lift and thrust vary. As long as the average lift and drag over the period of the wing motion are equal to the drag and weight, respectively, this will keep the animal in level and steady flight over time.

Aerodynamics

The primary difference in the aerodynamics of aircraft and animal flight is the slower speed and smaller size of flying animals, compared to that of manufactured aircraft. This difference is characterized by a parameter called the Reynolds number, which measures the effect of aerodynamic inertial forces compared to aerodynamic viscous, or frictional, forces. The lower the Reynolds number is, the more important the effects of fluid viscosity, or friction, become. The Reynolds value of most aircraft, whether general aviation craft, commercial airliners, or fighters, is in the millions. For birds and insects, however, the

Reynolds value is usually 100,000 or less and is sometimes even less than 1,000 for very small insects. For flying obects with a Reynolds value greater than 100,000, thick, curved, or cambered, airfoils work best, whereas those with Reynolds values of less than 100,000 tend to work best with thinner, flatter airfoils.

This difference is demonstrated by examining the value of the lift-to-drag ratio as a function of Reynolds number for a number of given airfoils. Most fat airfoils have a higher lift-to-drag ratio at high Reynolds numbers, whereas thin airfoils have a higher lift-to-drag ratio at low Reynolds numbers. This fact was originally discovered during World War I by the Germans, who determined that fat wings worked better on their faster biplane fighters. Likewise, as an animal's speed and size increases, the shape of its wings changes to reflect the increase in Reynolds number. Thus, large or fast birds, such as pigeons and falcons, have wing cross sections that look surprisingly similar to those of modern aircraft wings.

Another important aspect of speed or Reynolds number is how the roughness of a wing affects flight efficiency. The faster an object flies, the smoother the wing needs to be for maximum lift and minimum drag. At low Reynolds numbers, however, the lift dramatically drops for smooth wings, whereas it does not for rough wings. Thus, smooth manufactured wings do not operate as efficiently as rough wings, whether the animal wings are roughened by feathers, scales, or fur. Rough animal wings are most efficient for low speeds. The motion of the feathers and fur allows animals to sense when their wings are about to stall.

Whereas avian biomechanics are complex, insect biomechanics are relatively simple and easy to analyze. This simplicity lends itself well to duplication using modern mechanical technology. In the simplest of insect wings, wing motion is controlled by contraction of interior muscles. The motion in this case is indirect; other insect systems have a direct relationship between muscle movement and wing motion. Without examining complex muscle mechanics, however, one can quickly determine the limit to a flying animal's size by examining the weight in relation to the size.

Scaling determines whether ornithoptic propulsion is efficient for a given weight and length scale. The length scale is a measure of an animal's size, in either length or wingspan. A flier's weight is proportional to the length scale cubed, whereas the wing area is proportional to length scale squared. This is known as the cube-square law. Thus, one can deduce that the wing loading (weight divided by wing area) is proportional to the length scale. As size increases, the wing loading must also increase. Eventually, the wing loading will be too great for the bones and muscles of an animal to withstand, and any animal above this size will be unable to fly.

The required power or energy input for a given weight can be determined from commonly known aerodynamic relations and can be shown to increase as the 7/2 power of the length scale. Thus, if the wingspan of an animal doubles, the power required to fly must increase by more than ten times. Based on muscle-mass arguments stating that the amount of energy available is related to the amount of muscle mass, the power available to flying animals can be shown to quadruple as the wingspan doubles. Thus, as the size of a flying animal increases, required power will soon overtake available power, not only limiting the animal's maximum possible weight but also decreasing the animal's ability to take off, climb, and hover. Hence, larger flying animals tend to use soaring as the primary flight mode instead of powered flapping.

The ratio of unsteady lift, derived from flapping, compared to steady lift, derived from forward motion, shows that flapping frequency can be directly related to the size and weight of a flying animal. Using the flapping frequency as an approximate measure of this ratio and comparing it with the flier's length scale, it is shown that the frequency is inversely proportional to this length scale, which can also be related to the Reynolds number. Thus, as the Reynolds number increases, or as the speed or size of a flier increases, the frequency at which the wings flap decreases. Eventually, the flapping frequency will decrease to the point where the wings will be stationary, indicating that there is a limit to the efficiency of flapping as a flight mechanism, as size increases. On the contrary, as weight decreases, there is a limit below which flapping is a very efficient flight mode. This principle has direct applications to the development of manufactured microaerial vehicles: Instead of shrinking down conventional aircraft designs to a smaller scale, it may be more practical to design miniature aircraft that use flapping wings instead of fixed wings for lift generation and engine-propeller combinations for thrust generation. The efficiency of flapping flight for small birds may also be one reason why wings evolved over propellers for thrust generation. As the size of a flying animal decreases, the generation of unsteady lift becomes more important to its flight. This is especially true for insects that derive much of their lift from unsteady effects alone.

Bird Flight

Birds are by far the best-known animal fliers. There are more than 9,000 species of birds, of which only a handful, such as the penguin, kiwi, ostrich, and emu, are flightless.

Birds are characterized as warm-blooded, egg-laying vertebrates with feathered wings and strong hollow bones, many of which are fused together to increase strength and decrease weight. They have powerful muscles that allow for flight and require large amounts of food for energy. Birds evolved from dinosaurs approximately 150 million years ago.

Most birds appear to have evolved flight from ground-up gliding, used both to catch prey and to evade predators. Wings may also have developed as an aid to increase leaping distances and as a display to attract mates. Two scenarios for the evolution of flight include the ground-up scenario, in which running and leaping animals evolved wings, and the tree-down scenario, in which tree-dwelling creatures evolved wings to move from tree to tree. In either case, the ability to survive and gain access to unoccupied niches appear to be the greatest reasons for the development of bird flight.

Although it appears that modern birds evolved from dinosaurs, birds are not related to the now-extinct pterosaurs, or flying archosaurian reptiles. Pterosaurs were lizards and appeared to be proficient fliers with wing structures, similar to those of bats, that had an outstretched membrane over a thin upper limb. They had large heads that may have assisted their flight stability. Their wingspans ranged from a few inches to almost 40 feet. The pteranodon had a wingspan of up to 25 feet but weighed only 25 pounds. Due to their large sizes, most pterosaurs were probably soaring animals that relied on thermals to fly at high altitudes.

The oldest known bird is the archaeopteryx, named for the Greek "ancient wing," which lived around 150 million years ago. It had a wingspan of approximately 18 inches and weighed about 1 pound. With its feathers and beak, it had similarities to modern birds, and with its teeth and clawed wings, it had similarities to dinosaurs.

There is a wide variety of flying birds, including the small hovering hummingbird, the swift falcon, and the lumbering condor. Each adopted a mode of flight suited to its evolutionary niche. There are several differences between flying and flightless birds that illustrate requirements for successful bird flight. Flightless birds tend to have shorter, symmetrical wings, whereas flying birds have long, cambered wings that produce substantially more lift. To keep their weight low, flying birds tend to have fewer feathers than their grounded counterparts. Flying birds also have longer tails, or keels, that aid in flight stability.

Birds occupy almost every low-speed flight niche known. They are adept fliers, using their wing muscles and feathers to control the distribution of lift over the wings. This allows them to easily adjust to changes in ambient flight conditions, such as gusts or downdrafts. Their whole bodies are designed for flight. They have strong, hollow bones that minimize weight and withstand impacts. They have unique single-path pulmonary systems that constantly feed fresh oxygen to the lungs to maximize energy. They use their heads, tails, and feet to help control flight.

Variations across the bird species detail how well designed birds are for their particular niches. The hummingbird, for example, is well known for its ability to hover in one place in flight, beating its wings at an amazing 60 or more beats per second while feeding on the nectar of flowers. Although other birds, such as kestrels, terns, and gulls, can also hover, only hummingbirds can fly sideways and backward in hovering flight.

Insects

Insects are both the oldest and generally smallest of flying animals. The first winged insects appeared some 350 million years ago and were the first creatures to fly on Earth. There are one million species of insects, many of which fly. They range in size from barely visible to almost 1 foot in wingspan.

Insects are invertebrate arthropods with a hard exoskeleton and a three-part body consisting of head, thorax, and abdomen, three pairs of jointed legs, and two antennae. The legs and wings are attached to the thorax. Most winged insects have two sets of wings, fore and aft. Most flap their wings in synch, whereas a few, such as the dragonfly, flap their fore and aft wings asynchronously. In the former case, synchronous wing movement appears to be limited to approximately 200 beats per second, because the wing motion is related directly to the nerve inputs to the muscles. For asynchronously flapping winged insects, beat frequencies of more than 1,000 beats per second have been recorded, because the myogenic flight muscles used in asynchronous wing motion can contract more than once per nerve impulse.

Most insects cannot fly using the laws of conventional aerodynamics. Under these assumptions, lift is determined by the steady flow of air over a wing just as in aircraft flight. The wing areas of most insects are too small to obtain the required lift at their measured flight speeds, however. Much of their lift is instead derived from unsteady lift as described above. For insects, the clap-and-fling effect is used to generate the required lift. In this method, the wings are beaten together (clap) and rapidly pulled apart (fling). The air rushing in to fill the void develops a fast-moving vortex over the top of the wing that generates a large amount of unsteady lift. Insects must beat their wings rapidly and repeatedly to generate lift. Bees flap their wings more than 100 times per second. The common housefly beats its wings more than 20,000 times per minute, or about 300 times per second. A midge of the genus *Forcipomyia* has a measured wing-beat frequency of more than 1,000 beats per second.

The wings of most insects are less flexible than those of birds or bats. Most insects change direction and speed primarily by altering the motion and frequency of their wing beats. Pitch, yaw, and roll control involve changes in wing-beat amplitude on one wing with respect to the other, lateral wing twisting, or leg and abdominal movement. Some insects can twist their wings like those of a bird to control motion, such that a large area is projected on the downstroke and a small area is projected on the upstroke. These traits give great maneuverability to most insect species.

The number of flying insect species is enormous. Typical insect flight speeds range from 15 miles per hour for bees to 1 mile per hour for mosquitoes, and even less for smaller insects. The fastest flying insect may be the tabanid, with a flight speed estimated at 90 miles per hour; it has been observed to execute Immelman maneuvers while in flight. The Australian dragonfly can reach 36 miles per hour over short distances, outrunning most horses.

Some dragonflies have wingspans of up to 11 inches, and some butterflies have wingspans of up to 10 inches. Dragonflies have two sets of high-aspect ratio wings, and butterflies have two pairs of large low-aspect ratio wings covered with colorful, iridescent scales in overlapping rows. Lepidoptera, as butterflies and moths are known, are the only insects that have scaly wings. Flight speeds vary among butterfly species. The poisonous varieties fly more slowly than nonpoisonous varieties, because they do not have to fly as quickly to evade predators. The fastest butterflies can fly at about 30 miles per hour or faster, whereas slow-flying butterflies fly about 5 miles per hour.

Mammals

Only one mammal is truly capable of powered flight: the bat, of the order Chiroptera, a word that means “hand-wing.” All other so-called flying mammalian species do not actually fly but rather glide. Other mammals that fly by gliding include the flying squirrel and the flying lemur, neither of which actually fly and the latter of which is not actually a lemur. Bats, however, like birds, do attain true powered flight.

Bats are vertebrates with fur that bear and nurse live young. Nocturnal animals, they are found in all regions of the world except for the North and South Poles. There are more than 900 different species of bats, ranging in wingspan from the 6-inch bumblebee bat to the 6-foot flying fox. Some bats migrate, whereas others hibernate.

Because the fossil record is limited, the origin and evolution of bats remain unknown. It is believed bats appeared around fifty million years ago. Bats are related to the colugo, or flying lemur, but their common link is a mystery. They probably evolved from arboreal ancestors related to primates that used gliding and climbing as separate means of locomotion. The fact that the earliest bats had tails supports this assertion.

Bats are divided into two suborders based upon their method of navigation. Those of the suborder Microchiroptera use a type of sonar called echolocation to navigate and search for prey. They send off high-pitched sounds beyond the range of most human hearing. These sounds echo off surroundings and other animals, and bats use the echoes to determine the size and distance of the object. Microchiropteras include the vampire bat, the only mammal to feed exclusively on blood. Bats of the suborder Megachiroptera, such as the fruit bat, use their sense of smell to find food. Both types of bats have poor eyesight.

Bats are agile fliers. The bat wing is a membrane stretched across elongated fingers of the hand which support the distal, thrust-producing portion of the wing. Bats can change the effective airfoil cross section of the wing by moving their fingers. The fingers are extremely flexible, much like those of humans, and allow a bat to create almost any desired airfoil shape. The uropatagium, a membrane stretched between the hind limbs, helps stabilize the bat during flight and is often used to capture prey. Because gliding animals incorporate their hind limbs into their wings, this membrane is believed to have evolved from gliding.

Gliding mammals include the flying squirrel and flying lemur. Flying squirrels have a fold of skin extending from the wrist of the front leg to the ankle of the hind leg that forms a winglike gliding surface when the limbs are extended. The tail serves as a control device during glides to steer and stabilize flight. Colugos, or flying lemurs, arboreal climbers and gliders with lateral skin membranes and large, webbed, clawed feet, are found in certain regions of the Pacific Rim. They resemble large flying squirrels. Like bats, they have a short tail, which is used for stability and is connected to the hind limbs by skin folds.

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Antiaircraft fire

Definition: Surface-to-air weapons fire providing direct protection from aerial attack.

Significance: With the advent of aircraft as a military weapon delivering offensive ordnance, air defense weaponry has become a vital part of many nations' overall military strategies.

History

Ground-based antiaircraft gunnery began in 1871 during the Franco-Prussian War (1870-1871), when the Prussian army used a Krupp-produced weapon to shoot at message balloons being sent out from the besieged garrison of Paris. The first weapons expressly designed as antiaircraft weapons were manufactured in Germany in 1908 as quick-firing, car-mounted field pieces and were used to shoot down observation balloons.

During World War I (1914-1918), as positive results of aerial combat indicated the utility of aircraft as offensive weapons, specialized antiaircraft artillery became a priority. Such guns required mounts that allowed a high angle of fire, an all-around traverse, a high rate of fire, and a high muzzle velocity for a straight trajectory, and an improved accuracy.

By the start of World War II (1939-1945), two general types of antiaircraft gun were being produced: heavy, single-shot guns for attacking high-altitude aircraft and light, fast-firing machine guns and small-caliber cannons for low-level defense. The heavy guns could cycle as many as twenty-five rounds per minute to altitudes of 5,500 meters. The lighter weapons could fire nearly one thousand machine-gun rounds per minute. Small cannons, such as the 40-millimeter double-gun-mount Bofors, could fire 120 rounds per minute per gun.

Due to the poor general performance of early aircraft, antiaircraft gunners managed to bring down about one aircraft for every one thousand rounds of ammunition, excluding machine-gun ammunition, fired. As advances in aviation rapidly progressed, antiaircraft defense lagged behind in development. In 1939, German military planners determined that it would take fifty rounds of antiaircraft artillery to bring down one enemy airplane. On this basis, they established their air defense doctrine. Aircraft design and performance developed rapidly during World War II, outpacing antiaircraft weaponry. The German military found that it expended more than twelve thousand shells for each aircraft destroyed.

Between 1950 and 1980, surface-to-air antiaircraft missiles predominated as air defense weapons. The technology of the guided missile was thought to make other antiaircraft defenses obsolete. The reality, however, was that approximately fifty missiles were fired to bring down one enemy plane, at a cost much greater than that of the required twelve thousand artillery shells of World War II. Despite these results, heavy, single-shot artillery guns have been largely replaced by vehicle-mounted, in-place, or shoulder-held guided surface-to-air missiles. The advantage of a guided missile is its ability to completely destroy its target. Shrapnel from artillery rounds may only disable modern aircraft equipped with double- and triple-redundancy systems: A single missile hit will destroy an aircraft.

Since 1945, very high-flying bombers and guided missiles have made large antiaircraft artillery obsolete, but there remains the need to engage low-flying attack aircraft and helicopters. Although data suggest that missiles are barely as effective as antiaircraft artillery, the mere threat of surface-to-air missiles often forces aircraft to fly low enough to be shot at by smaller-caliber automatic weapons. At lower altitudes, where antiaircraft gunners can clearly see their targets, most aircraft losses to air defense happen.

During the Vietnam War (1961-1975), 80 percent of aircraft losses came from low-altitude machine-gun fire requiring about ten thousand small-caliber cannon and machine-gun rounds to down each airplane. The philosophy of rapid close-range fire as the most effective antiaircraft defense has resulted in the design and use of multibarreled unmanned radar-controlled systems such as the 20-millimeter Vulcan-Phalanx Close-In Weapon System (CIWS). This weapon fires 6,600 rounds of uranium-

*Antiaircraft fire, often called "ack-ack," lights up the sky over London during World War II. (*Digital Stock*)*

tipped ammunition up to 5,000 meters, providing a so-called wall of steel to down approaching aircraft or missiles.

Tactics

Antiaircraft fire is known to combat pilots by slang names such as "Archie," "Ack-Ack," "Flak," and "Triple A." The goal and lethal mission of air defense antiaircraft fire is attrition and deterrence. These goals are accomplished by forcing enemy aircraft either to abort their missions or to take heavy losses.

A four-step procedure establishes the basic tactics for providing successful antiaircraft fire. First, the enemy aircraft must be detected as early as possible. Second, the aircraft must be acquired to determine its direction and possible destination. Third, the aircraft must be tracked so weapons can be quickly targeted. Fourth and finally, the target must be destroyed.

Air defense artillery is employed to protect individual rear-area installations and vital military bases. Air defense weapons are deployed according to their range and mobility. Long-range, less mobile weapons are set far back from the fighting fronts to protect rear installations and to give high-altitude protection to front-line units. Mobile, short-range weapons are deployed nearer the fighting, where they can respond quickly to battlefield dynamics. The key to any successful air defense is the layering of defense at multiple depths and altitudes. In the past, air defenses had short ranges and low altitude. Modern surface-to-air systems can protect areas more than 100 kilometers from their bases and more than 10,000 meters high. A complete system can cover an entire operational theater of more than 1,600,000 square kilometers. The performance of antiaircraft fire is dependent on the destructive power of its ammunition, gained from high-impact velocities, explosive content, shrapnel, and blast and incendiary effect.

Historically, air defense has provided an impediment, and often a deterrent, to air attacks, but it has not in the long run been able to stop aerial attacks. Although aircraft have been touted as the preeminent weapon of modern warfare, they have failed to be overpowering, not because of air defense, but rather because of limitations in aircraft performance, weapons, and piloting. Modern air warfare tactics suggest that the best defense from enemy air attack is to destroy or suppress the enemy air force through air superiority.

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Apache helicopter

Also known as: AH-64, AH-64A, Longbow Apache (AH-64D)

Definition: U.S. Army antiarmor attack helicopter.

Significance: The Apache helicopter serves as the principal attack helicopter for the U.S. Army.

Equipment and Armament

The Apache is the U.S. Army's principal attack and antiarmor helicopter. It carries a crew of two, seated in tandem. The pilot sits in the rear seat, behind the copilot-gunner. Two General Electric T700-701C turboshaft engines that produce a total of nearly 4,000 horsepower provide power to the four-bladed, 48-foot diameter main rotor. Mission gross weight for the AH-64A is approximately 14,600 pounds, while for the AH-64D it is approximately 16,100 pounds. Top speed for the Apache is 167 knots.

Standard armament for the Apache consists of a 30-millimeter chain gun, located on the chin of the fuselage, and various combinations of other weapons which are attached to four weapons stations on the stub wings. These other weapons include the Hellfire and Hellfire II air-to-ground missile (four per weapons station) and the 70-millimeter Hydra rocket system (nineteen per weapons station). External fuel tanks (230 gallons each) to extend the range of the Apache may also be attached to the weapons stations.

The AH-64A Apache is also equipped with a target acquisition designation system (TADS) and pilot night vision system (PNVS), which are located on the nose of the aircraft. The TADS/PNVS are used in conjunction with the integrated helmet and display sight system (IHADSS) to allow the Apache to navigate and conduct precision attacks by day, by night, and in adverse weather conditions.

The AH-64D Longbow Apache is a remanufactured and upgraded version of the AH-64A. A remanufactured craft is completely stripped and then rebuilt with almost entirely new components. To many observers, the D model of the Apache appears to be identical to the A model. However, there are two observable differences. First, the forward avionics bays on the AH-64A are extended and expanded on the AH-64D to accommodate additional electronic components. Second, the Longbow Apache is equipped with a mast-mounted assembly, located above the main rotor, which accommodates the Longbow fire control radar. While the external differences between the AH-64A and AH-64D are minimal, the internal upgrades have made the Longbow Apache a much more capable weapon system. The Longbow fire control radar has the ability to detect, classify, and prioritize targets both on the ground and in the air. It also supports fire-and-forget Hellfire missiles, that is, missiles the gunner need not track until they hit the target. The all-new suite of digital instrumentation in the cockpit enhances the situational awareness of the pilot. Navigation is improved with a Global Positioning System (GPS).

Development

Although AH-64's are currently built by the Boeing Company in Mesa, Arizona, the Apache program has changed hands twice since it began in the early 1970's. In 1973, Hughes Helicopter Company won a contract to design an advanced attack helicopter for the U.S. Army. The Hughes Model 77 (YAH-64) made its first flight on September 30, 1975. In competition with the YAH-64 was the Model 409 (YAH-63) proposed by Bell Helicopter Company. In 1976, the U.S. Army awarded a full-scale development contract to Hughes to build the AH-64. The contract was completed in 1981 and, in 1982, the Army awarded Hughes a production contract for the aircraft now known as the AH-64A Apache.

In January, 1984, just before the February delivery of the first production Apache helicopter to the U.S. Army, McDonnell Douglas Corporation bought Hughes Helicopter Company. McDonnell Douglas then moved the Apache assembly facility from Culver City, California, to Mesa, Arizona. A total of 821 Apaches were delivered to the U.S. Army before production was transitioned to the AH-64D in 1997. International sales of Apache helicopters have included the nations of Israel, Egypt, Greece, the United Arab Emirates, Bahrain, Kuwait, and South Korea.

In the late 1980's, McDonnell Douglas began developing an advanced model of the Apache, which became known as the AH-64D Longbow Apache. The Longbow Apache made its first flight on April 15, 1992, and in 1996, McDonnell Douglas received a multiyear contract from the U.S. Army to remanufacture 232 AH-64A helicopters. The Boeing Company subsequently acquired McDonnell Douglas in August, 1997. In addition to the aircraft purchased by the U.S. Army, AH-64D Longbow Apache helicopters have been sold to the United Kingdom and the Netherlands.

Combat Performance

The AH-64A has participated in two major conflicts, as well as performing peacekeeping duties in Bosnia and Kosovo. In 1989, Apache helicopters played a key role in Operation Just Cause in Panama. Since much of the activity was at night, the advanced sensor and sighting capabilities of the Apache proved to be very effective against the antigovernment forces.

Operation Desert Storm, the liberation of Kuwait in 1991, provided an opportunity for the Apache to truly show off its capabilities. During the first hours of the war, Apaches destroyed key Iraqi radar sites, which allowed Coalition aircraft to penetrate deep into Iraqi territory without detection. In the course of the land battle, Apaches were credited with destroying more than five hundred Iraqi tanks and hundreds of armored personnel carriers, trucks, and other vehicles. Only one Apache was lost to enemy fire.

Donald L. Kunz

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See also: Boeing; Gulf War; Helicopters; McDonnell Douglas; Military flight; Rotorcraft

Apollo Program

Date: From May 28, 1964, to December 19, 1972

Definition: American project to land humans on the Moon.

Significance: The Apollo Program, designed to ensure America's international leadership in space exploration, resulted in the first landing of humans on the Moon. Apollo astronauts performed experiments and returned rock samples to Earth that helped determine the age and origin of the Moon.

The Program's Beginnings

In 1960, planners at the National Aeronautics and Space Administration (NASA) selected a crewed lunar landing as the follow-up to the Mercury effort to place a man in Earth orbit. In December, 1960, just before leaving office, President Dwight D. Eisenhower advised NASA officials that he would not approve the lunar landing project. However, after the Soviets sent Yuri A. Gagarin into Earth orbit in April, 1961, the new U.S. president, John F. Kennedy, announced on May 25, 1961, the plan "before this decade is out, of landing a man on the Moon and returning him safely to the earth." The project to accomplish Kennedy's objective was named Apollo.

The Apollo Spacecraft

To launch Apollo, NASA designed and built a huge, three-stage rocket, the Saturn V, which stood 363 feet tall and developed 7.5 million pounds of thrust at liftoff. In order to minimize the weight of the spacecraft, the Apollo engineers planned a lunar orbit rendezvous technique, requiring the Apollo spacecraft to have a modular design, consisting of three separate units, the Command Module, the Service Module, and the Lunar Module.

The Command Module, built by North American Rockwell, served as the control center for the spacecraft and provided 210 cubic feet of living and working space for the astronauts. It was designed to carry three astronauts from the earth to an orbit around the Moon and back. It was shaped like a cone, with a height of 10 feet 7 inches, a maximum diameter of 12 feet and 10 inches, and an approximate weight of 13,000 pounds. The Command Module was pressurized, so the astronauts could live and work without wearing spacesuits. The wide end of the cone was a blunt heatshield, covered with layers of special ablative material designed to burn away during reentry, dissipating the extreme heat caused by atmospheric friction.

The cylindrical Service Module, built by North American Rockwell, had a diameter of 12 feet and 10 inches and a length of 22 feet and 7 inches. It carried the electrical power systems, most of the electronics, and the life support gases. It also carried the computer system for guidance and navigation, the communications transmitters and receivers, and the oxygen and hydrogen used by the life-support and energy-generation systems. The Service Module's rocket engine produced 22,000 pounds of thrust. This rocket engine was used to slow the spacecraft to enter lunar orbit and then to speed it up for the return to Earth. Fully fueled, the Service Module weighed about 53,000 pounds.

The Lunar Module, built by the Grumman Aircraft Engineering Corporation, was designed to detach from the Command and Service Modules while they orbited the Moon and to carry two astronauts down to the lunar surface. The Lunar Module was a two-stage rocket, with each stage carrying its own fuel supply. The lower stage carried a 9,700-pound-thrust rocket engine to slow down the Lunar Module for a gentle touchdown on the lunar surface. Four landing legs, each with a landing pad to distribute the weight of the spacecraft over a larger area of the lunar soil, were attached to the Lunar Module descent stage. One of the landing legs was equipped with a ladder to allow the astronauts to climb down to the lunar surface. The upper stage of the Lunar Module consisted of a pressurized compartment providing life support for the two-man crew and an ascent engine to return the crew compartment to lunar orbit. The lower stage of the Lunar Module served as a launching pad for the upper stage. With the landing legs extended, the Lunar Module was 22 feet and 11 inches tall and weighed about 32,000 pounds.

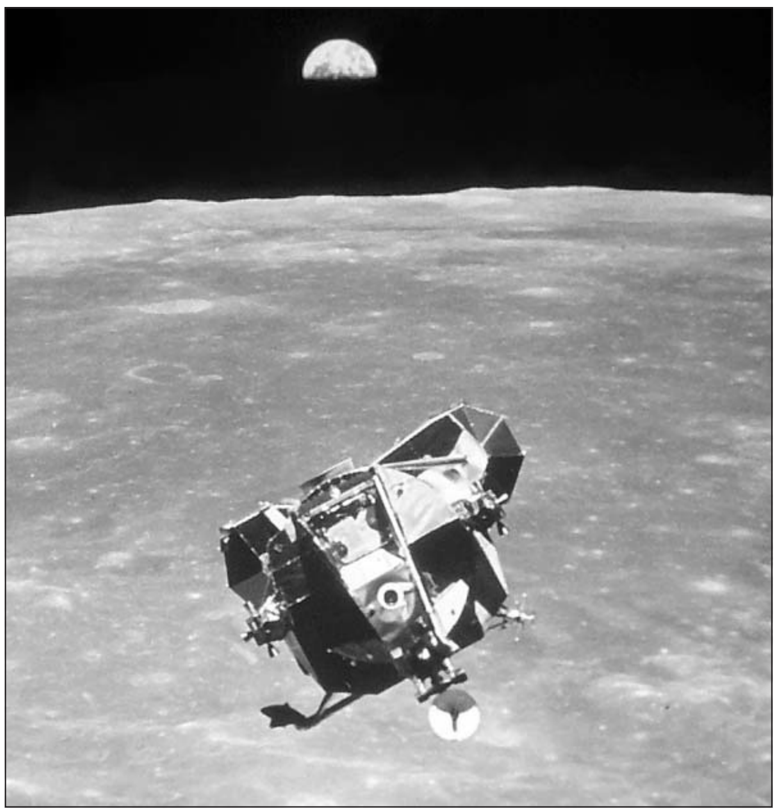
The Apollo Flights

On January 27, 1967, during a preflight test, a fire swept rapidly through the Apollo Command Module. The three astronauts participating in the test, Roger Chaffee, Virgil "Gus" Grissom, and Edward White, were killed in the fire. After the fire, NASA officials designated the test as Apollo 1, honoring the crew. An extensive investigation of the fire showed numerous design flaws in the Apollo Command Module, and crewed launchings were postponed for more than a year while an extensive redesign was conducted.

Apollo 7, the first manned test of the Command and Service Modules, was launched from Cape Kennedy, Florida, on October 11, 1968, on a Saturn IB rocket. Apollo 7 was the only crewed Apollo mission launched on a Saturn IB rocket, which was powerful enough to carry the Command Module and the Service Module into Earth orbit, but could not lift the full Apollo assembly, including the Lunar Module. The spacecraft crew consisted of commander Walter M. Schirra, Jr., Donn F. Eisele, and Walter Cunningham, who held the title of Lunar Module pilot despite the lack of a Lunar Module on the Apollo 7 mission. The crew orbited the earth 163 times and spent almost eleven days in space, demonstrating the reliability of the Command and Service Modules for a time comparable to that of a round trip to the Moon.

Apollo 8, launched on December 21, 1968, was the first crewed mission using the Saturn V rocket, and the first mission to take humans to the Moon and back. The three-person crew consisted of Frank Borman, the commander; James A. Lovell, Jr., the Command Module pilot; and William A. Anders, the Lunar Module pilot. Apollo 8 tested the flight path and operations for the trip to the Moon and back and demonstrated that the Apollo Command Module could successfully reenter the earth's atmosphere at the high speed of a return from the Moon.

The Apollo 9 mission, launched on March 3, 1969, was the first crewed flight employing all three components of the Apollo spacecraft. The crew, consisting of astronauts James A. McDivitt, the commander; David R. Scott, the Command Module pilot; and Russell L. Schweickart, the Lunar Module pilot, made 152 orbits of the earth. They demonstrated the crew transfer procedures and the rendezvous and docking procedures between the Command Module and the Lunar Module.



The Apollo Program had to devise spacecraft that not only would take humans out of Earth's atmosphere, but also land them on the Moon. The Lunar Module transported astronauts from their primary craft to the Moon's surface. (NASA CORE/ Lorain Valley JVS)

The final test of the Apollo spacecraft came with Apollo 10, launched on May 18, 1969. Apollo 10 was a complete Apollo lunar landing mission without an actual landing on the Moon. On the fifth day of the mission, astronauts Thomas Stafford, the commander, and Eugene Cernan, the Lunar Module pilot, descended inside the Lunar Module to within 14 kilometers of the lunar surface, while John W. Young remained in lunar orbit in the Command Module.

The Saturn V rocket carrying Apollo 11 lifted off from the NASA John F. Kennedy Space Center in Florida on July 16, 1969. The Command Module, named *Columbia*, carried astronauts Neil Armstrong, the commander; Edwin “Buzz” Aldrin, the Lunar Module pilot; and Michael Collins, the Command Module pilot, to the Moon and back. Astronauts Armstrong and Aldrin landed on the Moon in the Lunar Module, named *Eagle*, on July 20, 1969. Michael Collins remained alone in the *Columbia*, orbiting the Moon. *Columbia* served as a communications link between the astronauts on the Moon and mission control in Houston, Texas. After 28 hours on the Moon, the upper stage of the Lunar Module carried Armstrong and Aldrin back into orbit around the Moon, where they rendezvoused and docked with the *Columbia*. *Columbia*, the only part of the spacecraft to return to Earth, landed in the Pacific Ocean on July 24, 1969.

Apollo 12, launched on November 14, 1969, carried astronauts Charles Conrad, Jr., the commander; Richard F. Gordon, the Command Module pilot; and Alan L. Bean, the Lunar Module pilot. Astronauts Conrad and Bean landed on the Moon in the Sea of Storms, less than 600 feet from the site where the Surveyor 3 spacecraft had landed on April 20, 1967. The astronauts recovered pieces from the Surveyor 3 to allow scientists to assess the effects of the craft’s two-year exposure to the lunar environment. They also collected 75 pounds of rocks and soil for return to Earth and deployed the Apollo Lunar Surface Experiment Package to perform scientific experiments on the Moon.

Apollo 13, carrying astronauts James A. Lovell, Jr., the commander; John L. Swigert, Jr., the Command Module pilot; and Fred W. Haise, Jr., the Lunar Module pilot, lifted off on April 11, 1970. About 56 hours into the flight, an explosion in one of the oxygen tanks in the Service Module crippled the spacecraft. The crew was forced to orbit the Moon and return to the Earth without landing. The astronauts spent much of the flight in the Lunar Module, using its oxygen and electrical supplies, because of the damage to the Service Module. The astronauts landed safely on Earth on April 17, 1970.

Apollo 14, carrying astronauts Alan B. Shepard, the commander; Stuart A. Roosa, the Command Module pilot; and Edgar D. Mitchell, the Lunar Module pilot, was launched on January 31, 1971. Astronauts Shepard and Mitchell landed on February 5, 1971, within 160 feet of the target point, in the Fra Mauro region of the Moon, the intended landing site of the Apollo 13 mission. During a 4-hour, 20-minute period of extravehicular activity, Shepard and Mitchell climbed up the side of Cone Crater, providing the first experience of climbing and working in hilly terrain in the bulky spacesuits. The astronauts collected 94 pounds of lunar soil and rocks. The upper stage of the Lunar Module lifted off from the lunar surface on February 6, 1971, after 33.5 hours on the Moon. After the crew transferred to the Command Module, the Lunar Module ascent stage was guided to impact on the lunar surface, producing a seismic signal that was recorded by instruments deployed on the lunar surface by Apollo 12 and Apollo 14. The Command Module landed in the Pacific Ocean on February 9, 1971.

By 1970, public interest in lunar exploration had waned and federal budget cuts forced NASA to sacrifice current projects in order to support future ones. Apollo 15, 16, and 17 would be equipped to travel farther, stay longer, and perform more experiments than had previous missions.

Apollo 15, carrying astronauts David R. Scott, the commander; Alfred J. Worden, the Command Module pilot; and James B. Irwin, the Lunar Module pilot, was launched on July 26, 1971. Apollo 15 was the first in a series of advanced missions, carrying the Lunar Rover (LRV), which astronauts Scott and Irwin used to explore the Hadley Rille region of the Moon. The LRV allowed astronauts to travel tens of kilometers from the Lunar Module, in contrast to the hundreds of meters traveled in previous missions. The astronauts collected 173 pounds of samples from the low lunar plains, the Apennine Mountains, and the Hadley Rille, a long, narrow, winding valley. Although Apollo 15’s atmospheric entry was normal, one of the three parachutes that slowed the Command Module’s descent collapsed before landing. Nonetheless, the Command Module landed safely on August 7, 1971.

Apollo 16, carrying astronauts John W. Young, the commander; Thomas K. Mattingly II, the Command Module pilot; and Charles M. Duke, Jr., the Lunar Module pilot, was launched on April 16, 1972. This mission landed in the Descartes region, where astronauts Young and Duke collected 209 pounds of soil and rocks and used an ultraviolet camera and spectrograph to perform the first astronomical measurements from the surface of the Moon. The Apollo 16 crew returned to Earth on April 27, 1972.

Apollo 17, carrying astronauts Eugene A. Cernan, the commander; Ronald E. Evans, the Command Module pilot; and Harrison H. Schmitt, the Lunar Module pilot and, as a trained geologist, only scientist to visit the Moon, was launched on December 7, 1972. On this mission, astronauts Cernan and Schmitt conducted the longest LRV traverse on a single extravehicular activity, a trip of about 100 kilometers. They collected the largest amount of lunar soil and rock ever returned to Earth. Apollo 17's return to Earth on December 19, 1972, marked the end of U.S. efforts to send humans to the Moon.

Results of the Apollo Program

The major objective of the Apollo Program was accomplished with the landing of twelve American astronauts on the Moon and their safe return to Earth. These landings demonstrated the capability of American engineering, restoring American prestige by finally beating the Soviet Union in the space race. Scientists studying lunar rock samples were finally able to determine the age and origin of the Moon, finding that the Moon formed about 4,560,000,000 years ago, probably from the debris ejected when an asteroid struck Earth.

George J. Flynn

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Neil Armstrong

Date: Born on August 5, 1930, in Wapakoneta, Ohio

Definition: As commander of the Apollo 11 lunar landing mission in 1969, the first human to walk on the moon.

Significance: In addition to his outstanding and pioneering contributions to the National Aeronautics and Space Administration's (NASA) crewed spaceflight program, Armstrong has served with distinction as a professor of aerospace engineering, chairman and director of several corporations, and member of presidential commissions.

Early Life and Education

Born to Stephen and Viola Louise Armstrong in Wapakoneta, Ohio, in 1930, Neil Armstrong was an avid enthusiast of flying from an early age. He received his student pilot's license at age sixteen, before receiving a driver's license. In 1947, he entered the aeronautical engineering program at Purdue University with a scholarship from the U.S. Navy. Two years later, he was called to active duty and earned his pilot's wings at the Naval Air Station in Pensacola, Florida. As the youngest pilot in his squadron, he flew seventy-eight combat missions from the flight deck of the USS *Essex* in Korea in 1950. He won three Air Medals for his combat duty. At the end of the war, Armstrong returned to Purdue and received his baccalaureate degree in 1955.

Professional Activities at NASA

After graduating from Purdue, Armstrong joined NASA's Lewis Flight Propulsion Laboratory in Cleveland, Ohio. Later, he transferred to NASA's High-Speed Flight Station at Edwards Air Force Base, California. There, as an aeronautical research pilot, he flew X-15 airplanes to altitudes over 200,000 feet, at speeds up to 4,000 miles per hour. As a test pilot, Armstrong also flew the X-1 rocket airplane, the F-100, F-101, F-102, F-104, F-5D, B-47, and other aircraft. Armstrong's experience with the X-15 led to his selection as a pilot of the X-20 Dyna-Soar, an experimental craft that could leave the atmosphere, orbit the earth, reenter the atmosphere, and land like a conventional aircraft. However, the X-20 project was canceled in 1962, and Armstrong then decided to become an astronaut.

In September, 1962, Armstrong was one of the first two civilians selected for astronaut training. In his first flight assignment, he served as a backup command pilot for the Gemini GT-5 mission. On March 16, 1966, Armstrong served as the command pilot for Gemini 8, and, along with pilot David R. Scott, successfully docked two vehicles in space for the first time. The flight was terminated ahead of its three-day schedule due to a malfunctioning thruster.

Demonstrating exceptional piloting skill, the crew overcame the problem and brought the craft to a safe landing. Subsequently, Armstrong served as backup command pilot and backup commander for the Gemini 11 and the Apollo 8 missions, respectively.

Armstrong's most significant role as an astronaut occurred during his command of the manned lunar landing mission of Apollo 11 from July 16 to July 21, 1969. The crew for this historic flight consisted of spacecraft commander Armstrong, Lunar Module pilot Edwin "Buzz" Aldrin, and Command Module pilot Michael Collins. On July 20, 1969, the human race accomplished what many consider the single greatest technological achievement of all time. For the first time in human history, a man set foot on a celestial body beyond the earth. After landing on the lunar surface at about 4:18 P.M. eastern daylight time, Armstrong radioed back to mission control the now-famous words, "Houston, Tranquillity Base here. The *Eagle* has landed." Six hours later, Armstrong stepped off the Lunar Module onto the surface of the Moon. Taking his first steps on the Moon, he uttered the immortal words, "That's one small step for man, one giant leap for mankind." Shortly thereafter, he was joined by Aldrin, and the two astronauts spent twenty-one hours on the lunar surface, collecting 46 pounds of lunar rocks. Their liftoff from the surface of the Moon was partially captured on a television camera they left behind, and they successfully docked with Michael Collins, who had continued to orbit the Moon alone in the Command Module *Columbia*.

Post-NASA Activities

Following his historic walk on the Moon, Armstrong received a master of science in aeronautical engineering from the University of Southern California. In the fall of 1971, he accepted a position as professor of aerospace engineering at the University of Cincinnati, an interdisciplinary post he held until 1980. Thereafter, he served as the chairman of the board of Cardwell International Corporation in Lebanon, Ohio, until 1982, when he became the chairman of the board of Computing Technologies for Aviation (CTA) Incorporated of Charlottesville, Virginia.

In 1984, along with the test pilot Charles E. "Chuck" Yeager, Armstrong joined the National Commission on Space (NCOS), a presidential panel created to develop goals for the space program in the twenty-first century. However, the explosion of the space shuttle *Challenger* on January 28, 1986, placed the commission's report on hold. Following the *Challenger* disaster, Armstrong was named vice chairman of the Presidential Commission on the Space Shuttle *Challenger* Accident. Over the years, Armstrong, an intensely private and unassuming man, has avoided as much as possible making public appearances. On the occasion of the thirtieth anniversary of the first lunar landing on July 20, 1999, he gave a lighthearted speech before the National Press Club in Washington, D.C., on behalf of the National Academy of Engineering. He described spaceflight as one of the greatest engineering achievements and observed that while "science is about what is, engineering is about what can be."

Monish R. Chatterjee

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See also: Apollo Program; Korean War; National Aeronautics and Space Administration; Space shuttle; Test pilots; X planes; Chuck Yeager

Astronauts and cosmonauts

Definition: The astronauts and cosmonauts were a select group of men and women trained by the United States and the Soviet Union to travel in outer space.

Significance: The astronaut and cosmonaut programs provided the world with the talented pilots who formed the foundation of human exploration of outer space. These men and women extended knowledge of the universe and brought the human race to the surface of the Moon. Politically, astronauts and cosmonauts were also used as warrior-heroes in the Cold War.

Background

The space race was the product of the worldwide struggle between the communist and industrial-democratic nations known as the Cold War. This conflict began at the end of World War II when the antifascist alliance, led by Great Britain, the United States, and the Soviet Union, began to unravel.

Science occupied an important position in the competing philosophies of democratic capitalism and socialist communism. In the Enlightenment model that underlies American and Western European democracy, science unlocked the natural laws of nature, and through the use of human reason these universal truths could be used for the betterment of the human community. Enlightenment intellectuals believed in human equality before God, but also believed in individual inequalities in intelligence, self-discipline, and drive. This would lead to a natural aristocracy based upon merit and achievement, who would create an environment in which natural law would be used for the welfare of the entire community.

Socialist philosophers believed that the workers and the peasants had the natural right to control the means of production. In this paradigm, the proper application of science and technology would create a system that would establish an egalitarian society governed by the "Dictatorship of the Proletariat." These two different worldviews had a profound impact on the development of the astronaut and cosmonaut programs. The successes and failures of the two programs would be used as examples of the strengths or weaknesses of the two competing ideologies. This was especially true in the competition for the hearts and minds of the Third World nations that were the main targets of this struggle.

The Original Soviet Voyagers

The success of Sputnik, the first artificial Earth satellite, generated momentum within the Soviet government to initiate a program designed to send a human into space. Initially, twenty candidates were chosen to be the first cosmonauts. A special facility outside of Moscow, designated "Star Town," was constructed to carry out the necessary training. By 1960, the original twenty had been reduced to twelve, and it was from this select group that the first voyagers were chosen.

The Soviets developed a strict set of standards that each potential cosmonaut had to meet. Since the original space capsules were small, these first pilots could be no taller than 5 feet, 11 inches. The stress and strain of the rigorous training and missions necessitated that the cosmonauts be both emotionally and physically fit. The unknown aspects of spaceflight required pilots who were able to act decisively under great stress and who possessed the confidence in their own abilities to handle any problems that they might encounter. The Russians looked to their military establishment for their space program because the cosmonauts would have to be able to take great risks, yet at the same time be completely obedient to their supervisors. The Soviets wanted individuals who were intelligent in the areas of science and technology, but who were not deeply philosophical. The leadership of the Soviet Union did not welcome questions about the logic and ethics of a program that would expend billions of dollars in a race that would turn the cosmos into another Cold War battlefield.

The cosmonauts also had to reflect the ideology of socialist heroes in the struggle between the philosophies of communism and democratic capitalism. It was important that they be physically attractive, so as to optimize their impact as traditional heroes. More importantly, they had to possess the politically correct characteristics of the new Soviet citizen. The vast majority of the candidates were the children of factory workers or peasants. Their ethnicity was "pure" Russian, which reflected the centuries-old belief that the Russians were the natural leaders of the Slavic peoples. The communal nature of socialist ideology was always reflected in the cosmonauts' statements concerning the importance of their voyages to the welfare of all Earth's people.

Russia's first cosmonaut embodied all these important characteristics. Yuri Gagarin was a man of the common people, and his proletarian background was made to order for his great communist achievement. He spent the first years of his young adult life working in a Russian factory, and through hard work and determination he not only became a member of the Russian military but also attained the high status of a test pilot in the Soviet air force. The Russian government and propaganda machine focused upon his peasant heritage as an example of how the communist system, supported by a strong scientific and technological community, could transform a man of the working class into the first voyager into space. His successful flight in Vostok 1 on April 12, 1961, provided Soviet General Secretary Nikita Khrushchev with a powerful propaganda weapon in his struggle against the West. This socialist egalitarianism crossed gender lines on June 16, 1963, when Valentina Tereshkova completed forty-eight orbits in Vostok 6 to become the first woman in space. The world communist community declared that it was now perfectly clear that the socialist model was the philosophy that created true equality between men and women.

Tereshkova is a significant example of how politics and ideology played an important role in the Soviet space program. She was primarily chosen because of her proletarian heritage; in fact, Khrushchev was so intent on making an ideological statement that she was selected over a number of better-qualified women. Tereshkova's flight was extremely taxing and she suffered from the effects of space sickness, which so physically drained her that on one occasion she fell into a deep sleep and the Russian ground control had serious concerns about her health.

Khrushchev's propaganda about gender equality played far better outside the Soviet Union than it did domestically. There were numerous articles in the U.S. press about the impact of the flight on the movement for universal women's rights. Ironically, the leaders of the Russian space program used Tereshkova's weakened physical reaction as proof that women did not belong in space.

Eventually, Tereshkova's life took on the aspects of a soap opera. Her wedding to fellow cosmonaut Andrian Nekoloyev was broadcast throughout the Soviet Union. Their first child, a baby girl, was subjected to a series of biological examinations to see if Tereshkova's exposure to cosmic rays had affected her daughter's health. The pressures of a life in the spotlight eventually took its toll on her marriage and she divorced in June, 1964.

The original Russian cosmonaut program also had some important problems that reflected the dark side of the personalities of these unique individuals. The fearless aggressiveness so characteristic of these exceptional people at times erupted into antisocial behavior that on several occasions ended in death. The problem of alcoholism that has damaged large segments of Soviet society also took its toll on the first cosmonauts. Grigori Nelyubov was a superior candidate who was widely respected for his great skill and coolness under stress. One evening, when he was returning from a weekend leave, he had an altercation with local authorities that ended in a physical confrontation. As a result, he was dismissed from the cosmonaut program. Nelyubov became deeply depressed, developed a severe drinking problem, and eventually took his own life. The Soviet government was successful in its initial attempts to cover up such stories. Nelyubov became a nonperson, with all traces of his connection to the cosmonaut program erased from the official records. The Soviet propaganda machine could not allow the world to know that these serious problems existed in the socialist paradise.

The Original U.S. Astronauts

The United States decided to pursue a crewed spaceflight program in 1958 as a result of the impact of Sputnik on the U.S. political scene. The Eisenhower administration viewed the Soviet space program as another political threat to the strategic balance of the Cold War. The containment policy adopted by the United States during the Truman administration was based upon two important concepts: first, the Soviet empire had to be contained within the original East-West borders as defined in Winston Churchill's "Iron Curtain" speech, and second, that inherent philosophical weaknesses in the communist model would result in the downfall of the Soviet empire. George F. Kennan, who developed the policy, believed that one of its most important aspects would be how it enabled the West to win the struggle for the allegiance of developing nations. By 1958, it was evident to everyone in the United States that Sputnik had created the impression that the science of the new socialist order could produce profound technological achievements. If containment was to be successful, the United States would have to surpass the Soviets in the race for space.

When the Kennedy administration took office in January, 1961, the astronaut program was placed on hold because of the more pressing problems concerning the Cuban Revolution. The military disaster of the Bay of Pigs left the new president looking for a way to recover the confidence of the American people. This fact, coupled with the continued success of the Soviet space program, moved Kennedy to reinstate the astronaut program. The new program was placed before the American people in Kennedy's famous speech challenging the country to land a man on the Moon by the end of the decade.

Immediately, the nation was awash in articles describing the men who would be the first voyagers into outer space. These space travelers would epitomize the outstanding characteristics of democratic Enlightenment thought. The astronauts were perfect examples of a space-age "aristocracy of merit." They were required to hold at least a bachelor of science degree in engineering or related technology. Like the cosmonauts, every candidate had to be in excellent physical condition and possess the emotional strength to handle the hazards of spaceflight. The astronauts were required to have at least 1,500 hours of flight time and also to cut a handsome figure for media purposes. Unlike the Soviet cosmonauts, however, the United States astronaut program did not include women.

The United States was looking for national heroes who would reflect the strength of its political system. To the American public, the original seven astronauts were portrayed as the ultimate Cold Warriors. They were soldiers who risked their lives every day to make sure the United States would not fall behind the Soviet Union in the race to control outer space. In reality, these men were more like ancient Greek heroes who performed great acts of bravery but who also lived lives of physical and material excess. The one man who never strayed was John Glenn. He not only remained focused on his assignment, but on a few notable occasions, he also castigated fellow astronauts for their lack of restraint. In the late 1950's and early 1960's, the U.S. press did not pursue this type of sensational story, and the exploits of the original astronauts went unreported.

The United States began its crewed presence in outer space on May 5, 1961, when Alan Shepard took the Mercury capsule *Liberty Bell 7* for a fifteen-minute flight. The mission was a success in every possible way and was a major turning point in the U.S. space program. Technologically, it confirmed that a pilot could control a space capsule in both a state of weightlessness and at significant g forces. When Shepard returned, it also became evident that astronauts could travel in space and not experience any negative physical or emotional problems. The flight of *Liberty Bell 7* also had an important political impact. Domestically, it helped return a sense of optimism about the ability of the United States to compete in space with the Soviets. Internationally, the flight helped to emphasize the openness of the U.S. system. Unlike the Soviet launches, every minute of the flight of *Liberty Bell 7* was broadcast to the entire world. Many of the news stories in the international press praised the United States for allowing this event to be covered uncensored by the government.

On February 20, 1962, U.S. astronauts obtained full status with the Soviets when John Glenn became the first American to orbit the earth in his ship *Friendship 7*. This was the flight that showed the important difference between the two programs. During the course of his trip into space, Glenn was confronted with two potentially deadly problems, and on both occasions the U.S. decision to allow the pilot some control of the craft allowed him to avoid disaster. Early in the flight, the automatic stabilization system malfunctioned and the capsule began to drift off course, but because Glenn was able manually to maneuver the craft, he eventually brought it under control. Most important, when the capsule's heat shield malfunctioned upon reentry into Earth's atmosphere, Glenn once again was able to take steps to help his situation. These two incidents exemplified the American ideal of an "aristocracy of merit" that possessed the "right stuff" to overcome possible disaster. This differed substantially from the original Soviet system, in which the cosmonaut essentially "went along for the ride."

The Apollo-Soyuz Test Mission in July, 1975, was the first joint space project between the United States and the Soviet Union. The meeting of astronauts and cosmonauts in outer space marked the beginning of an era of cooperation rather than competition between the two countries. (NASA CORE/Lorain Valley JVS)

The Race to the Moon

The quest of the United States to land a man on the Moon required an expansion of the astronaut program in both the number of personnel and the technological skill required for this next phase of the space race. The Gemini Program was given the mission to perfect the concept of a multicrewed mission and to develop the necessary skills to successfully dock with another craft. A successful Moon mission would require three astronauts, two of whom would actually land on the Moon's surface. These two men would have to separate a smaller craft from the mother ship, land, then take off from the Moon to dock once again with the original spacecraft. The successful completion of these tasks set the stage for the Apollo Program.

The Russian cosmonauts were trying to expand their presence in space by flying missions in the Voskhod Program, which was the Russian attempt to compete with the multicrewed missions of the United States. Unfortunately, the Voskhod was just a retooled version of the one-seat Vostok capsule, and it foreshadowed the decline of the Soviet space program. Despite these problems, cosmonauts continued to make important accomplishments in the field of space science. The most significant event of the Voskhod Program occurred on March 19, 1965, when Alexei Leonov became the first man to walk in space.

The Apollo astronauts perfected the three-man mission that put an astronaut on the Moon. The spacecraft itself was the most advanced ship to date and required technological capabilities well beyond those of either Mercury or Gemini. The worst accident in the history of the Moon program occurred on January 27, 1967, when the Apollo capsule containing Gus Grissom, Ed White, and Roger Chaffee filled with pure oxygen and exploded, killing all three men. U.S. astronauts finally reached the Moon on July 24, 1969, when Neil Armstrong spoke those famous words, "One small step for man, one giant leap for mankind."

The Moon landing also played an important role in the Cold War. By 1969, the United States found itself deep in the quagmire of Vietnam, and U.S. armed forces were suffering about five hundred casualties a week. At a time when the American people were beginning to question their country's ability to successfully carry on the war, the landing on the Moon was looked upon by the Nixon Administration as confirmation of the power of the United States. Thus it is evident that, from the very beginning of the space race, the astronauts and cosmonauts were considered soldiers in the Cold War.

Shuttles and Space Stations

The problems of the Vietnam War created a sense of despair and a loss of confidence among the American electorate, while pressing problems of race relations, poverty, and rising inflation helped extinguish the enthusiasm for further space exploration. In the Soviet Union, the communist system could no longer produce the resources needed to successfully place a cosmonaut on the Moon. Both nations decided to reorient their focus to develop programs that would continue to expand humankind's knowledge of the cosmos, while at the same time working within their drastically reduced budgets.

The United States developed a program that would create a series of reusable shuttle craft that would be launched into Earth orbit to perform duties ranging from scientific experiments to the repairs of sophisticated space telescopes. The next generation of astronauts shifted from explorers to experimental scientists. This new orientation opened the way for the first women astronauts, whose scientific and technological skills were needed for successful shuttle missions. The astrophysicist Sally K. Ride, who in 1983 became the first American woman to travel into space, exemplified the educational background of these new astronauts.

The Soviets decided to concentrate on the development of large space stations that would be used as laboratories for the development of the next generation of space scientists. Once again, the new generation of cosmonauts were oriented toward academic research and created an impressive schedule of experiments, ranging from space-based communication systems to solar research. Unfortunately, the collapse of the Soviet Union drastically reduced Soviet expenditures and the space station program was devastated by this lack of funding.

Beginning in the 1990's, the United States carried out a series of varyingly successful robotic missions to Mars that have rejuvenated interest in space exploration. A new international program consisting of members from various European, Asian, African, and Western Hemisphere states could form the foundation of humanity's next step into the universe.

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See also: Apollo Program; Neil Armstrong; Crewed spaceflight; Yuri Gagarin; Gemini Program; John Glenn; Mercury project; Russian space program; National Advisory Committee for Aeronautics; National Aeronautics and Space Administration; Alan Shepard; Space shuttle; Spaceflight; Valentina Tereshkova; Uncrewed spaceflight

Jacqueline Auriol

Date: Born on November 5, 1917, in Challans, France; died on February 12, 2000, in Paris, France

Definition: Pioneer female test pilot and world speed record holder.

Significance: Beginning her aviation career as a stunt pilot, Auriol went on to fly more than one hundred different types of planes as one of France's most successful military test pilots of either gender. She held many world speed records throughout the 1950's and was the second woman to break the sound barrier.

Jacqueline Auriol did not start flying until she was thirty years old, when she did so only out of curiosity. The daughter of a wealthy timber importer and shipbuilder, she studied drawing and painting at the École du Louvre and psychotherapy at the Sorbonne. In 1938, she married Paul Auriol, the son of future French president Vincent Auriol, and together they were active as part of the French Resistance during World War II. The couple had two sons, Jean-Paul and Jean-Claude.

Encouraged by her husband, Auriol first qualified as a tourist pilot in 1948 and later studied aerobatics with Raymond Guillaume, considered by many to be one of France's greatest stunt pilots. As her interest grew, she realized she would need a military license if she wanted access to planes used by the Groupe de Liaisons Aériennes Ministérielles (GLAM), an elite group of military pilots.

Auriol's life changed dramatically in 1949, when a seaplane on which she was a passenger crashed into the River Seine, and she was severely injured. She underwent twenty-two operations to rebuild her face and did not permit her two children to see her for nearly two years because of her disfigurement. While in the United States for the final two operations, she earned her helicopter pilot's license in only four weeks.

Auriol did not allow her injuries to prevent her from becoming licensed as a military pilot in 1950. She was accepted as a test pilot at the French Flight Test Center in Bretigny, France. In 1951, she reached a speed of 507 miles per hour in one of the first Vampire jets, breaking American aviator Jacqueline Cochran's speed record. For this, the first speed record attained by a French pilot since World War II, she received the French Légion d'Honneur and the American Harmon Trophy.

Overall, Auriol held the women's world speed record five times between 1951 and 1964. In 1953, she became the second woman to break the sound barrier and was one of the first pilots of either gender to pilot the Concorde. Auriol later worked with the French Ministère de la Coopération, locating water and mapping crop species by using remote sensing techniques. For her agricultural work, Auriol received the Ceres Medal of the United Nations Food and Agriculture Organization.

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See also: Aerobatics; Concorde; Military flight; Sound barrier; Test pilots; Women and flight

Autopilot

Also known as: Automatic flight control systems or integrated flight control systems

Definition: A device used to control an aircraft in flight automatically.

Significance: Autopilots are equipped on large commercial, military, and many small aircraft. By reducing pilot workload, autopilots greatly increase flight safety.

Nature and Use

Many aircraft are equipped with autopilots that will fly an aircraft automatically while the pilot accomplishes other tasks. These systems vary greatly in sophistication, from simple wing levelers to completely integrated flight control systems.

The simplest autopilot is a single-axis system. Most single-axis autopilots are designed to control the motion of the aircraft around the aircraft's longitudinal axis, passing from the front of the aircraft to the rear. When movement around the longitudinal axis becomes unstable, then the aircraft will roll, or tip, from side to side. In its simplest form, the single-axis autopilot may be referred to by pilots as a wing leveler. Upon activation, a wing leveler will stabilize the aircraft by leveling the wings. By adding features such as turn, heading, and navigational control, pilots can use a single-axis system throughout most of the flight.

Another common type of single-axis system is known as the yaw damper. This autopilot maintains control of the aircraft around the vertical axis, running through the aircraft from top to bottom. When movement around the vertical axis becomes unstable, the aircraft is considered to be slipping or skidding sideways. This motion is known as yaw. Yaw dampers are designed to prevent slipping and skidding.

A form of autopilot commonly used on medium-sized aircraft is the dual-axis system. A dual-axis autopilot will maintain control of the aircraft around both the lateral and the longitudinal axes. The lateral axis of an aircraft is an imaginary line passing from wingtip to wingtip. Movement around the lateral axis causes the front of the airplane to move up or down.

For example, a dual-axis autopilot will be able to keep both the wings and the nose of the aircraft level. Pilots may use the dual-axis system to hold a particular direction, follow commands from a navigation system, maintain an altitude, and climb or descend at a specified rate.

The three-axis autopilot is a combination of a dual-axis system and a yaw damper. Airliners and large business aircraft are normally equipped with a three-axis autopilot. Three-axis systems are connected with navigation and flight-management systems. In addition, they may include features such as throttle control and ground steering.

Integration

Many autopilots can connect to, or be integrated with, a navigation system. In a single-axis autopilot, this may merely be a connection to the directional gyro. In a complex three-axis system, all of the navigation devices may be connected to the autopilot. In this case, the autopilot could be considered an integrated flight control system.

Most integrated flight control systems include a special attitude indicator known as a flight director indicator. In addition to the symbolic airplane and horizon reference line found in most attitude indicators, a flight director indicator includes a special set of needles called flight director, or command, bars. The flight director bars will move up, down, right, and left to indicate where the autopilot intends to fly. Often, these bars are operated by a special computer running in parallel with the autopilot computer. In case of an autopilot failure, the flight director computer will still be able to manipulate the flight director bars. Pilots can manually fly a precise flight path by keeping the bars centered. By allowing the flight director computer to make the complex calculations involved in flying a precise flight path, pilots are still able to reduce their workload.

How the System Works

In order to control the aircraft, an autopilot must be able to sense attitude. To do this, autopilots rely on gyroscopic instruments, or accelerometer-based sensors. Often, the attitude gyro is used to transmit information regarding pitch and roll attitude to the autopilot computer. A turn and bank indicator or a turn and slip indicator can be used to supply yaw information. The autopilot computer will compare the actual flight attitude of the aircraft with the desired flight attitude and, if necessary, move the appropriate control surface.

The device that operates the control surfaces of the aircraft is called a servo. A servo converts electrical energy into mechanical energy. Servos may be electric, hydraulic, or pneumatic. Electric and hydraulic servos are quite common. Electric servos are widely used on aircraft with mechanical or fly-by-wire controls, and hydraulic servos are widely used on aircraft with hydraulic controls.

Electric servos contain a small, electric motor. In this type of system, the computer sends a voltage to the servo, causing the motor to rotate. The motor is connected to the aircraft controls, and as the motor turns, the controls are moved.

Hydraulic servos contain a small, electrically controlled, hydraulic actuator. In this type of system, the computer sends a voltage to the actuator. Valves within the actuator channel hydraulic fluid in and out of small cylinders containing pistons. The pistons are connected to the control surface, and, as they move, the surface moves.

Pneumatic servos contain electrically operated valves. These valves channel air into bellows that are connected to the aircraft controls. The inflation and deflation of the bellows causes the controls to move.

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See also: Airplanes; Avionics; Flight control systems; Instrumentation; Pilots and copilots; Roll and pitch

Avionics

Also known as: Aviation electronics

Definition: A combination of the words "aviation" and "electronics."

Significance: Many aircraft cannot fly without avionics. Avionic equipment includes a variety of systems designed to assist pilots, aviation maintenance technicians, and passengers.

History

From the time avionics were invented in 1903 until approximately 1930, pilots rarely used them, navigating instead by known landmarks on the ground. In the 1930's, however, engineers began installing communications and navigation equipment in airplanes. The first system designed for airplane navigation was the direction finder (DF), also known as a homing beacon. In the late 1930's, the government began installing the first range stations, which allowed pilots to follow a specific course. Before World War II (1939-1945), electronic equipment was large, heavy, and often required an extra person to operate; therefore, only large aircraft used avionics.

During World War II, both Allied and Axis forces developed radio detection and ranging, or radar. In addition, the Allies developed the identification, friend or foe (IFF) system. The IFF system became the air traffic control (ATC) transponder. Throughout the 1940's, engineers made many improvements in the size and reliability of avionics. During the late 1940's and early 1950's, the very high frequency omnidirectional range beacon was developed, which was a great improvement to the original range stations.

In the 1960's, radios became lighter and smaller, mostly due to the application of the transistor to avionic equipment. The first avionics to use transistors were hybrids, or radios containing both vacuum tubes and transistors. In the 1970's, manufacturers introduced the first reliable solid-state avionics, using semiconductor devices rather than electron tubes. Simultaneously, avionics using digital systems were introduced. These developments allowed for even smaller, lighter, and easier to use systems. Consequently, small personal aircraft of the 1970's were able to have more complex avionics than could the large airliners of the 1950's.

The introduction of the microprocessor and database technology in the 1980's created a revolution in the avionics industry. For the first time, pilots could use long-range navigation systems, such as loran-C and Omega, for aircraft navigation. This new technology also allowed for increasingly smaller, lighter, and even easier to use avionics.

The 1990's brought the introduction of satellite navigation, known as the Global Positioning System (GPS). By the end of the decade, the U.S. government decommissioned the Omega navigation system, which GPS had made obsolete.

In the early twenty-first century, improvements in microprocessors allowed many more improvements in avionics systems. Three-dimensional moving map displays and low-cost electronic flight instrumentation are a few of the improvements to come about in the first decade of the third millennium.

Navigation

Avionics assist the pilot to navigate the aircraft in several ways. Many different navigation systems help pilots find their way across the globe and locate runways.

The automatic direction finder (ADF) indicates the direction of special radio navigation stations and AM broadcast stations. This system receives radio signals in the low- and medium-frequency bands. An indicator in the instrument panel simply points toward the source of the radio signals.

The very high frequency omnidirectional range beacon system provides the pilot with directional information relative to a course. This system receives radio signals in the very high frequency range from a station on the ground. The system is made up of a radio receiver connected to a device that converts the radio signal to visual information. The pilot chooses a bearing to fly, and a special indicator in the panel shows whether the airplane is to the left or right of a course, also known as a radial, that passes through the navigation station.

Loran-C provides pilots with long-range area navigation. The name "loran-C" is an abbreviation of "long-range navigation," with the "C" representing the fact that the current system is the third generation of loran. Originally, loran-C worked as a maritime navigation system; however, with microprocessor and database technology, it became available to pilots. Loran-C does not require the pilot to use a navigation station as a reference point, as do the very high frequency omnidirectional range beacon and the automatic direction finder. Instead, the pilot simply chooses an origin and destination within the loran-C coverage area, and the loran-C guides the pilot directly from the origin to the destination. The system consists of a low-frequency receiver, computer, database, and an indicator. The receiver listens for pulses from a set of transmitting stations, and the computer measures the time delay between pulses to determine position.

The Global Positioning System (GPS) provides pilots with a worldwide area navigation system. Although GPS is similar in design to the loran-C, it is much more accurate. Twenty-four GPS satellites orbit the earth and provide pilots with three-dimensional navigation signals. Often, the GPS system will work with a moving map display to show exactly where the airplane is. The system consists of an ultrahigh frequency receiver, computer, database, and indicator. The receiver listens for pulses from the satellites, and the computer measures the time delay between pulses to determine position. With wide- and local-area augmentation systems, GPS can be used as the sole means of navigation.

The Instrument Landing System (ILS) gives pilots guidance toward runways and consists of three major components. The first, the aircraft's localizer transmitter, is integrated with the VHF omnirange. When the pilot selects a special ILS channel, the VHF omnirange system switches to localizer mode. Now, instead of having several courses to choose from, the pilot has only one, which will lead to the end of the runway. The course directing indicator (CDI) will indicate whether the course is to the pilot's left or right.

The second ILS component, the glide slope, provides pilots with vertical guidance to the end of the runway. The glide slope consists of a UHF receiver and circuitry that converts navigation signal information to visual information. When the pilot selects an ILS channel with the VHF omnirange system, the glide slope automatically becomes active and provides information on the CDI to indicate whether the pilot is above or below the proper glide path.

The final ILS component, the marker beacon, then turns on a light in the cockpit as the aircraft passes over certain checkpoints during the approach to the airport. A special receiver in the airplane is tuned to 75 megahertz and will listen for special signals from marker transmitters placed along the localizer course.

Distance measuring equipment (DME) uses radar principles to measure the distance between the aircraft and special navigation stations on the ground. The DME displays distance, speed, and time to or from the navigation station. The aircraft system consists of a transmitter and a receiver. The UHF transmitter sends pairs of pulses to a ground station, which the ground station then sends back to the aircraft. The DME will measure the time elapsed from when the pulses were sent to when they return and will calculate distance, speed, and time.

Communication

There are many communications systems on board aircraft. In small airplanes and helicopters, the system will consist of a VHF transceiver for the pilot to communicate with air traffic controllers. Similar to a citizen's band radio, this more powerful system can have up to 2,280 channels. Many aircraft also have an intercom with which to communicate with other crewmembers and passengers.

In addition to the VHF transceiver and intercom, some aircraft may have high-frequency transceivers or satellite transceivers to allow long distance communication on transcontinental flights. Although similar in purpose, the design of these two systems is quite different. The high-frequency (HF) transceiver transmits and receives frequencies between 3 and 30 megahertz. Radio frequencies within this range have the ability to stay in the earth's atmosphere and travel around the world. The satellite system uses ultrahigh frequencies and an antenna that swivels to remain pointed at a communications satellite in orbit above the earth. The signal travels from the airplane to the satellite and is then relayed to any place on Earth.

Another communications system is the aircraft communications and reporting system (ACARS), a private, low-speed, digital communications system used by the airlines to communicate between the aircraft and the operations center. Aircraft may also include passenger address systems that allow the pilots to speak to passengers and a radio telephone system that allows passengers to call friends, relatives, and business associates.

Surveillance

Air traffic controllers use two systems to track the movements of aircraft: the primary surveillance radar and the secondary surveillance radar. The primary surveillance radar uses a powerful transmitter and a large rotating antenna to send strong bursts of microwave energy into the air. The microwave energy reflects off the aircraft, returns to the large antenna, and shows up as a dot on the air traffic controller's radar display. However, not all aircraft reflect microwaves well, and such aircraft may not show up on the radar display.

For this reason, all private and commercial aircraft are required to have special equipment on board that acts as part of the secondary surveillance radar system. Secondary surveillance radar sends a pulse code to a special radio in the aircraft called an ATC transponder. The ATC transponder replies with its own pulse code, which may contain a variety of information, such as altitude, speed range, and assigned codes, that will show on the air traffic controller's radar screen.

Aircraft can also perform surveillance on each other. Airliners and large business aircraft use a system called transponder-based collision avoidance system (TCAS). A TCAS-equipped aircraft sends a pulse code to which other aircraft with ATC transponders reply. A special instrument in the first aircraft displays the location of the second, indicates collision threats, and recommends a flight direction to avoid collision.

Many aircraft are equipped with weather-surveillance systems. These come in two varieties, active and passive. The active system uses radar. Mounted in the nose of the aircraft, the antenna points forward and sweeps back and forth. The radar transmits energy in front of the aircraft, and water droplets reflect this energy back to the radar antenna. Rain will display on a screen in the instrument panel of the aircraft.

The passive weather-surveillance system uses a special loop antenna to detect the electrical activity associated with thunderstorms and air turbulence. The activity is shown on an indicator in the instrument panel of the aircraft. Both systems help pilots avoid dangerous weather and, in some cases, can be combined into a single, comprehensive weather-avoidance system.

Autopilots

Many aircraft are equipped with autopilots, which fly an aircraft automatically while the pilot accomplishes other tasks. The simplest autopilot is a single-axis system. The single-axis autopilot controls the airplane on only one of the axes of flight. For example, a wing leveler will keep the wings level, but the pilot will be responsible for keeping the nose level, and keeping the tail in line. The dual-axis autopilot controls two axes of flight, keeping both the wings and the nose of the aircraft level, for example.

The three-axis autopilot maintains control of the aircraft in all axes or directions. Often, two- or three-axis systems are interconnected with navigation and flight-management systems, and may include features such as throttle control and ground steering. In these cases, the autopilot is considered an integrated flight-control system.

Passenger Entertainment and Convenience

There are many systems designed for passenger entertainment and convenience. Many aircraft have special telephones that passengers may use to make telephone calls. In addition, multichannel sound systems deliver several styles of music from which passengers may choose. In larger airliners, video systems allow passengers to watch movies or play video games. In some aircraft, passengers can keep track of the flight's progress by viewing a moving map display. In addition, business jets may have a local area network, printers, and modems to allow passengers to work while in flight.

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B

Baggage handling and regulations

Definition: Airline procedures and processes for carrying passengers' baggage from their points of departure to their final destinations.

Significance: Airline baggage handling procedures and regulations help to ensure that passengers' baggage will accompany them on their flights and be at their destinations when they arrive. Airline procedures also ensure that all items accepted as baggage meet safety and security guidelines and regulations to protect passengers and airline personnel.

The Process

The baggage handling process begins when passengers present themselves to check in for their flights. Much like the passengers themselves, who receive seat assignments and boarding passes, baggage is also checked in. At baggage check-in, either computerized or handwritten baggage or destination tags are attached to each bag and a claim check is given the passenger. The baggage tag specifies the passenger's airline, flight, connecting cities (if any), and final destination. Computerized tags may also display the passenger name, date, time, and reservation information.

At some airports, passengers can have their baggage checked and tagged in either one of two places, at skycap locations or at airline ticket counters. Skycaps are individuals stationed at curbside locations in front of airport terminals. They offer the convenience of immediate baggage checking, enabling passengers to proceed directly to their departure gate for boarding passes. Curbside checking was banned at many airports for security reasons in the aftermath of the terrorist attacks of September 11, 2001. Airline ticket counters offer all baggage, passenger, boarding, and ticketing services.

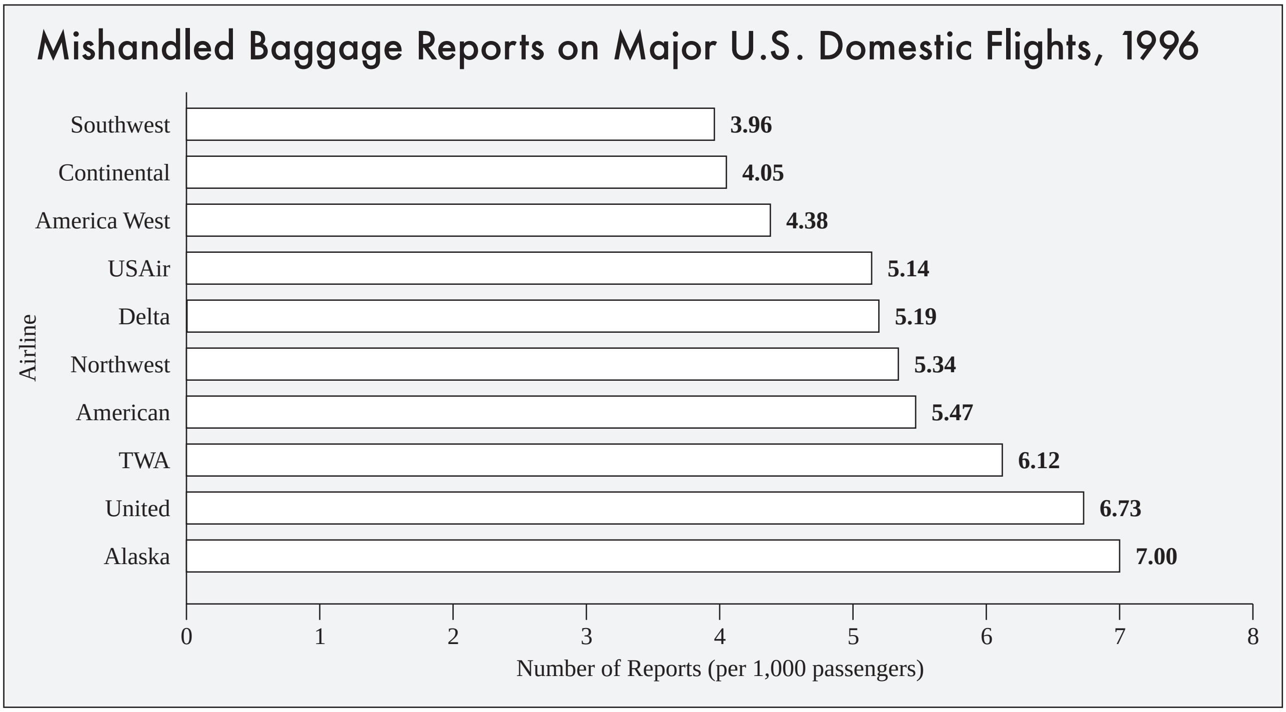
Both skycaps and airline ticket counter agents must follow certain precautions and procedures when checking baggage. For safety and security, they must ask all passengers whether anyone unknown to them has asked them to carry any items on their flight and whether any of the items with which they are traveling have been out of their immediate control since the time they were packed. To ensure that all of a passenger's baggage arrives at its destination, skycaps and airline ticket counter agents use a procedure called "Ask, Tag, and Tell." "Ask" reminds the skycap or agent to ask the passenger's final destination and the number of bags being checked. "Tag" reminds the skycap or agent to produce the correct number of tags to the correct destination and to affix the tags to the bags. "And" is a reminder to ask whether each bag has a separate passenger identification tag. "Tell" reminds the skycap or agent to tell the passenger how many bags have been checked to their final destination.

After the bags are checked and tagged, they are usually put on a baggage belt conveyor system. Bag belt systems take bags from skycaps or ticket counters and transport them to the baggage makeup area. Airline employees in a baggage makeup area sort baggage by flight numbers and destinations and place them into carts or other conveyor systems to transport the baggage to the aircraft. At the aircraft baggage is further sorted for loading and unloading purposes. Bags going only to the aircraft's destination are loaded in one section, usually called local baggage. Bags that are going to a connecting flight are loaded into another section, usually called connect bags. Messages are sent to the destination city after the plane takes off, telling where the different bags have been loaded.

Upon landing, the process is reversed. Local baggage is unloaded into specific carts or conveyor systems that transport it to the baggage makeup area. There it is placed onto other conveyor systems that transport it to the baggage claim area. In baggage claim areas, passengers pick up their bags. Connect bags are unloaded into other specific carts or conveyor systems that transport them either to the baggage makeup area to be brought back out to the connecting airplanes or directly to the connecting airplanes.

Missing or Lost Baggage

In the event that a passenger's bags do not arrive with the passenger or a bag arrives without a passenger, airline baggage service offices in baggage claim areas handle missing, lost, or found baggage reports. These reports document how many bags are missing or found, the tag and flight numbers from the claim checks, descriptions of the



Source: Data taken from U.S. Department of Transportation.

bags and their contents, and passenger contact information. This information is entered into bag tracing systems that are intelligent databases. These systems constantly search themselves to identify and match missing or found bags to the passengers who checked them. The industry average of missing or lost bags is approximately 3 percent of every one thousand bags transported. Of that 3 percent, most are located and reunited with passengers within forty-eight hours.

Baggage Acceptance Guidelines

For the safety and security of an airline and its passengers, airlines have established baggage acceptance guidelines. These guidelines concern themselves with baggage contents, how the contents are packed, and liability for their damage or loss.

Baggage acceptance guidelines address what are known as acceptable, conditionally acceptable, and unacceptable articles. Acceptable articles are considered to be the personal property necessary or appropriate for the purposes of the passenger's travel. Typical acceptable articles are clothes, shoes, personal, or business items. Airlines accept a liability of $2,500 per bag for damage or loss. Conditionally acceptable articles are those items considered irreplaceable, fragile, perishable, or improperly packed. Conditional acceptance also addresses the condition or quality of the receptacle containing a passenger's contents. Any suitcase or box must be of reasonable durability, must stay closed or sealed, and must be able to withstand normal handling. Conditional acceptance limits the liability of an airline for damage or loss. Unacceptable articles are those considered hazardous to passengers or aircraft. At no time are they ever accepted for transport.

Other acceptance guidelines address airline and aircraft security. These include requirements that passengers cannot check a bag onto a flight for which they do not have a ticket. Bags may not be checked to a different destination than that of the passenger. For most international flights, bags are not loaded until it is known that the passenger checking them has boarded the aircraft. There are also time requirements that specify how early or how late passengers may check their bags.

Other acceptance guidelines address how many, how heavy, or how large baggage may be. Although each airline has its own specific guidelines, generally speaking, most airlines allow three bags per passenger, including carry-on items passengers keep with them in the aircraft. Most airlines do not allow any bag that weighs more than 70 pounds or that exceeds 60 to 65 inches in outside linear measurement. When any of these guidelines are exceeded, extra baggage charges, which may be significant, are incurred. There are exemptions to allow for special items, such as wheelchairs, or other devices a passenger may require.

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See also: Air carriers; Airline industry, U.S.; Ticketing

Balloons

Definition: Fabric containers holding a lighter-than-air gas so that the containers and any payload are buoyed up and float in the sky.

Significance: One of humanity's oldest dreams has been to float in the sky. Balloon flights first transformed that dream into adventure, and they continue to do so. For more than a century after the first balloon flight, balloons were the cutting edge of science and aviation technology, and they remain the best craft for scientific missions operating in altitudes of roughly 10 to 30 miles, which are too high for airplanes and too low for orbiting vehicles.

Nature and Use

The term "balloon" may refer to the gas bag, or envelope, or to the balloon and any additional objects attached to it, which are usually hung below. Objects are attached to smaller balloons by a single line, but larger balloons require netting to spread the load over the entire gas bag. A large cargo below is called a gondola or basket, often a large wicker basket.

Buoyancy is the key to balloon flight. The ancient mathematician Archimedes stated that a body immersed in a fluid is buoyed up by a force equal to the weight of the displaced fluid. For balloons, a lighter-than-air (LTA) gas provides buoyancy to lift the balloon containing it as well as any payload. LTA gases include gases with densities lower than that of air and warmed air that has expanded and is thus lighter than the surrounding air. The two low-density gases used for balloons are hydrogen and helium, which require the balloon to be sealed so that they do not mix with the heavier air.

Air is usually heated for buoyancy by burning propane or kerosene. Warmed air rises through an open base, and air that has cooled drains out of that same orifice. Warmth is constantly drained away at the surface of the balloon so hot-air balloons require frequent firings of their burners. Consequently, they tend to have shorter range than balloons with low-density gas.

More importantly, hot air has less lifting capacity than hydrogen or helium. Typically, hydrogen has a net lift of 60 pounds per 1,000 cubic feet, but hot air provides only 17 to 20 pounds of lift. Thus, hot-air balloons must be three times larger to lift the same payload. However, hot-air balloons are less expensive to operate, because they do not have to accommodate the complexities of hydrogen and helium.

Although helium lifts 14 percent less than hydrogen (53 rather than 60 pounds) per 1,000 cubic feet, it has the major safety advantage of being nonflammable, whereas hydrogen can ignite explosively.

As a balloon increases its altitude, the density and pressure of the surrounding air decreases, meaning there is less lift available per unit volume, so the balloon must be larger to carry a given payload to higher altitudes. A partially compensating factor is that the buoyant gas also grows less dense as the pressure decrease allows it to expand, but the trend is toward miniscule lift per unit volume, as most of the atmosphere is left below. Balloon builders can compensate with lighter payloads, such as remotely controlled instruments, but at some point, the weight of balloon fabric alone matches the lift from the gas volume, and even the largest balloons can go no higher.

Balloonists have two other ways to vary the buoyancy of their craft. They can descend by decreasing buoyancy or land by valving out some of the lifting gas. They can increase buoyancy by dropping ballast, which is water, sand, or other material carried along for that purpose. In extreme conditions, balloonists have dropped all articles in the gondola and even the gondola itself.

History

For centuries, the Chinese made toy hot-air balloons of a design that could and might have been scaled up to carry passengers. There are accounts from twelfth century B.C.E. China of people in balloons, but the records are too old and incomplete to be confirmed. Likewise, drawings on pottery associated with the Nazca Lines, constructed more than two thousand years ago in southern Peru, suggest that these massive earthen line drawings were made with overhead direction from hot-air balloons.

Confirmable accounts begin in the eighteenth century. In 1782 and 1783, Joseph-Michel and Jacques-Étienne Montgolfier, two French brothers, flew hot-air balloons larger than toys, with animals as their first passengers.

Ironically, in their first balloons, the Montgolfiers had wanted to use hydrogen, which British chemist Henry Cavendish had discovered in 1776, noting in his experiment reports that this "inflammable air" was lighter than ordinary air. The French Academy in Paris was working toward a rubberized or varnished fabric to contain the troublesome gas that seeped through ordinary fabrics and escaped. When Joseph-Michel Montgolfier experienced the same problem, he noted that scraps of paper in a fireplace rose up the chimney. Paper, which the Montgolfier family manufactured, could contain smoke, so the Montgolfiers' made hot-air balloons and successfully flew three animal passengers: a rooster, a sheep, and a duck. King Louis XVI's permission was required for people to fly because it was not known whether leaving the ground might be harmful to people.

Jean-François Pilâtre de Rozier, a young doctor who wanted to take the risk of human flight, recruited the Marquis François d'Arlandes to serve as copilot and, more importantly, to secure the king's permission. On November 21, 1783, having obtained permission, the two men flew over Paris for twenty-five minutes while desperately stoking their lifting fire and sponging out fires in their rigging caused by sparks. Below them, nearly the entire populace of Paris watched.

Only a few days later, on December 1, 1783, Jacques-Alexander-César Charles, of the French Academy, flew a hydrogen balloon. The preparation required the production of large quantities of hydrogen gas and the careful varnishing of cloth to render it relatively airtight. The flight illustrated the advantages of hydrogen balloons over hot-air balloons. Because hydrogen is more buoyant than hot air, the hydrogen balloon could be a third the size of a comparable hot-air balloon. Charles flew for two and one-half hours, dropped off his passenger at sunset, and then rose high enough to be the first person to see the sun set twice in one day.

Shortly thereafter, balloonists began attempting not only to fly but also to reach destinations. Jean-Pierre Blanchard, another Frenchman, and John Jeffries, an American, decided to be the first aeronauts to fly across the English Channel to France, which they did on January 7, 1785. However, they were somewhat humbled upon arrival, because they had jettisoned most of their clothes, along with the gondola and the articles within it, in order to avoid falling into the Channel.

A rivalry ensued with the French wanting to have a flight from France back to England. Pilâtre de Rozier, who had piloted the first hot-air balloon, had another balloon made that advanced balloon technology. This hybrid de Rozier balloon had a hydrogen balloon that rode over a hot-air balloon. The pilot could vary the balloon's buoyancy, and thus its altitude, by adjusting the fire under the hot-air balloon instead of valving out hydrogen gas or dropping ballast, neither of which could be replenished. On June 15, 1785, Pilâtre de Rozier and his copilot floated in this balloon toward England.

Unfortunately, Pilâtre de Rozier fell prey to two problems of early balloonists. He had no reliable weather reports, and when the wind changed, he floated back toward France. Worse, his hydrogen lifting gas was very flammable and the varnished cloth only slightly less so. As the audience who had joyously witnessed the launch watched, the balloon caught fire, lost buoyancy, and plummeted the two aeronauts to their deaths. After Pilâtre de Rozier's death, hot-air balloons fell out of favor until experiencing a renaissance in the 1960's.

Similar problems plagued ambitious balloon flights for the next century. Attempts at crossing the Atlantic Ocean lost credibility as balloonists waited vainly for suitable weather. Balloon flights crossed the Alps in Europe, and John Wise crossed a third of North America, but the final destination of long-distance flights was always a surprise, and disaster was always just a spark away.

Despite its shortcomings, the balloon went to war in 1793 when revolutionary France was attacked by a number of neighbors. At the Battle of Fleurus in 1794, the fledgling French balloon corps fielded a single reconnaissance balloon tethered on a line several hundred feet above the ground. Observers in the balloon, who could see several miles past the line of battle, provided tactical reports via notes dropped from the gondola. The most important observation was that the attacking Austrian army had pitched an empty tent city in an effort to overawe the French commander into retreating. Because of that vital bit of intelligence, the French did not retreat but rather fought on with their exotic new technology looming over and unnerving their opponents, until they eventually won the battle.

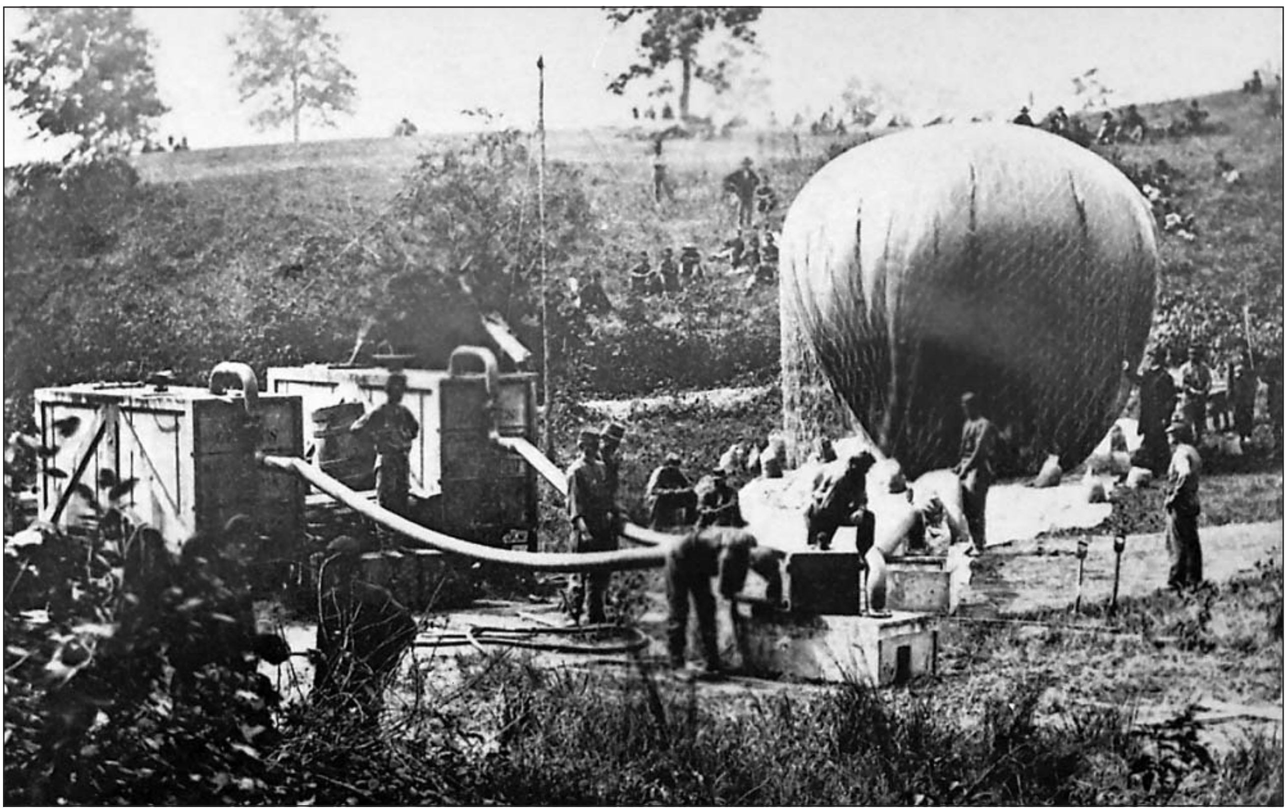
Aerial reconnaissance was reinvented in the American Civil War (1861-1865), in which several groups operated observation balloons. The most successful was inventor Thaddeus Sobieski Coulincourt Lowe, who organized an aeronautic corps of balloon observers for the Union. Although balloon technology had not advanced tremendously, communications technology had. Lowe's observers transmitted their reports either by signal flags or by telegraph wire running down to the ground.

The potential of Lowe's reports is shown by accounts of one 1862 engagement, in which Lowe directed Union cannon fire at an area invisible to Union guns because it was behind a hill. When the Confederate horsemen rode away from the shell impacts, Lowe had the guns redirect their fire. After the war, Confederate accounts revealed that one of the horsemen was showered by so much dirt from a near-miss that his colleagues feared he had been hit. That horseman was Jefferson Davis, the Confederate president. Nearby, also in danger, was Robert E. Lee, Davis's commander of all Confederate armies. Despite Lowe's successes, a change in the Union Army high command caused Lowe to fall from favor and come under stringent control by an unsympathetic regular officer. Lowe ultimately resigned from his post, and his entire corps withered away.

Military ballooning was next reinvented by the French during the Franco-Prussian War of 1870-1871. The Prussians smashed the regular French army and surrounded the French capital city of Paris. The plucky Parisians responded by raising a militia to hold off attacks and launching balloons to carry observers and send messages out of the city, rallying the countryside. Fifty-four of sixty-two balloons got through, carrying one hundred people and two and one-half million pieces of mail. Although France eventually accepted harsh peace terms, the utility of war balloons was established.

By the time World War I began in 1914, observation balloons were in use by both sides. By the end of the war, they were being replaced by heavier-than-air airplanes.

Surprisingly, small balloons did evolve into an important military and civilian use during World War II. The development of small radio transmitters combined with remotely operating weather instruments made possible



Balloons, such as this one photographed by Matthew Brady, were used during the American Civil War and other nineteenth century wars for military observation. (Corbis) balloon-borne radiosondes that reported temperature, pressure, and relative humidity. Angle data from antennas tracking the radiosondes yielded the more important factors of wind speed and direction at different heights. The use of weather balloons has continued into the twenty-first century to help predict weather, to plot sky conditions for aircraft, and to fire artillery more accurately.

Finally, in the 1990's, tethered balloons returned to service as aerostats, providing platforms at altitudes as high as 10,000 to 15,000 feet for radar stations and communications repeater stations.

Scientific Applications

Some have said that balloons are a pacifist technology. They are big, slow, and cannot be piloted accurately, particularly when the wind changes. Yet, balloons do a number of things well. They move gently and can carry large payloads that would not fit in an airplane fuselage. Most importantly, they can reach high enough altitudes to perform many of the research tasks generally performed by spacecraft. However, balloons can accomplish this research more cheaply and quickly than can spacecraft, and without the vibration and acceleration forces of a rocket launch into space.

In the twentieth century, a number of supporting technologies radically improved, allowing the balloon to become much more practical for research applications. Most importantly, helium became widely available as a nonflammable lifting gas. Synthetic fibers, such as nylon, polyethylene, and Kevlar, supplied fire-resistant materials with the lightness of silk and strengths approaching steel. Vulcanized rubber allowed light, cheap, disposable balloons. Virtually all measuring instruments shrank in size. Finally, worldwide weather databases and communications links made it more possible to guide balloons on long voyages.

The quest for altitude began as both an adventure and a science. The first balloonists had no idea whether the atmosphere continued indefinitely or became lethal a short distance above the ground. They soon discovered that pressure and temperature decreased with increasing altitude. Those who attempted altitude records discovered temperatures tens of degrees below the freezing point of water. However, the greatest risk was hypoxia, or oxygen deprivation, which causes weakness, shakiness, mental confusion, and eventual death. To deal with these problems, balloonists developed oxygen-supply systems and learned to use equipment that would not freeze in the bitter cold.

However, even the breathing of pure oxygen was found to be insufficient above altitudes of 49,000 feet. Swiss balloonist Auguste Piccard surmounted this problem with a pressurized cabin that essentially represented the first space capsule. On May 27, 1931, Piccard and an assistant launched from southern Germany and reached 51,793 feet, making them the first fliers ever to reach the stratosphere. More importantly, they discovered that cosmic rays increased with altitude, proving that these rays came from somewhere in space and not from radioactivity within the earth.

From 1933 to 1935, the governments of the United States and the Soviet Union foreshadowed the space race that would begin nearly a quarter-century later. Balloon flights carried personnel and instruments to steadily greater heights and developed many technologies that were later used in the space race. For example, on May 4, 1961, the American Stratolab High V balloon reached a world-record-breaking altitude of 113,600 feet, with an open gondola so that the two pilots could test space suits in near-space conditions for the Mercury orbital-flight program.

In retrospect, the best high-altitude science data began to be collected in the 1960's, after improved robotic instrumentation allowed shedding the weight of the balloonists and their life-support gear. Over the closing decades of the twentieth century, astronomic balloon-borne instruments conducted sky surveys in a number of frequency bands that cannot penetrate the lower atmosphere and provided valuable weather data from the lower stratosphere.

By the late twentieth century, the National Aeronautics and Space Administration (NASA) began using superpressure balloons for relatively small payloads of several tens of pounds. Balloons called zero-pressure balloons expand when warmed by the sun and contract at night when cooled. When warmed at high altitude, they must vent excess helium to prevent bursting. This gas loss limits mission duration to only several days. Superpressure balloons, in contrast, keep the same maximum shape when the balloon is warmed. Because no gas is lost, such balloons can operate for weeks or months, and some of these balloons have circled the globe one or more times. By the early twenty-first century, NASA had begun flying large superpressure balloons in a program called the Ultra Long Duration Balloon (ULDB). These large balloons could carry several tons of instrument payload for weeks at a time. Less well documented are flights of small superpressure balloons by U.S. intelligence agencies since the 1950's.

Recreational Applications

Although ballooning is no longer the world's primary means of aviation, a balloon ride remains a beautiful and awe-inspiring experience. Balloonists enjoy panoramic views that float by below them and sounds that float up from the ground.

However, a recreational balloon ride was a rare experience until the so-called renaissance of hot-air ballooning, which was started by American balloonist Edward Yost. While Yost was developing high-altitude balloons for the U.S. government in the 1950's, it occurred to him that polyethylene-coated nylon would be a lighter, less flammable material than that used for the Montgolfiers' balloons. He used an acetylene welding torch as a less labor-intensive source of hot air than that used by the Montgolfiers. After some development, such as replacing the welding torch with a propane burner, Yost made the first "modern" hot-air balloon launch from Bruning, Nebraska, on October 10, 1960.

Beginning in the 1960's, the new hot-air balloons radically reduced the cost and complexity of supplying buoyant gas. Thus were born ballooning clubs, competitions, and tour services. Hot-air balloons have been flown, primarily for advertising, in whimsical shapes, including those of spark plugs, light bulbs, human faces, and even a mansion.

A combination of Yost's hot-air technology, lightweight insulating material lining the gas bag, and helium made the de Rozier balloon practical for more ambitious, long-distance flights. Varying the amount of heat in the inner balloon provides altitude control for hunting favorable winds. That capability, along with worldwide weather reports, made it possible to make balloon flights across the Atlantic and Pacific Oceans. In March, 1999, another Piccard, Auguste's grandson, Bertrand, and Brian Jones spent twenty days flying 30,000 miles to make a complete circumnavigation of the globe.

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See also: Richard Branson; Buoyant aircraft; Lighter-than-air craft; Montgolfier brothers; Auguste Piccard

Barnstorming

Also known as: Gypsy flying, air circus

Date: Beginning in the 1920's

Definition: Originally a theater term, "barnstorming" refers to pilots and aerial performers who traveled between small, rural U.S. towns putting on air shows and selling plane rides.

Significance: Barnstormers introduced the concept of air travel to rural Americans, providing aerial displays and airplane rides. Many barnstormers were World War I veterans flying war surplus planes.

Beginnings

In the early part of the twentieth century, most people had only heard of airplanes. World War I created the first demand for planes and pilots, and although more than nine thousand men trained to fly, fewer than eight hundred of them actually saw combat. When the war ended in 1918, surplus planes, mostly Curtiss JN-4D biplanes, also known as Jennys, were both available and affordable.

During the postwar years, the civil aviation industry was in its infancy, and a pilot's license was little more than an honorary certificate. Anyone who wanted to fly an airplane could do so. Veteran aviators purchased these surplus planes and became the first barnstormers, itinerant pilots who provided many rural Americans with their first experience of flight. Barnstormers thrived in the open farmlands of the American Midwest, where a typical barnstorming season lasted from May to October. Weekends were ideal times to sell rides, and some barnstormers planned their routes to coincide with county fairs or local holiday celebrations.

Operations

Barnstorming pilots circled a town a few times to advertise their presence before landing in a nearby field and waiting for the customers to find them. On average, five minutes of flying time cost fifty cents in gas and earned the pilot five dollars. A small percentage of that sum went to the farmer who owned the field, and the rest paid for the pilot's gasoline, maintenance, and expenses. The average barnstormer made between thirty and one hundred dollars per week.

As the novelty of air flight began to wear off, barnstorming pilots found they needed to do more than give rides, and stunt-flying became part of the performance. One of the most common airborne stunts was the inside loop, in which the pilot flies upward then arches back over, while centrifugal force holds the pilot in the seat. More unusual was the outside loop, in which centrifugal force worked against the pilot. Other stunts included rolls, stalls, and reverses.

As barnstormers continued to expand their acts by adding additional performers, the air circus was born. Exhibition jumpers demonstrated parachutes, which were first deployed by a cable attached to the plane's wing. The invention of the ripcord allowed jumpers to control the length of their free fall, making the plunge appear even more dangerous.

Wing-walkers, many of whom were women, stepped out of the cockpit and into specially constructed harnesses that allowed them to defy gravity while the pilot performed a series of aerial maneuvers. Famed aviator Charles A. Lindbergh got his start traveling with a barnstormer, working for free and paying his own expenses while performing as both a parachutist and a wing-walker.

Developments

Stunts became more dangerous as spectators grew used to the sight of airplanes. The Locklear Flying Circus advertised stuntmen who would change planes in midair, and the fee per performance grew to three thousand dollars. Daredevils jumped from plane to plane, from planes to trains, climbed ladders from automobiles, motorboats, motorcycles, and horses. Repairs, part changes, and refueling operations were all performed in midair. Although parachuting had been an early part of barnstorming performances, air shows began advertising that their pilots and stuntmen performed without parachutes.

Publicity was everything. The growing motion picture industry fueled the fire, as cameras could be attached to spinning airplanes. One pilot, Leslie Miller, arranged a demonstration in which he would "loop" a Florida bridge, agreeing beforehand to fail on his initial attempt, so that on the next day, the crowd would swell in the expectation of seeing him crash.

Regulations

The Federal Air Commerce Act of 1926 marked the beginning of the end for the barnstormers. Under these new regulations, pilots had to be both licensed and medically approved for flying, air schools had to be certified, and planes had to be inspected for airworthiness and then registered and marked. Stunt flying, especially near populated areas, was severely restricted.

Although enforcement was lax, most pilots balked at the restrictions. Those who continued to fly either confined their flying to less populous areas or moved to Mexico, where the regulations held no sway. Many small-town airports were established by retired barnstormers who had settled down to give flying lessons. The air circuses gradually faded away as well. Denied their death-defying stunts, most barnstormers had gone out of business by 1930.

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See also: Aerobatics; Air shows; Crop dusting; Jennys; Charles A. Lindbergh; Safety issues; Wing-walking; Women and flight; World War I

Bats

Definition: Flying mammals that can be found in nearly every habitat, except extremely hot deserts and extremely cold polar regions.

Significance: Worldwide, there are almost 1,000 species of bats, the only type of mammal that can fly.

Bats are beneficial in nature because they eat insects, pollinate flowers, and help scatter the seeds of many plants.

Background

The fact that bats can fly makes them unique among mammals. Flying squirrels and flying lemurs, despite their names, do not really fly. Because they do not have wings, they merely glide through the air as they jump from trees. Bats, however, have wings that are the result of millions of years of evolutionary development.

Bats belong to the order Chiroptera, a word that means hand-wing. There are two suborders: Megachiroptera, which includes 42 genera and 173 species of flying foxes and Old World fruit bats, and Microchiroptera, made up of 144 genera and 813 species. The members of the first suborder are found only in Europe and Asia. Flying foxes have foxlike faces with very large eyes, but, unlike other bats, they do not use echolocation, a kind of natural radar for finding insects and other objects.

Echolocation is a process used by bats and a few other animals to identify objects in their environment and measure their distance from them. This ability involves listening to echoes of sounds produced sent by the hunter to bounce off his prey. A person who shouts in a tunnel and listens for the echo is using a simple form of this process. Because animals of the suborder Microchiroptera have this natural radar, they are much more successful and widely distributed than animals of the suborder Megachiroptera. Bats are among the most numerous mammals in the world's rainforests. In some forests, bats pollinate or disperse the seeds of more than 30 percent of all trees.

Evolution

The oldest bat fossils date to about 60 million years ago, and show that bats are native to North America. Scientists believe that the ancestors of bats were tiny, mouse-like mammals that ate flying insects and lived high up in trees. Over time, these animals developed membranes between their forelegs and their bodies that gave them the ability to glide from branch to branch, much like modern flying squirrels. This membrane gradually transformed into a moveable wing that gave bats a major advantage over their rivals: the ability to fly above the trees to catch their prey.

Students of bat evolution speculate that early species had developed the ability to echolocate, which gave them the ability to catch flying insects at night, but the exact origin of this power is unknown. Bats are sometimes compared with birds, because both can fly. However there are about eight times more species of birds than bats. This is because bats are a younger group than birds, which means they developed their flying ability long after birds took to the air. Another difference between birds and bats is that bats cannot use their legs, which are attached to their wings, to swim, dive, run, or dig. Birds' legs are separate from their wings and can thus be used for food gathering and other activities.

Flight

True flight offers many advantages to creatures, such as bats, birds, and insects, that have the ability. Flight gives these creatures access to many new sources of food and is a very effective way to evade enemies and predators. Flight also makes long-distance migrations possible and allows animals the ability to get past obstacles, such as rivers, oceans, and mountains, which flightless species cannot cross without difficulty or assistance. Flying also requires less energy than other modes of movement, such as walking or swimming. Bats and birds use less than one-fourth of the energy used by land-based animals for locomotion.

Most animals have not developed the complex structures necessary for flight. The basic requirements for flight include a method of keeping the body above the ground (lift), a means of moving the body through the air (thrust), and a design that minimizes air resistance. The bat's wing provides both lift and thrust. It contains the same basic arm and hand bones found in all mammals, except that the bat's five finger bones are very long and slender.

The membranes used for flight are extremely thin sections of skin, which are stretched between the arms, fingers, body, legs, and feet. Although they appear delicate, the membranes are actually stronger than rubber gloves and can be torn only with great force. The muscles that move the wing are located on the chest, back, and shoulder. This arrangement allows bats to fly with less energy than if the muscles were on the wing. Because bats' legs are used more for flight than for moving around on land, their pelvises and legs are very small, giving their bodies a streamlined, slender body shape that cuts down on air resistance.

Bats achieve lift and propulsion by the downstroke of their wings. The lift is caused by air moving faster over the top of the wing than under it. To increase their speed, both bats and birds increase the speed of air moving past their wings by changing the angle of the downstroke and changing the curvature of the wing. Most bats begin flight by taking off from a roosting site. Bats spend more than one-half of their lives roosting in places, such as caves and trees, in which they are protected from both weather and predators. They hang upside-down resting in their roosts, usually during the day.

When hunting, bats eat a wide variety of foods, including pollen, fruits, leaves, mosquitoes and other insects, scorpions, fish, frogs, birds, and sometimes even other bats. Most bats are intelligent and can be trained to fly or walk through mazes. They can also be taught to respond to commands. The activities of bats are regulated by light. Because they are active mainly at night, they avoid competition with birds for food. They can also escape from being captured by owls, hawks, and falcons.

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See also: Animal flight; Birds; Evolution of animal flight; Forces of flight; Insects

Battle of Britain

Date: From July 10, 1940, to October 31, 1940

Definition: A series of aerial bombings made by the Germans over British cities during World War II.

Significance: The Battle of Britain, designed to completely demoralize the British by destroying the nation's industrial and military infrastructure, was the first major battle to be fought almost entirely in the air.

Background

By the end of June, 1940, the German army had conquered almost every country that had opposed it. Only Great Britain, protected by the English Channel, remained in the fight, even though it had lost much of its army on the Continent in fruitless support of its allies. Thus, when German chancellor Adolf Hitler offered peace to Britain, much of the world thought his offer would be accepted. When Britain refused, Hitler issued orders for an invasion, a vital preliminary to which would be the elimination of the British Royal Air Force (RAF).

Protagonists

To carry out the destruction of the RAF, the German Luftwaffe had 1,050 fighter aircraft and 1,600 bombers, based on airfields from Norway to the Atlantic coast of France. The actual number of these craft that were serviceable and available for operations varied from day to day. Against these, the RAF could field 550 single-seat fighters immediately available and serviceable, in about fifty squadrons stationed on airfields from the north of Scotland to the west of England. The figures of available aircraft for both sides varied as the battle progressed, but the proportions remained much the same.

Aircraft

Although the German bombers were the Luftwaffe's main agents of destruction, the fighters were the most important, because they could sweep away the RAF fighters to allow the bombers clear passage. Similarly, the fighters in service with the RAF were the only weapons that could stop the German bombers from ranging over the country.

The Luftwaffe's main fighter, the Messerschmitt Bf-109E, could reach a speed of 355 miles per hour and an altitude of 36,000 feet, but it had an operating range of little more than 400 miles. This limitation meant that the Bf-109E could spend a very small amount of time over the target area if it was to have sufficient fuel to return to base. The Luftwaffe also used the Messerschmitt Bf-110, a large twin-engine aircraft that was designed to fly long distances but could also take on defending fighters like its single-engine cousin, the Bf-109. However, the Bf-110 was quickly found to be more of a liability than an asset when confronted by the RAF's more nimble Spitfires and Hurricanes.

In defense of Great Britain, the RAF employed two types of single-engine fighter, the Spitfire and the Hurricane, of which the latter made up about three-fifths of the total. The Hurricane had a top speed of 330 miles per hour and could reach altitudes of 34,000 feet. It had a range of 500 miles and could absorb a great deal of battle damage while serving as a good, steady gun platform. The Spitfire was a slightly younger aircraft and benefited in its construction from slightly newer technology. It could reach a speed of 360 miles per hour and an altitude of 32,000 feet and had a range of 400 miles. Possessing great maneuverability, the Spitfire was armed much like the Hurricane, with eight 0.303-inch machine guns. Although these were

Germany's first mass air raid on London on September 7, 1940, marked the beginning of the Battle of Britain. (Digital Stock)

perhaps outclassed by the armament of the Bf-109 and Bf-110, which carried 20-millimeter cannon, they were sufficient to shoot down Luftwaffe bombers. The range of the British fighters was not as critical as that of the Bf-109, because the Spitfires and Hurricanes had a critical advantage in the RAF's advanced and efficient fighter control system.

Fighter Control

The best fighter aircraft flown by the finest pilots would have been to no avail if they had not known where their enemy was. The RAF, however, relied upon a combination of radar to warn of enemy formations approaching the coast, an observing organization to track the enemy over land, a system of control rooms, each responsible for a certain area, with radio communications between them, and the airborne pilots themselves to make the most efficient use of its resources. In this way, the outnumbered Spitfires and Hurricanes were able to intercept the incoming Luftwaffe directly, without wasting their efforts in flying patrols simply looking for the enemy.

Convoys

The English Channel, one of the busiest waterways in the world, in 1940 served innumerable convoys carrying materials and supplies along the British coast. In early July, the Luftwaffe began attacking these convoys to force the RAF into battle to protect them. Over the next four weeks, the Spitfires and Hurricanes were in combat almost daily with the Luftwaffe. After a month, losses were almost two to one in favor of the RAF. However, the Luftwaffe's large superiority in numbers meant that it could hold out longer than the RAF, which would eventually lose. Shipping in the Channel was reduced, but never completely halted, in order to remove the potential target from the Luftwaffe's sight.

Attack of the Eagles

To some extent, the Luftwaffe's convoy battles had been merely a means of distracting the RAF while the Luftwaffe prepared and positioned its resources for the main battle. On August 13, called Eagle day by the Germans, the main attacks started, beginning four weeks of concentrated bombing designed to destroy the RAF and generally weaken the country's ability to resist an invasion. Attacks on airfields, ports, and dockyards by large formations of German aircraft set the scene for the next weeks and betokened hard, intense fighting for both sides. At the end of the day, the Luftwaffe had lost forty-six aircraft; the RAF had lost only thirteen fighters, but many of the fighter squadrons' airfields and communications were damaged. The Luftwaffe hit more and more airfields and also damaged several radar stations but, apparently not realizing the importance of the radar system, failed to follow up on these particular attacks.

The airfield damage, however, was soon felt by the RAF squadrons, and a reduction in their fighting strength and efficiency became apparent. It was clear that if the Germans continued to attack in this fashion, they might achieve victory, an outcome which had not previously been considered by the British. The RAF continued to shoot down German aircraft at a greater rate than it lost its own aircraft and achieved notable success on some occasions. German bombers based in Norway attacked northern England without a fighter escort, on the assumption that all RAF fighters would have been drawn south to the Channel coast. At a cost of fifteen bombers, the Germans discovered they were wrong.

After another month, the Luftwaffe had lost some 670 aircraft, and the RAF had lost about 400 fighters. Damage to British airfields increased, whereas production of Spitfires and Hurricanes began to fall behind their losses. Pilots also were being injured and killed faster than the training system could replace them. It could be only a matter of time before the RAF became exhausted.

Air Raids on London

On September 7, the Luftwaffe changed tactics, turning their bombers away from British airfields and factories and heading for London. Nearly 1,000 German aircraft crossed the Channel and headed for the capital, to be met by some 250 British fighters that struggled to break through the fighter escort and attack the bombers. Many German bombers did get through, however, and heavily bombed London's East End, starting many fires in the docklands area. The RAF fighters had some success, shooting down thirty-six of the German raiders, but they also lost twenty-six Spitfires and Hurricanes of their own. Similar raids continued for another week, and the RAF used the time to repair and strengthen itself while intercepting the Luftwaffe at every opportunity. Then, on September 15, the Luftwaffe attacked with the largest number of aircraft ever, more than 1,000 aircraft headed for London once more, only to be intercepted and their formations broken up before they reached the city. In the fighting, the RAF again lost twenty-six fighters, but the Germans lost sixty aircraft. This date was the high point of the battle for the RAF and has since been known as Battle of Britain Day. Two days later, Hitler postponed the invasion of Britain indefinitely.

Later Stages

The battle continued through the remainder of September and most of October, as the Luftwaffe increasingly turned its efforts toward night bombings. From time to time, it mounted large raids during the day but mainly flew small, high-altitude raids, often with bomb-carrying Bf-109's rather than bomber aircraft. These stood a much greater chance of hitting their targets and flying away again without being shot down, but their effect was minimal. Finally, at the end of October, the battle fizzled out as autumn rain set in, but the people of Britain still had months of night bombing to endure. The German effort to defeat the RAF, however, had failed.

As the air battle progressed, the Germans prepared finally to invade Britain. As part of this effort, they had gathered from the canals of Europe a vast number of barges in which to transport their troops across the Channel. These barges, assembled in the Channel ports of France, were quickly spotted by RAF bombers, who regularly attacked them, causing considerable damage both to the barges themselves and to the port facilities that would be needed to mount the invasion. The bombers were also active against the Luftwaffe, attacking airfields from which the German aircraft flew, often at considerable loss to themselves.

Losses

From the beginning of July to the end of October, the two air forces had fought a massive battle, which neither had anticipated and which only the RAF had been designed to fight. Although both sides suffered severely, the Luftwaffe's losses were sufficient to make it realize it could not achieve its objectives. The RAF was able to absorb its losses and inflict upon the Germans their first defeat of the war.

The RAF lost 1,023 aircraft, including aircraft destroyed in air raids, and 537 men. The Luftwaffe's losses were much higher: 1,887 aircraft and 2,662 men. The differing ratios of aircraft to men is accounted for by the fact that the RAF losses were almost exclusively single-seat fighters, whereas the Luftwaffe losses included many bombers carrying crews of four or five. Also, an RAF pilot who bailed out unhurt was over his own country and might be back in the air the next day, whereas any Luftwaffe airman who bailed out was inevitably taken prisoner.

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See also: Bombers; Fighter pilots; Luftwaffe; Messerschmitt aircraft; Royal Air Force; Spitfire; World War II

Beechcraft

Definition: A Wichita, Kansas-based producer of small aircraft, including both propeller- and jet-driven models.

Significance: Beech Aircraft, often shortened to "Beechcraft," developed a reputation for high-performance, luxurious airplanes during the 1930's. The company continued this legacy, eventually expanding into business jets. Beech also became a mainstay in Wichita's economy.

Beginnings

Walter Beech, founder of Beechcraft, trained to be a pilot during World War I. Beech did not let the fact that he was not an engineer deter him from pursuing aviation as a career after the war. After a stint as a barnstormer, he joined the E. M. Laird Airplane Company of Wichita in 1921 as a pilot and salesman. Beech and Laird engineer Lloyd Stearman left the company in 1925 to form a new company, TravelAir, taking on another partner, Clyde Cessna. TravelAir produced several well-respected aircraft, most notably the Model 5000, but Beech's partners both decided to leave the company. In 1929, TravelAir became part of the Curtiss-Wright Company, and Beech moved to new executive offices in St. Louis. The United States' enthusiasm for aviation ended with the onset of the Great Depression, and TravelAir went out of business in 1932.

Birth of Beechcraft

After TravelAir folded, Beech and his wife Olive Ann moved back to Wichita determined to reenter the aircraft manufacturing market. Beech wasted little time, establishing the Beech Aircraft Company the same year TravelAir ceased to exist. Beech's chief engineer Ted Wells developed a masterful new design, the Model 17 Staggerwing. The plane carried five people at the remarkable speed of nearly 200 miles per hour. The Model 17, advertised as the "Beechcraft," and the successor, the Model 18, sold well given the economic conditions of the 1930's, and Beech enjoyed its first $1 million sales year in 1938.

War Years

Beech's successful Models 17 and 18 ensured the company a prominent place in the United States' defense expansion leading up to World War II. The company sold Model 18's to the Philippines and China, and General Henry Harley "Hap" Arnold ordered 150 modified Model 18's for the U.S. Army Air Corps in 1941. During the war, Beech produced some 7,400 twin-engine aircraft for the military, and only 22 for the civilian market. The company was among the 3 percent of manufacturers to earn the prestigious Army-Navy "B" production award five consecutive times. Beech also produced wings for the A-26 Invader during the war.

Postwar Aircraft

Beech, like its Wichita competitor, Cessna, looked to take advantage of an expected boom in private plane ownership following World War II. Some experts believed that airplanes would become nearly as ubiquitous as automobiles for family transportation. Both Wichita companies held excellent positions for competing in this new market. Following traditions established before the war, each focused its efforts in a different direction. Cessna emphasized a low-priced, efficient model, while Beech looked to attract a more affluent customer by offering greater luxury. In 1947, Beech introduced the Model 35, better known as the Bonanza. The Bonanza utilized a distinctive

Beechcraft Specifications

	Performance			*Engines*	*Weights*		*External Dimensions*			*Internal (Cabin) Dimensions*		
Aircraft	*Maximum Cruise Speed (miles per hour)*	*Certified Ceiling (feet)*	*Maximum Range (nautical miles)*		*Basic Empty Weight (pounds)*	*Useful Load (pounds)*	*Wingspan*	*Maximum Length*	*Maximum Tail Height*	*Length*	*Width*	*Height*
Beechjet 400A	539	45,000	1,742	Pratt & Whitney Canada JT15D-5	10,250	5,650	43 feet, 6 inches	48 feet, 5 inches	13 feet, 11 inches	15 feet, 6 inches	4 feet, 11 inches	4 feet, 9 inches
King Air 350	362	35,000	1,806	Pratt & Whitney Canada PT6A-60A	9,440	5,460	57 feet, 11 inches	46 feet, 8 inches	14 feet, 4 inches	19 feet, 6 inches	4 feet, 6 inches	4 feet, 9 inches
King Air B200	336	35,000	1,807	Pratt & Whitney Canada PT6A-42	8,420	3,970	54 feet, 6 inches	43 feet, 10 inches	14 feet, 10 inches	16 feet, 8 inches	4 feet, 6 inches	4 feet, 9 inches
King Air C90B	284	30,000	1,267	Pratt & Whitney Canada PT6A-21	6,810	3,150	50 feet, 3 inches	35 feet, 6 inches	14 feet, 3 inches	12 feet, 7 inches	4 feet, 6 inches	4 feet, 9 inches
Baron 58	232	20,688	1,569	Teledyne Continental Motors IO-550-C	3,890	1,634	37 feet, 10 inches	29 feet, 10 inches	9 feet, 9 inches	12 feet, 7 inches	3 feet, 6 inches	4 feet, 2 inches
Bonanza B36TC	230	25,000	1,169	Teledyne Continental Motors TSIO-520-UB	2,740	1,126	37 feet, 10 inches	27 feet, 6 inches	8 feet, 7 inches	12 feet, 7 inches	3 feet, 6 inches	4 feet, 2 inches
Bonanza A36	203	18,500	930	Teledyne Continental Motors IO-550-B	2,530	1,133	33 feet, 6 inches	27 feet, 6 inches	8 feet, 7 inches	12 feet, 7 inches	3 feet, 6 inches	4 feet, 2 inches
Beech 1900D	326	25,000	1,505	Pratt & Whitney Canada PT6A-67D	10,485	6,375	57 feet, 11 inches	57 feet, 10 inches	14 feet, 11 inches	25 feet, 3 inches	4 feet, 6 inches	5 feet, 11 inches

Source: Data taken from (www.raytheon.com/rac), June 6, 2001.

V-shaped tail configuration, and carried its passengers in quiet comfort at an impressive 175 miles per hour. To demonstrate the plane's reliability, a Bonanza flew nonstop from Honolulu to Teterboro, New Jersey, a distance of 5,273 miles, with no maintenance problems and a cost of only $75 in fuel. This performance made the Bonanza famous, and despite being relatively expensive, the plane was an enormous success for Beech, which sold ten thousand Bonanzas by 1970.

The company followed up with variations of the Bonanza, as well as several different models, before developing the twin-engine turboprop King Air 90 in 1964. This plane fit into the niche between the truly private planes and the luxurious corporate jets that began appearing in the early 1960's. The King Air created such enthusiasm that the company had a $28 million backlog of orders when the first plane came off the assembly line. Purchasers of the King Air included such notables as Volkswagen, Walt Disney Productions, and Art Linkletter. By 1984, half of the twin-engine turboprop planes delivered were King Air models. During the 1960's and 1970's, Beech looked for ways to enter the growing business jet market. The company's Wichita competitors, Cessna and Learjet, dominated the field, but Beech had trouble developing its own model. Ultimately, Beech abandoned its own design and purchased the established but struggling Mitsubishi Diamond 2 business jet program. Beech moved production of the Diamond 2 from Texas to Wichita and redesignated the plane the Beechjet 400. The 400 series did not match Beech's competitors in terms of performance, but an Air Force order for 211 400's helped attract attention to the model. Beech also worked to convince owners of the King Air to purchase the 400 models, rather than competitors' offerings. Despite performance shortcomings, the 400 series became a formidable presence in the business jet market by the early 1990's, thanks to Beech's aggressive marketing efforts.

Corporate Changes

Walter Beech guided Beech Aircraft until his death in 1950. Fortunately for the company, Beech's wife, Olive Ann, proved to be an outstanding leader. Mrs. Beech guided the company for eighteen years before handing it over to her nephew Frank Hedrick. In 1979, with Hedrick ready to retire, the company merged with Raytheon, a manufacturer of missiles, electronics, and appliances. In 1982, Raytheon removed Mrs. Beech and Hedrick as managers of the company, prompting Beech to resign from the board of directors and marking the end of an era.

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See also: Aerospace industry, U.S.; Airline industry, U.S.; Airplanes; Corporate and private jets; Manufacturers

Bell Aircraft

Date: Founded in 1935

Definition: The United States' most important developer and manufacturer of helicopters, aircraft, and rocket engines, with twenty aviation development firsts to the company's credit from World War II to the present

Significance: Bell Aircraft developed some of the most important aircraft of the twentieth century, including fighter planes, booster rockets for spacecraft, and helicopters.

Lawrence Dale Bell's interest in flight was first sparked by his older brother, Grover, when the two were teenagers in Santa Monica, California, in 1910. After Grover's death in a plane crash in 1913, Larry Bell renounced his interest in aircraft, but was persuaded to join the fledgling Martin Company, quickly rising to vice president and general manager. He left Martin in 1928 to work for Consolidated Aircraft in Buffalo, New York, and when that company relocated to California in 1935, Bell decided to form his own company. Bell Aircraft had a slow start, but has been a leader in rotorcraft, or helicopter, design, and development since 1941, when Bell opened a research facility in Gardenville, New York, headed by Arthur Young and his assistant Bartram Kelly.

Events in Bell Aircraft History

1941: Larry Bell, entrepreneur and founder of Bell Aircraft Corporation, encourages inventor Arthur Young in helicopter development.
1946: Young's Model 47 helicopter becomes the first commercially licensed helicopter in the world and Bell delivers its first unit to the U.S. Army.
1950-1953: The military use of helicopters for medical evacuation increases during the Korean War, in which 80 percent of helicopters used are of Bell design.
1951: Bell Aircraft creates a separate helicopter division in Fort Worth, Texas, to accommodate the overwhelming demand for production.
1957: After the death of Larry Bell, the helicopter division is reorganized as Bell Helicopter Corporation.
1960: Textron purchases several Bell Aircraft companies, including the Bell Helicopter Corporation.
1961-1975: The military use of helicopters is cemented during the Vietnam War.
1976: Bell Helicopter becomes Textron's largest division.
1982: Bell Helicopter is incorporated as a subsidiary of Textron, now officially known as Bell Helicopter Textron.

Bell Aircraft developed the Airacuda, the first World War II twin-engine, multiplace escort fighter, with 37-millimeter cannon and flexible gun turrets. Bell also developed the XP-77, the first all-wood modern fighter aircraft, and the P-59, the United States' first jet-propelled fighter aircraft. On October 14, 1947, Bell's X-1 piloted by Chuck Yeager broke the sound barrier at 662 miles per hour, an accomplishment followed by development of the X-1A, which in 1953 set a world speed record of 1,650 miles per hour. In 1957, Bell developed the Agena rocket engine, known as the "workhorse of the space age," with a 99.7 percent reliability record. The Agena was used on the Thor, Atlas, and Titan booster rockets in the Discover, Ranger, Mariner, and Gemini space programs.

Bell Helicopters

Bell Aircraft started the U.S. commercial helicopter industry when the Bell Model 47 was granted the first commercial license issued by the Civil Aeronautics Administration on March 8, 1946, and awarded the first Helicopter Type Certificate on May 8, 1946, shortly after Bell delivered its first production-line helicopter to the military. The Bell Model 47 became the foundation of the helicopter industry in the United States and is used for police work and in the medical, mining, and farming industries. The Model 47 was used for medical evacuation during the Korean War and in the United States. Five thousand Model 47's in twenty different configurations were built before Bell stopped production in 1973.

Bell Helicopter has remained the leader in medical evacuation helicopters, with the Model 206 widely used by police, fire departments, and medical ambulance services. Having built more then thirty-four thousand helicopters since 1946, Bell is the world's most prolific manufacturer of rotorcraft.

In 1951, the Bell Aircraft Corporation created a separate helicopter company which was headquartered in Fort Worth, Texas. This corporation was bought by the global conglomerate Textron in 1960 and became its subsidiary. Bell Helicopter Textron has eight thousand employees scattered among ten plants, including the state-of-the-art Bell Helicopter Textron Canada facility at Mirabile, Quebec, with 1,800 employees.

Twenty-first Century Rotorcraft

The company's newest helicopters are the Model 427 and 407 LongRanger. In 2001, Bell Helicopter Textron's current military production was the AH-1W Super Cobra, for the U.S. Marine Corps, and the OH-Kiowa Warrior. The company completed a 137-aircraft order for the TH-67 Creek trainers for the U.S. Army. Other contracts included one hundred CH-146 Griffons, which are highly modified 412-EP's, for the Canadian Forces utility tactical helicopter program.

With Boeing Vertol, Bell also produces the V-22 Osprey tilt-rotor aircraft for the U.S. Marine Corps and Special Operations Command. The V-22, another Bell first, can take off, hover, and land like a helicopter and can fly forward with the speed and range of a high-speed turboprop fixed-wing aircraft.

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See also: Airplanes; Helicopters; Manufacturers; Missiles; Osprey helicopter; Rockets; Sound barrier; Vertical takeoff and landing; X planes; Chuck Yeager

Bermuda Triangle

Also known as: Devil's Triangle, Limbo of the Lost, Hoodoo Sea, Port of Missing Ships, Twilight Zone

Definition: A triangular section of the Atlantic Ocean roughly defined by a line connecting the tip of Florida, the Bermuda Islands, and Puerto Rico, that is an area notorious for unexplained disappearances of boats, ships, and aircraft.

Significance: Although reports of unexplained disappearances in the Bermuda Triangle have been made since the mid-nineteenth century, the lack of substantial evidence ensures that the area's significance lies mainly in the popular imagination.

Origins of the Bermuda Triangle

A September 16, 1950, Associated Press dispatch by reporter E. V. W. Jones contains the first recorded mention of mysterious disappearances between Bermuda and the Florida coast. The dispatch ran in various newspapers within the next few days. Two years later, in October, 1952, *Fate* magazine published an article by George X. Sand on the same subject that defined the targeted area as a triangle bounded by Bermuda, Puerto Rico, and Florida.

Morris K. Jessup's *The Case for the UFO: Unidentified Flying Objects* (1955), Donald E. Keyhoe's *The Flying Saucer Conspiracy* (1955), and Frank Edwards's *Stranger Than Science* (1959) furthered speculation about the area's disappearances, blaming them on aliens from outer space. The first published use of the name "Bermuda Triangle" appears in Vincent H. Gaddis's article "The Deadly Bermuda Triangle" in the February, 1964, edition of *Argosy*. Gaddis's article, along with his 1965 book, *Invisible Horizons: True Mysteries of the Sea*, brought widespread popular attention to the region for the first time. Since then, the Bermuda Triangle has gained global renown, but the U.S. Board of Geographic Names neither recognizes the name officially nor maintains an official file on the area.

Unexplained Disappearances

The unexplained disappearances of vessels or crews that have given the Bermuda Triangle its mysterious reputation are said to have happened without warning during fair weather and have left no traces of either wreckage or bodies. When each incident is examined, however, mundane causes are often obvious, with facts frequently embellished or omitted for dramatic effect. Because the Bermuda Triangle's shipping lanes are busy, and because aircraft crisscross its skies in large numbers every day, it is not surprising that, over the years, many disasters have occurred in its waters.

Probably the most famous and dramatic disappearance is that of Flight 19. At 2:10 P.M. on December 5, 1945, five Avenger torpedo bombers took off from the Fort Lauderdale, Florida, Naval Air Station on a routine two-hour training mission in good weather. At 3:45 P.M., the flight leader and flying instructor reported that neither of his compasses was working. Voice communication stopped at 4:25 P.M., and the last radio signal was received at approximately 7:00 P.M. The most likely contributing factors to the disaster, aside from the malfunctioning compasses, were the flight leader's unfamiliarity with the area, the lack of clocks in the planes to keep track of time, few clear radio signals, and four inexperienced pilots who were unwilling to openly contradict their superior. In addition, as the weather worsened throughout the afternoon, extreme turbulence and unsafe flying conditions were reported.

The flight leader had been asked to switch to the emergency channel, but he refused, because he did not want to risk losing contact with the other four Avengers. Thus, his initial assumption that they were flying over the Florida Keys instead of the Bahamas could not be corrected by direction-finding stations. Ironically, when the flight leader first reported himself lost, he was probably right on course above the Bahamas. Although the search continued for weeks, it turned up no sign of the bombers or the fourteen men aboard. It is likely that the planes went down in the ocean by 8:00 P.M., somewhere east of the U.S. coast and north of the Bahamas, after flying around lost for four hours.

Adding to the magnitude of the tragedy was the fact that another plane was lost that night. However, its fate is more certain. A Martin Mariner seaplane with a crew of thirteen was one of several planes sent out on the search mission. An explosion was observed from a ship shortly after the plane's takeoff. Martin Mariners were nicknamed "flying gas tanks" because they tended to leak fumes. It is likely that a spark from some source ignited the plane's fuel and caused the explosion.

Many other aircraft have disappeared over the Bermuda Triangle. In 1948, a British Tudor IV airliner, the *Star Tiger*, was en route to Bermuda from the Azores when it vanished without a trace some time after the pilot radioed Bermuda to ask for a bearing. Because the plane was never recovered, no cause for the disaster could be determined, but unpredictable winds could have driven the aircraft off course after contact was lost at 3:15 A.M., giving the sea time to sweep crash debris from the scene. A Douglas DC-3 also disappeared in 1948 while flying from San Juan, Puerto Rico, to Miami, Florida. After the pilot reported being only 50 miles from the airfield in Miami, contact was lost, and the plane was never found, possibly sinking in the 5,000-foot depths of the Straits of Florida. In this case, the plane had been having trouble with its landing gear, batteries, and transmitter when it landed in San Juan and continued to have transmission problems as it left for Miami.

Although seagoing vessels have been lost in the Bermuda Triangle since the time of Christopher Columbus, most have vanished during severe weather or after a history of mechanical or personnel problems. Moreover, many disappearances associated with the area have actually occurred elsewhere. For example, the famous case of the *Mary Celeste*, encountered drifting without its crew in 1872, is often cited in stories about the Bermuda Triangle, but the ship was actually found near the Azores. The USS *Cyclops*, which sank in 1918 on a voyage from Barbados to Norfolk, Virginia, most probably lies, wrecked either by a storm or by its heavy load of manganese, on the ocean floor near Norfolk.

Possible Causes of Disappearances

Many fantastic theories exist to account for the disappearances, ranging from alien abductions to black holes to mysterious magnetic anomalies. Ivan T. Anderson claims that “vile vortices” caused by magnetic aberrations create “time slips” that convey the disappeared to other locations on Earth, including an advanced civilization allegedly lurking under the sea. Charles Berlitz has identified this civilization as the mythical lost Atlantis mentioned in the writings of the Greek philosopher Plato. Vincent Gaddis suspects that small black holes may pull ships and planes into other times or universes. However, there is no proof to substantiate any of these theories.

One recent theory has suggested that some unexplained disappearances might have been caused by large bubbles of methane hydrate, found during exploratory oil drilling in the Bermuda Triangle in 1995. Methane hydrate is a gas created when ice and methane are mixed together under conditions of high pressure far below the seabed. When the temperature rises or the pressure is released by a seaquake or underwater slide, the bubbles of gas rapidly expand at a rate of about 1 liter of hydrate to 45 gallons of methane. If the methane bubbled up under a ship, it would create a huge hole that would cause the ship to drop suddenly and sink. Aircraft might also be affected. Because methane is lighter than air, it would continue to rise in the atmosphere, causing potential problems for anything flying through it. Engine failure, explosions, or other problems could occur. However, this theory, too, remains unproven.

Although many boats, ships, and aircraft have disappeared in the Bermuda Triangle over the years, Lloyd’s of London, an insurer of some of the missing vessels, has stated that there is no evidence that more disappearances occur within the Triangle than in any other similar expanse of ocean. The U.S. Navy and Coast Guard maintain that environmental causes, mechanical failures, and human errors are to blame.

However, the Bermuda Triangle does have some unique environmental characteristics that are likely to have contributed to both the area’s disasters at sea and its eerie reputation. When Christopher Columbus sailed toward the vicinity of the Triangle in 1492, he became the first to record many of its most notable phenomena, among them the Sargasso Sea, an area almost the size of the continental United States, centrally located in the North Atlantic Ocean. The Sargasso Sea’s name is derived from the Portuguese word for the seaweed that clogs its waters. The seaweed is inhabited by unusual species of animals adapted to life on the weeds. This strange region is isolated by strong currents that cause it to slowly rotate clockwise and leave it with more salt and less wind, clouds, and rain than the rest of the North Atlantic. It is a repository for debris, wreckage, and spilled oil drifting in from all over the world, including derelict ships that have made it known as a ships’ graveyard. Because sailing ships could become stranded there for months, it is understandable that sailors learned to fear the region.

Columbus also noted curious compass variations in the Bermuda Triangle. Alleged magnetic variations have been blamed for some of the disappearances in the Triangle, but there is some compass variation almost everywhere, ranging from 0 up to 20 degrees, depending on longitude. During Columbus’s time, it was assumed that the compass pointed to the North Star, but Columbus realized that the compass must be attracted to something else, later thought to be the North Pole, but eventually found to be the north magnetic pole.

Navigators are trained to compensate for variation between the magnetic pole and the true pole as a matter of routine. Close to Florida, however, it is not necessary to compensate for magnetic variation because Florida happens to be in line with both the magnetic pole and the North Pole. With a magnetic variation of zero, getting lost is actually less likely than it would otherwise be. Mysteriously spinning compasses have also been implicated in disappearances, but compass needles frequently swing or spin with the motion of a boat or plane. Compass headings are calculated by averaging the high and low readings of the swinging needle.

Thunderstorms, tornadoes, waterspouts, and hurricanes can develop very suddenly in the Bermuda Triangle and are often more violent there than anywhere else on the globe. Contrary to the claims that the disappearances have occurred during fair weather, the reality is that most occurred during severe conditions. Columbus documented some of the storms common to the Bermuda Triangle, including a hurricane in 1502 in which ten ships were lost. Strong turbulence in and around storm clouds can cause aircraft to disintegrate, and freak waves up to 115 feet high can capsize and break apart even the largest of ships.

Unusually strong ocean currents like the Gulf Stream flow swiftly through the Bermuda Triangle. These currents frequently thwart successful search-and-rescue missions and add to the mystery of the Triangle by quickly dispersing wreckage. Many of the disappearances have occurred at night or near dusk, giving the currents hours to sweep away evidence of disaster. Unpredictable currents are also caused by the region's topography, varying from some of the world's deepest marine trenches to extremely shallow shoals that surround the islands, creating tricky navigational hazards.

Mechanical failure and human error can have even more disastrous results when compounded by severe weather conditions. Every year, countless inexperienced vacationers pilot boats and small aircraft between the islands off Florida's coast. Simple navigational errors can cause these craft to become hopelessly lost at sea. Small boats can be capsized easily in even moderately bad weather, hence the frequency of small craft warnings. At night, small boats can be run over by large ships and sink without being noticed. Even large ships can capsize in high seas or because they are overloaded or top heavy. Boats can suffer hull damage in collisions with other ships, reefs, and other obstructions. Corrosion and metal fatigue can cause ships to break apart. Similar problems or structural failures in aircraft, such as a jammed rudder or loss of an engine or wing, are even more deadly. In addition, faulty wiring, leaking fuel, and combustible cargo can cause fires and explosions. Catastrophic equipment failures or damaged communications can make calling for help impossible. Even hijacking, sabotage, and insurance fraud are suspected of causing some unexplained disappearances.

Sue Tarjan

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See also: Accident investigation; Hijacking; Instrumentation; UFOs; Weather conditions

Biplanes

Definition: An airplane with two levels of wings.

Significance: Most early aircraft utilized the biplane configuration, and biplanes remain popular for sport flying and aerobatics.

Reasons for the Biplane Configuration

From the early, pioneering flights of Orville and Wilbur Wright in 1903 through the 1920's and 1930's, biplanes represented the most practical aircraft configuration for both structural and maneuverability reasons. By the 1940's, they remained a practical choice only for training aircraft. Since then, biplanes have retained a certain popularity as sport and aerobatic and air show aircraft.

Until sufficiently light and powerful aircraft engines were developed, a large wing area was required to keep an aircraft aloft, and the biplane structure provided the most strength with the least weight. It was initially thought that thin wing sections were necessary for efficient generation of lift. In a biplane configuration, interplane struts and wire bracing provide a bridge-like strength and rigidity to the wing. Biplanes can use lesser wingspans, and both wings can use ailerons, resulting in the added advantage of maneuverability. Thus, for the first few decades of flight, biplanes were the configuration of choice for training aircraft, sport aircraft, military fighters, military bomber aircraft, and transport aircraft.

Famous Biplanes

America's best-known aircraft during World War I was the Curtiss JN "Jenny" trainer. It used a four-bay wing with eight interplane struts and many bracing wires, but it could fly two people with only a 90-horsepower OX-5 engine. After the war, Jennys were surplused and became the barnstormer's choice of airplane. The most famous World War I fighters were biplanes. In England, the De Havilland Tiger Moth was the trainer of choice between the world wars. In the 1930's, the Curtiss P-6E Hawk fighter biplane delighted the eye. In World War II, the best-known U.S. trainers were the Piper Cub monoplane and the Boeing-built Stearman PT-17 biplane. The Stearman had a reputation for indestructibility in the air and remains a popular sport biplane. When the Stearman was declared to be surplus after the war, it became the favorite of crop dusters, who took advantage of its great strength and load-carrying ability. It also survives as a popular sporting aircraft.

The biplane flowered in the interwar period. Travelair, which began producing biplanes in 1925, bettered the Jenny in control, comfort, speed, and safety. The Travelair D-4D is arguably the best-looking open-cockpit biplane ever built. During the 1920's and 1930's, the Waco Aircraft Company of Troy, Ohio, was by far the largest airplane manufacturer in the United States, building thousands of open-cockpit and cabin biplanes. The first Waco biplanes were built in 1922, but the Waco 9 appeared at the same time as the first Travelair and was highly regarded. The Waco Taperwing, using a tapered wing planform on both wings, remains popular.

Disadvantages of the Biplane Configuration

One disadvantage of the biplane is related to the extra drag of its wires and supporting struts and the interference drag between its two wings, which result in reduced cruising and top speeds for a given engine power. Another disadvantage is a poor lift-to-drag ratio that results in poor glide angles. By the 1920's, the most efficient aircraft were monoplane designs, such as Charles A. Lindbergh's *Spirit of St. Louis*. A monoplane is more simple and less costly to build. When aircraft designers learned how to make strong, internally braced aircraft entirely of aluminum, and when powerful and relatively light engines became available, the monoplane replaced the biplane as the configuration of choice for all high-speed aircraft.

The primary lifting surface of a wing is its upper surface, so the lower wing suffers the most from this; the gap between the wings is therefore usually made at least as large as the wing chord. If the wings are set at different angles (decalage), the relative loading of the wings and stall characteristics can be adjusted. Often the upper wing is mounted ahead of the lower wing, an arrangement known as positive stagger. This is particularly true for open-cockpit biplanes in which the front cockpit is under the wing and the rear cockpit, for stability reasons, is not placed too far back on the fuselage. However, the famous Beechcraft Staggerwing has a closed cabin and uses negative stagger. A biplane that has a smaller lower wing is known as a sesquiplane.

Most biplanes use the lighter tailwheel configuration for their landing gear, but the higher center of gravity and the poor view for the pilot upon landing mean that the directional instability of the tailwheel configuration requires significantly more pilot alertness and skill. Usually, the lower wing has a dihedral angle to provide lateral stability and to keep the tips farther from the ground, whereas the upper wing is straight, to simplify its construction.

Sport, Aerobatic, and Air-Show Biplanes

The biplane configuration has long been preferred for aerobatics because of its inherently good roll rate and because the extra drag of brace wires and struts prevents a rapid buildup of speed in the diving aspect of maneuvers. The 1920's and 1930's Great Lakes Trainer biplane was considered the best aerobatic aircraft of all U.S.-manufactured aircraft until the arrival of the Pitts Special. When the Great Lakes Trainer was first flown, it was found that its center of gravity was too far aft. This problem was corrected most simply by giving the upper wing rearward sweep. This correction had the side benefit of making the airplane a better snap-roll performer.

Biplanes remain favored aircraft for many air-show pilots, because of their extra visibility to spectators and because of the additional possibilities for wing-walkers. Only in the last decade of the twentieth century did monoplanes begin to dominate aerobatic competition at the highest levels. The appeal of the open-cockpit biplane, a sort of motorcycle of the air, will live on indefinitely, as pilots feel the sheer joy of flying between two wings in warm summer air.

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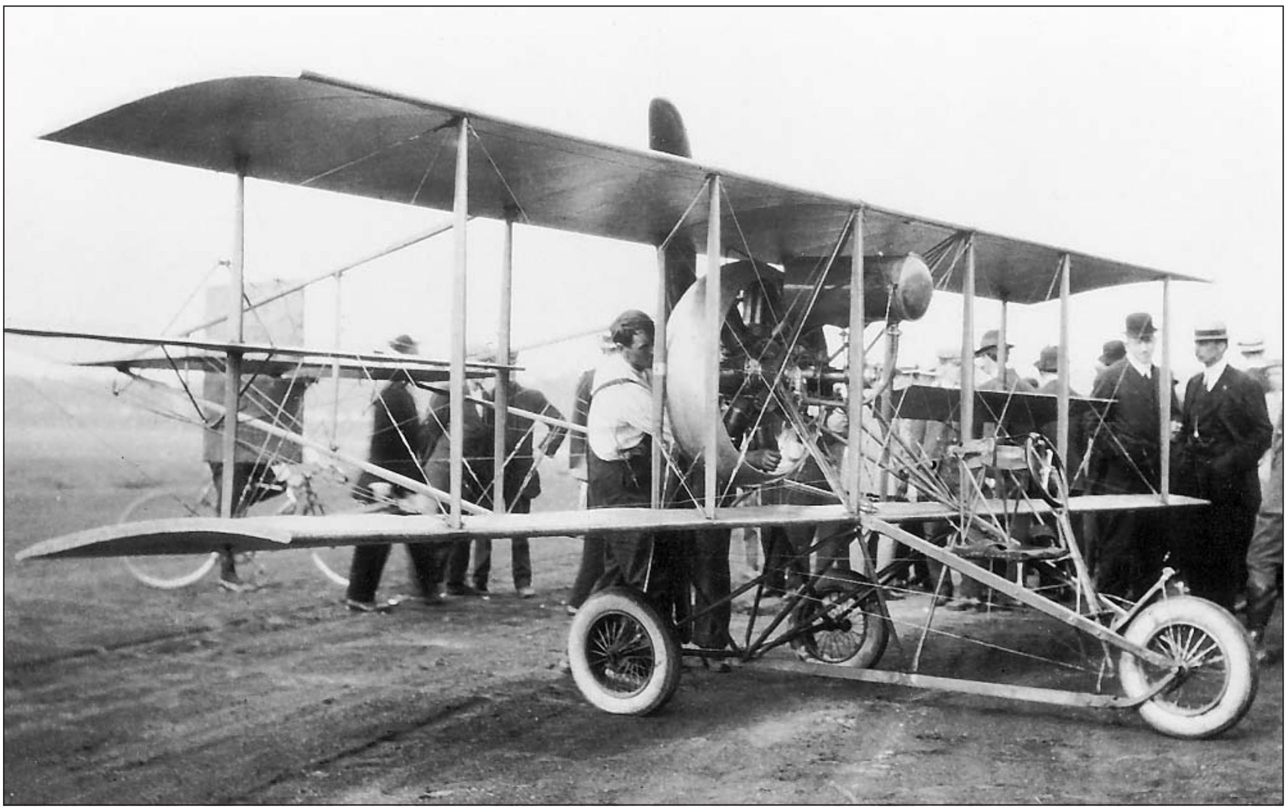
See also: Aerobatics; Air shows; Airplanes; Barnstorming; Jenny; Charles A. Lindbergh; *Spirit of St. Louis*; Wing designs; Wing-walking; Wright brothers; Wright *Flyer*



Biplanes are so called because they have two parallel levels of wings; these offered early aviators the largest wing area and strength for the least weight. (Library of Congress)

Birds

Definition: Warm-blooded organisms capable of flight.
Significance: Birds have provided humans with much information about heavier-than-air vehicle design.

About 8,800 species of birds make up most living organisms capable of flight. Believed to be evolved from reptiles, their weights vary from a few ounces, for tiny, flying hummingbirds, to to 300 pounds, for flightless ostriches. Most birds, however, fly well, and humans learned a lot about heavier-than-air vehicle design from observing them. Birds differ from heavier-than-air aircraft primarily in that their wings are movable, or flappable. Most aircraft have fixed wings, which do not move.

Birds' bodies are specially engineered for flight. Their skeletons are light, often weighing less than their feathers. Feathers combine the qualities of lightness, strength, and flexibility; a feather, bent double, quickly regains its shape upon release. Made of keratin, feathers also keep birds warm, dry, and protected from injury.

Bird lungs and hearts are designed for the high metabolic rates needed to produce the huge amounts of energy required by all flying machines, biologic or manufactured. Birds' respiratory systems allow for a much larger oxygen uptake than that of earthbound animals. Birds also have relatively large hearts, capable of passing all the oxygen needed for energy metabolism through the circulatory system to the other tissues.

Aerodynamics and Birds

To understand flight requirements, a background in aerodynamics, a branch of fluid dynamics that studies movement of bodies, such as birds or aircraft, through gases such as air, is essential. For example, the fifteenth century Italian artist and engineer Leonardo da Vinci studied bird flight and proposed to enable human beings to fly with flappable wings. His ideas failed because da Vinci knew nothing about aerodynamics, a science which did not exist then.

Any heavier-than-air flying vehicle must conquer gravity before it can climb into the air in controlled flight. Three main forces, exclusive of weight, are involved. The first is thrust, which birds produce by flapping their wings. Flapping merely enables a bird to move forward as long as its design allows enough thrust to exceed the drag caused by the viscosity of the air through which the bird moves. Drag diminishes the speed of moving objects due to air resistance. In vehicle design, thrust-to-drag ratios can be increased by streamlining to minimize drag.

The third aerodynamic force, lift, is the key to flight. Lift, enabling an object's rise into the air, operates upward perpendicular to the direction of forward motion, and is supplied in both birds and aircraft by wings and tails (airfoils). Bird wings are designed so the angle at which they meet air passing them causes it to flow much more rapidly past the upper airfoil surface than past its lower surface. This design lowers air pressure above the airfoil compared to that under it and engenders the lift that raises a bird into flight. In birds, this unsymmetrical airflow is produced by muscle movement that changes both the positions of wing feathers and the angle at which wings meet the air, known as the angle of attack.

The importance of the angle of attack is demonstrated in aircraft by a pilot's use or misuse of the angle during flight. An aircraft's angle of attack is changed by altering its position in space. Angles of attack of up to 15 degrees increase lift and enable faster climb rates while also slowing airspeed. If the angle is too steep, decreased lift occurs, making the aircraft drop toward the ground, or stall. When pilot misjudgment causes a stall, an aircraft will crash unless the angle of attack is adjusted to a safe value. Birds, unlike aircraft, constantly make quick wing adjustments, moving their wing muscles to prevent stalls.

Wing Design and Flight

Birds create lift with downstrokes of their wings, attached by flight muscles to a large breastbone. Birds contract flight muscles to cause this downstroke, during which long primary and secondary flight feathers spread out to provide the maximum possible surface area to push against air below. The downstroke is followed by an upstroke in which the feathers fold to minimize air resistance while positioning the wings for the next downstroke.

Bird wings have a short upper arm bone that moves up and down during flapping. They also have rigid elbow and wrist joints that move horizontally to spread or fold the wing. Furthermore, the wrist and hand bones are a carpometacarpus, derived from palm bones, a one-boned thumb, a two-boned second finger, and a one-boned third finger. Flight feathers are attached to wing bones. The primary flight feathers, most essential to flight, attach to the carpometacarpus, second finger, and third finger. Up to forty somewhat less important secondary flight feathers attach to the ulna, one of the forearm bones.

When a bird opens its wings, the bones straighten, the primary feathers spread as the elbow joint extends, and the wrist stretches. Wingspread is limited by a tendon running from shoulder to wrist. The bases of the flight feathers interconnect via a ligament running from the elbow to the second fingertip. Spreading a wing stretches the ligament, moving flight feathers into positions perpendicular to the bones to which they are attached. While the wing is spread, muscle action can either spread primary feathers further or fold them back. The greater importance of primary feathers is clear, because removing even their tips prevents flying, while more than one-half of each secondary feather must be removed to do this.

There are four basic types of bird flight. In skimming flight, birds such as albatrosses use winds to stay aloft. In soaring flight, birds such as eagles, hawks, and vultures can remain aloft for long periods of time, seeking prey below. In active flight, birds such as swallows fly all day, flapping their wings continuously. Finally, game birds such as quail conceal themselves and, when endangered, burst into the sky. They pick up speed quickly and fly short distances before landing and hiding again.

There is a wing shape most efficient for each flight type. Skimming birds have wings that are long, slender, and ribbon-shaped, with parallel edges and many secondary feathers. Skimming wings are the most highly developed, helping such birds ride the winds. Soaring birds have wings that are large, broad, almost square, and rich in primary feathers. Swallows and other birds engaging in active flight have long, tapering, pointy wings with broad bases and slender tips. Finally, game birds have short wings that beat rapidly, enabling them to get to speed quickly. However, these wings are not useful in long flights.

No bird has wings designed entirely for one type of flying. However, in gliding, birds use gravity as thrust to overcome drag and move forward, as their wings produce lift to hold them up. Drag slows down a gliding bird and causes it to sink earthward. To maximize glide time, or soar, a glider sets its wings at the angle of attack giving a good lift-to-drag ratio. Low forward speed helps, and, to alter speed, such a bird spreads its wings to increase their area and reduce glide speed or closes them to cause the opposite effect. Long-winged birds glide by adopting positions with small glide angles, avoiding stall by twisting the wings to reduce the angle of attack. This angle can also be varied along the length of each wing. For example, gliding birds may have their secondary feathers at a high angle of attack and their primary feathers flat.

Active flight requires thrust force and expenditure of energy sufficient to overcome drag and keep the bird on course. This is achieved by flapping the wings for lift and propulsion. The wing parts function differently at each stage of a wing beat. For example, many fast-flying birds start downstrokes with wings fully extended and well above the horizontal. As they flap down vertically, forward movement through the air generates lift along the entire wing. At a downstroke end the wings fold and primary feathers close. No propulsion is generated in the upstroke, at the end of which the primary feathers produce enough lift to raise and extend the wing, preparing for the next downstroke.

Body Design and Flight

A second group of characteristics enabling bird flight is the design of the bird's body. Body weight is important to flight: The heavier an object is, the larger its wings need to be to enable liftoff and maintain flight. In birds this problem is met by their relatively small, light bodies. For example, hawks and eagles have cat- or even dog-sized bodies, but they weigh only 25 to 35 percent as much as the earthbound mammals. Birds' light weight is due to several factors. First, under their feathers, birds have relatively small bodies. Second, although their feathers are bulky, they are also very light. In addition, birds have fewer bones compared with other animals, and their bones are thinner, or even hollow. This special anatomy, combined with wings that engender appropriate amounts of lift, allows birds to fly. Depending on their wing size and shape, birds can fly, soar, or skim.

Energy Needs

To meet the energy needs of flight, birds must eat a relatively large amount of food each day. For their muscles to work well, birds need efficient blood circulation to quickly supply fuel and oxygen and to remove wastes. In both birds and mammals, the blood circulatory system has a four-chambered heart that directs blood to the lungs, where the blood picks up oxygen and then travels on to the muscles and other organs, where the oxygen is used. Carbon dioxide is picked up at the same time and carried, via blood, to the lungs for disposal. The difference between bird and mammal circulatory systems is the relatively larger size and greater power of a bird heart, which is two to three times heavier, compared to body weight, than that of a mammal. Bird heartbeat rates are also much faster than those of mammals, usually from 200 to 1,000 beats per minute, compared to 80 in humans. The combination of a large heart and a faster pulse rate results in a blood-pumping capacity for birds that is relatively much greater than that of mammals.

A bird's respiratory system is very different from the bellows-type lungs of mammals. Bird lungs are relatively small, but they connect to inflatable air sacs located throughout the body, even in bones and breast muscles.

These sacs are thought to cause very efficient exchange of oxygen and carbon dioxide with the bloodstream via one-way airflow through the lungs. When a bird inhales, air enters the lungs, posterior air sacs, and anterior air sacs. Exhalation causes air from posterior sacs to enter the lungs, and air from anterior air sacs is exhaled. Thus the air constantly passes through the lungs, ensuring a more efficient absorption of oxygen and removal of carbon dioxide compared to that of mammal lungs, in which only a fraction of the air is flushed out at each breath. Bird lungs are not worked via diaphragm. The air sacs are pumped by rib movement.

Thus, with its wings; its small, light body; its superbly useful feathers; and its high-capacity heart and lungs, a bird is superbly designed to be airborne.

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See also: Animal flight; Bats; Evolution of animal flight; Forces of flight; Insects

Black Sheep Squadron

Date: From April, 1943, to January, 1944

Definition: U.S. Marine Squadron 214, one of the most renowned U.S. fighting units of World War II, which fought against the Japanese in the Pacific theater.

Significance: The Black Sheep Squadron, composed of young and inexperienced replacement fliers, received publicity not only because of its success in warfare but also because of the war record of their leader, fighter ace Gregory "Pappy" Boyington.

Pappy Boyington

At thirty years of age, Gregory Boyington was referred to by his younger fliers as "Pappy," "Gramps," and "Skipper," because he appeared old for his age. Through his off-duty indulgence in alcohol, gambling, and fighting, he had earned a dubious reputation as a troublemaker, much to the disapproval of his superior officers.

By 1940, before the United States entered World War II, Boyington, a Marine pilot, resigned from the Marines and signed up as a paid mercenary flier for the American Volunteer Group, known as the Flying Tigers, in China. Led by General Claire Lee Chennault, the Flying Tigers successfully used their P-40 fighter planes against the Japanese. During this tour of duty from November, 1941, to July, 1942, Boyington was officially credited with shooting down six Japanese aircraft.

After the United States entered World War II, Boyington returned to the mainland and was reinstated into the Marines. He was transferred to the Pacific theater, where his first job, administrative in nature, was primarily to find replacements for American flier casualties. In his autobiography, *Baa Baa Black Sheep* (1958), Boyington claimed to have provided strategic input to the secret air mission that intercepted, shot down, and killed the commander in chief of Japan's navy, Admiral Isoroku Yamamoto, over Bougainville in the Solomon Islands on April 18, 1943. Yearning to return to combat duty, he convinced his superiors that he could make a greater contribution to the war effort by training and leading a newly formed squadron.

The Squadron's Formation

The popular history of the Black Sheep Squadron primarily centers on the period from the squadron's initial formation at the Russell Islands, off New Guinea, to the date several months later when Boyington was shot down by a Japanese plane. During that time, the unit as a whole would be credited with downing ninety-four Japanese airplanes, strafing and disabling a large number of enemy aircraft parked on the ground, and successfully protecting many U.S. bomber aircraft missions.

The Black Sheep Squadron's third mission on September 16, 1943, was to escort U.S. bombers and torpedo planes attacking the Japanese airfield at Ballale Island, near Guadalcanal. On this mission, twenty Corsair aircraft of the Black Sheep Squadron engaged about forty Japanese fighter planes. In the ensuing air battle, Boyington shot down five enemy planes but had to make an emergency landing at Munda, in the Solomon Islands, because he was low on fuel. Soon after returning safely to home base, the squadron had a meeting to evaluate the mission. At this meeting, the young men wanted informally to name the squadron "Boyington's Bastards," but Boyington insisted on the more polite "Black Sheep Squadron."

Boyington's Capture

On January 3, 1944, on a mission from Bougainville to Rabaul in the Solomon Islands, Boyington shot down three enemy aircraft to bring his war total to twenty-eight, a new U.S. combat record. However, on this same mission, he was himself shot down, by a Japanese fighter aircraft. After parachuting from his aircraft, he survived for several hours in the cold waters of St. George Channel before being captured by a Japanese submarine. For the remaining eighteen months of the war, he remained a prisoner, suffering frequent beatings and interrogations, starvation, and unsanitary conditions. Because the Japanese would neither inform the neutral Swiss government of Boyington's capture nor release his identity publicly, the U.S. military officially assumed that Boyington was dead and awarded him a posthumous Congressional Medal of Honor in 1944.

After Boyington's capture, the Black Sheep Squadron continued with constant changes of officers and pilots and transfers to other units. The squadron's final wartime assignment was aboard the small aircraft carrier USS *Franklin*. The *Franklin* suffered severe casualties and damage when a Japanese dive-bomber landed a bomb on the flight deck full of armed and fueled U.S. aircraft ready for takeoff.

Postwar Honors

After the end of the war, Boyington was safely returned to U.S. military officials and sent to the mainland United States. The media had made him a popular war hero, and he went on a tour of appearances. On October 5, 1945, U.S. president Harry S. Truman personally awarded Boyington his Medal of Honor in a White House ceremony. The president's words were, "Congratulations, I would rather have this honor than be President of the United States."

The Black Sheep Squadron as a whole received the Presidential Unit Citation, which recognized its air-to-air combat missions from April 7, 1943, to January 6, 1944. The squadron was credited with 132 pilots, 160 downed Japanese airplanes, 70 airplanes lost, 28 pilots killed or permanently missing in action, 13 pilots wounded, and a casualty rate of 30 percent. Some of the original members later flew in the Korean War and in the 1948 Israeli War for Independence.

In his autobiography, Boyington mentions a happy reunion with twenty of the Black Sheep Squadron members in Oakland, California, soon after the war's end. Until his death in 1988, he kept in touch with many of his fliers, who, in interviews throughout the years, were generous with praise for their colonel, mainly because his teaching and experience helped them return home safely from the war. However, the fliers believed that the news media and the 1976-1978 television series *Baa Baa Black Sheep*, for which Boyington was a paid adviser, exaggerated the rowdy behavior of the unit as a whole. Boyington freely admitted in his autobiography his own troubles but provided very few examples of rowdy behavior by his men.

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See also: Bombers; Fighter pilots; Flying Tigers; Kamikaze missions; Marine pilots, U.S.; World War II

Blimps

Also known as: Airships, nonrigid or pressure-airships, dirigibles, balloon-dirigibles

Definition: A lighter-than-air, pressurized airship, comprising an elliptical, gas-filled bag, a means of propulsion, a means to control buoyancy and flight, and one or more gondolas to hold crew, passengers, the power unit, and cargo.

Significance: The nonrigid airship was the first form of controlled human flight, and the blimp was the last airship to be used in wartime.

Development

The early days of aviation witnessed a competition between two very different vehicles: the heavier-than-air airplane and the lighter-than-air airship. Although the airship initially prevailed, it would, by the 1930's, be largely replaced by the airplane. Airships, however, continue to perform functions that are beyond the capabilities of airplanes.

Airships evolved from the free, or hot-air, balloon, first launched in 1783 near Lyons, France, by Jacques-Étienne and Joseph-Michel Montgolfier. This balloon would be modified. Henry Cavendish, a British chemist, found that hydrogen gas was at least seven times lighter than air, and by 1785, French army engineer Jean Baptiste Marie-Meusnier designed a bag of an ellipsoidal shape. French inventor Henri Giffard took these notions, added mechanical propulsion and steering, and flew a dirigible-balloon, named from the Latin *dirigere*, "to steer," on September 24, 1852. This 143-foot-long airship, driven by a screw propeller rotated by a 3-horsepower steam engine, traveled at the speed of 10 miles per hour. It was the first successful flight of an airship. Thirty-one years later, the Tissandier brothers, Albert and Gaston, built an electrically powered, 37,000-cubic-foot airship. On August 9, 1884, Charles Renard and Arthur Krebs piloted the 66,000-cubic-foot, electrically driven *La France* for 5 miles, returning safety to the point of departure. A Brazilian aeronaut, Alberto Santos-Dumont, who "mused on the exploration of the aerial ocean," launched a series of fourteen airships in France before 1905. His airship *Number 6* made headlines when it successfully circled the Eiffel Tower. The eccentric Santos-Dumont popularized airships by parking them over the rooftops of his Parisian hosts, descending to join them for dinner.

Design

An airship has five crucial components: an elliptical bag filled with either hydrogen or helium and covered with a strong, light "envelope" (an outer skin initially made of cotton and rubber; today synthetic fabrics are used); a means of propulsion, using propellers and engines powered by fuels ranging from steam and electricity to gasoline; control of buoyancy attained by releasing ballast for ascent, gas for descent; flight control, with the pilot using vertically hinged rudders for steering, horizontally hinged elevators for lift; and one or more gondolas for crew, passengers, the power unit, and cargo.

There are three classes of airship. One is the nonrigid, or pressurized, airship. Without a metal frame, the bag collapses when the gas is released. During World War I, this type of airship was the most common in the Royal Navy and gave rise to the slang term "blimp," which took its initial "b" from "British Class B Airship," and "limp" from its nonrigid nature.

Another type of airship is the semirigid, in which, to maintain the form, gas pressure acts in conjunction with the longitudinal keel. A third type is the rigid airship, or zeppelin, named for the German count, Ferdinand von Zeppelin, who perfected it. With a skeleton, it retains its shape when deflated.

Use

The Germans stressed the rigid, the British the nonrigid type. During World War I, the Germans had some sixty-seven zeppelins flying a variety of missions. The British Navy favored blimps, deploying over two hundred of them for submarine and mine detection, aerial observation, coastal patrols, scouting, and escorting troop and merchant vessel convoys.

Following World War I, rigids were preferred. That popularity ended dramatically when Germany's pride, the *Hindenburg*, perished in fire at Lakehurst, New Jersey, in 1937. The United States, fortunately, had not abandoned blimps. By 1930, the Goodyear Tire and Rubber Company had a fleet of twelve blimps, used primarily for advertising. The only nation to make effective use of blimps in World War II, the United States had a fleet of 150 of them, serving in fifteen airship squadrons on three continents, patrolling three million square miles. The first nonrigid airship crossing of the Atlantic occurred from May 29 and June 1, 1944, when a U.S. Navy blimp squadron made the 3,145-mile flight from South Weymouth, Massachusetts, to Port Lyautey, French Morocco. Blimps proved effective in detecting German submarine wolfpacks. Not a single blimp-escorted convoy lost a ship. Only one blimp was downed by enemy fire.

During the Cold War, blimps were of value not only for coastal patrols, but also as an early-warning device against piloted bomber flights. In 1958, the U.S. Navy commissioned a series of four ZPG-3W airships, each 403 feet in length, 85 feet in diameter, with a capacity of 1,500,000 cubic feet. These were the largest blimps ever. When, after 1962, the piloted bomber gave way to the intercontinental ballistic missile, the value of blimps declined.

By the 1990's, however, there was a renewed interest in blimps. From a commercial standpoint, they could carry passengers and cargo cheaply and efficiently. Television networks used them for aerial views of sporting events. Advertising (as with the well-known Fuji and Goodyear blimps) was profitable. The recreation use of airships was appealing. Synthetic fibers, computer-aided design, and enhanced engineering led to such "super blimps" as the *Sentinel 5000* launched in 1997. It had a three-story pressurized gondola. Virtually impervious to weather (icing, snow, sleet, rain, fog, hail) and radar, it traveled in excess of 60 miles per hour. Blimps, because of their range, fuel efficiency, low cost of development and maintenance, capacity for in-flight refueling, and lack of negative environmental impact, proved attractive to both military and civilian agencies for a variety of surveillance work. The blimps promise to have a long and useful future.

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See also: Buoyant aircraft; Dirigibles; Goodyear blimp; *Hindenburg*; Lighter-than-air craft; Montgolfier brothers; Reconnaissance; Alberto Santos-Dumont; World War I; World War II; Ferdinand von Zeppelin

Blue Angels

Also known as: The United States Navy Flight Demonstration Squadron

Date: Formed in 1945; first flight demonstration on June 15, 1946

Definition: A flight demonstration team organized to showcase naval aviation and serve as positive role models and goodwill ambassadors for the United States military.

Significance: The Blue Angels demonstrate the pinnacle of precision flying, representing the United States Navy to the civilian community, providing exciting entertainment for millions of spectators every year, and serving as a recruitment tool for the United States Navy and Marine Corps.

Formation and Development

At the end of World War II, Admiral Chester W. Nimitz, the Chief of United States Naval Operations, ordered the formation of a flight demonstration team to illustrate precision flying and maintain public interest in naval aviation. After several months of organization and practice, the first squadron demonstrated its initial public aerial performance on June 15, 1946, at the Southeastern Air Show and Exhibition at the Naval Air Station (NAS) at Craig Field in Jacksonville, Florida. They won the trophy for the most outstanding performance. The flight leader was Lieutenant Commander Roy "Butch" Voris. The other team members were Lieutenant Mel Cassidy (left wing), Lieutenant Maurice "Wick" Wickendoll (right wing), Lieutenant Al Taddeo (solo), and Lieutenant Gale Stouse (backup). The aircraft they flew was the Grumman F-6F Hellcat.

On August 25, 1946, the Blue Angels changed their aircraft to the Grumman F-8F Bearcat. By 1947, Lieutenant Commander Robert Clarke had become the flight leader. He introduced the diamond formation, which became the trademark of the Blue Angels. Near the end of the 1940's, the squadron was flying their first jet aircraft, the Grumman F9F-2 Panther.

With the outbreak of the Korean War, the Blue Angels were assigned to the aircraft carrier USS *Princeton* in 1950, forming the core of Fighter Squadron 101, which became known as "Satan's Kitten." They adopted a squadron insignia that portrayed a fiendish cat riding the devil's three-pronged fork and hurling lightning bolts at the enemy. In 1951, they were sent to the NAS in Corpus Christi, Texas, where they began flying the Grumman F9F-5 Panther. In October, 1951, a directive from the Chief of Naval Operations reactivated the Blue Angels to perform the same duties that they had performed prior to the war.

In 1954, the Blue Angels were assigned to their present home at the NAS at Sherman Field in Pensacola, Florida, where the crew began flying the newer, faster, swept-wing

Grumman F9F-8 Cougar. In 1957, the Blue Angels began flying the Grumman F-11 Tiger. By 1969, they were doing their aerial shows in a dual-engine jet, the McDonnell Douglas F-4J Phantom II.

New Focus

In December, 1974, the Blue Angels were reorganized as the United States Navy Flight Demonstration Squadron, with Tony Less as the commanding officer. Further changes included the addition of a number of support officers and a new aircraft, the McDonnell Douglas A-4F Skyhawk II. The mission of the squadron became focused on Navy recruiting. In celebration of their fortieth anniversary in 1986, the Blue Angels flew the sleek McDonnell Douglas F/A-18 Hornet. This aircraft 3was the first dual-role fighter and attack jet serving on the front lines of U.S. defense.

After a nineteen-year absence, the Blue Angels were deployed on a one-month European tour in 1992. Over a million people in Sweden, Finland, Russia, Romania, Bulgaria, Italy, Spain, and the United Kingdom witnessed their performances. In November, 1998, the first Blue Angel jet was landed on an aircraft carrier, the USS *Harry S. Truman*, by squadron Commander Patrick Driscoll.

The only Marine Corps aircraft that performs with the Blue Angels is the Hercules Transport C-30, nicknamed "Fat Albert." It is flown by an all-Marine crew consisting of three pilots and five enlisted personnel. In the course of a show season, Fat Albert is flown over 140,000 miles. It transports the necessary personnel and equipment that support the Blue Angels from one performance site to another.

Blue Angels Aircraft

Years of Use	*Manufacturer*	*Model*
1946	Grumman	F-6F Hellcat
1946-1949	Grumman	F-8F Bearcat
1949-1951	Grumman	F9F-2 Panther
1951-1954	Grumman	F9F-5 Panther
1954-1957	Grumman	F9F-8 Cougar
1957-1969	Grumman	F11F-1 Tiger
1969-1974	McDonnell Douglas	F-4J Phantom II
1974-1986	McDonnell Douglas	A-4F Skyhawk II
1986-present	McDonnell Douglas	F/A-18 Hornet

Source: Data taken from (www.chinfo.navy.mil/navpalib/aircraft/b-angels/blues.html), June 6, 2001.

Demonstrations

The flight demonstrations of the Blue Angels exhibit choreographed refinements of Navy-trained flying skills. Flight shows include graceful, aerobatic maneuvers of the four-plane diamond formation, in conjunction with the fast maneuvers of its two solo pilots, and the renowned six-jet delta formation. During the show season (April to December), the Blue Angels are stationed at Pensacola, Florida. During the other three months of the year, they are stationed for training at the NAS at El Centro, California.

At the beginning of a Blue Angels show, Fat Albert often demonstrates its jet-assisted takeoff capability. Eight solid-fuel rockets are attached to the sides of the aircraft. When they are ignited, Fat Albert climbs at a 45-degree angle to an altitude of 1,000 feet in a few seconds. Shortly thereafter, six Blue Angel Hornets engage their afterburners and climb into the sky to perform their maneuvers. Each Hornet is 56 feet in length, 15 feet high, with a wingspan of 40 feet, and the capability of reaching speeds well in excess of supersonic velocities.

Since the inception of the Blue Angels in 1946, there have been twenty-three pilots killed in air shows or training. Two Blue Angels were killed on October 28, 1999, in southern Georgia while trying to land during a training flight. The last fatality prior to that incident was on July 13, 1985, when one pilot died in a fireball crash after two planes collided during an air show.

During 2001, the Blue Angels performed in nearly seventy shows at thirty-six locations in the United States and Canada under the direction of Commander Robert A. Field. In 2000, they performed before more than 17 million fans. Since their first show in 1946, the Blue Angels have performed for more than 374 million spectators.

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See also: Aerobatics; Hornet; Military flight; Navy pilots, U.S.

Boarding procedures

Definition: Airline procedures that process passengers and allow them onto the correct aircraft for their destination.

Significance: Boarding procedures ensure that only ticketed passengers board the correct aircraft for their destination. Boarding procedures ensure on-time departures by taking place within a scheduled time period.

Boarding procedures were established to ensure that passengers are boarded onto the right airplane at the right time and are seated in assigned or available seats. To accomplish this task, a number of steps are taken before, during, and after passengers get onto their aircraft.

Boarding planning first considers the kind of flight that is being processed. Flight departures can be of two types: one in which an aircraft is coming from another location and proceeding on to its destination or one in which the departure is the flight's origination point. Operations departments determine whether the flight is on schedule, what gate will be assigned for the departure, and the expected number of passengers. Passengers are of three types: first, local passengers are those beginning their trip; second, connecting passengers are those arriving on other aircraft to continue their trip on the departing flight; and third, continuing passengers are those arriving and continuing onto the flight's destinations. If the flight is oversold, or overbooked, oversale procedures are initiated.

Keeping in mind that a departure may involve an arriving aircraft, gate agents report to the assigned gate typically thirty minutes before an aircraft's arrival or one hour before its departure. They prepare and post signs that indicate departure information such as the flight number, the destination, and the scheduled or adjusted departure time, if necessary. Adjusted departure times reflect any information that may or will, if known, affect the departure, such as weather, air traffic, maintenance, or crew matters.

When passenger counts are low, all of the boarding procedures can be performed by one person. When twenty-five or more passengers are expected, it is customary to have two gate agents. Three to four gate agents are needed for flights of larger aircraft in which two to three hundred passengers are expected.

Boarding responsibilities are divided into two functions, known by a variety of titles. The boarding agent, or coordinator, is responsible for all announcements, for the actual taking of tickets and boarding passes from passengers, and for all communication with the crew. The gate, or control, agent is responsible for checking passengers in if needed, for producing all needed reports, and for making the entries that calculate and finalize how many passengers are on board.

Within the hour before departure, passengers begin to arrive at the gate. Some need to be checked in and given their seat assignments. Most already have been checked in at a ticket counter or in their originating location if they are on a connecting flight.

Different aircraft have different boarding requirements and time frames that take into account the aircraft's size and the number of passengers. A full medium-sized aircraft may take as much time as a half-full large aircraft. Boarding may begin as much as one hour or as little as fifteen minutes before departure.

Preboarding

Boarding begins with a consultation and agreement with the flight crew that all is in order on board the aircraft. Boarding is managed and coordinated by announcements usually made through a public-address system. The first announcements identify the airline, the flight number, the destination, the departure time, and also include certain reminders regarding the size and the number of carry-on items allowed. Recognizing that certain passengers have special needs and that certain passengers enjoy the privileges of being preferred customers, the second announcement is called the preboarding announcement. Preboarding allows those with special needs or those with preferred privileges to board ahead of others. The third announcement begins the general boarding process. Row numbers, normally in sets of five, are called to board, starting with the back rows and progressing toward the front. Boarding from the rear rows to the front eliminates congestion on board the aircraft and allows passengers to proceed without interruption to their assigned seats.

After preboarding and while general boarding is conducted, other steps leading to final passenger and departure documentation take place. Almost every airline makes what is called a cutoff announcement twenty minutes prior to departure. Computer entries are then made releasing the advance seat assignments of passengers who have not already checked in. Other entries are then made to assign seats to standby passengers. Standby passengers are of two kinds, revenue and space available. Revenue standby passengers are passengers that were ticketed for earlier or later flights. Space-available passengers are passengers who are traveling on various kinds of passes and are boarded only if there are remaining available seats.

Final Boarding

At ten minutes prior to departure, the final boarding announcement is made. Passengers arriving at the departure gate after this announcement are late and may not be boarded. After the final boarding announcement is made, various reports and passenger counts are prepared and calculated and are given to the crew and to operations departments. At five minutes prior to departure, there is another consultation with the crew notifying them that all passengers who can be boarded have been boarded, and that the gate is prepared to close the door. The authority and direction to close the door comes from the captain. After the plane has left, the gate staff take several other steps, such as generating several other reports, documenting the actual time of departure and the exact number of passengers and crew, sending the now-used tickets to airline accounting departments, and communicating any relevant passenger information to the destination city.

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See also: Air carriers; Airline industry, U.S.; Airports; Baggage handling and regulations; Overbooking; Takeoff procedures; Ticketing

Boeing

Also known as: The Boeing Company

Definition: The world's largest builder of commercial aircraft.

Significance: Throughout its history, Boeing has been the world's largest commercial aircraft manufacturer, a major U.S. defense contractor, and an active participant in the U.S. spaceflight program. During the 1960's, Boeing lent the skills of 2,000 employees to the U.S. effort to land humans on the Moon.

Early History

In 1903, the same year that the Wright brothers completed their first flight at Kitty Hawk, North Carolina, William Boeing left Yale University's college of engineering for the West Coast. After accumulating a considerable amount of money trading in forest lands around Grays Harbor, Washington, Boeing moved to Seattle, Washington, in 1908.

Boeing had always been curious about air travel, which was in its infancy during his youth. In 1910, he attended the first American air meet in Los Angeles, California. He sought a ride on one of the airplanes shown at the meet, but not one of the dozen aviators participating would do him the favor. Little did the early pilots realize that they were refusing a man whose name would become synonymous with commercial aviation around the world.

In 1916, Boeing formed the Pacific Aero Products Company, which was renamed the Boeing Airplane Company the following year. He and G. Conrad Westerveldt developed the B & W seaplane. World War I brought Boeing lucrative contracts for Navy trainers and flying boats. However, by 1919, after the war's end, the company was on the brink of bankruptcy. Boeing scrambled to keep his workers busy making furniture, repairing Army planes, and building speedboats that would become popular with local bootleggers during Prohibition.

Boeing also earned money by pioneering airmail service. The Air Mail Act of 1925, also known as the Kelly Act, authorized the U.S. Post Office to contract with private carriers on designated routes. On September 15, 1926, Vern Gorst's Pacific Air Transport (PAT) delivered Seattle's first bag of domestic airmail to a Boeing airstrip. The following year, Boeing purchased PAT and introduced larger Model 80 and 80A trimotors. The cabins, carrying up to eighteen passengers, were attended by registered nurses who became the first flight attendants.

On February 1, 1929, William Boeing and Fred Reutschler, president of the Pratt & Whitney engine manufacturer, formed the United Aircraft & Transport Corporation (UATC). It quickly acquired other aircraft companies, including Stearman, which established Boeing's presence in Wichita, Kansas. In March, 1931, this carrier, a pioneer in commercial aviation, would be incorporated, along with numerous others, as United Air Lines.

The years immediately following the end of World War II were filled with changes for Boeing. After the military canceled its bomber orders, Boeing factories shut down, and 70,000 people lost their jobs. The same day the plants closed, attorney William M. Allen took over as company president. Allen promised to start hiring people back as soon as airlines ordered the Stratocruiser, a luxurious commercial airliner version of the company's four-engine C-97 troop transport first flown in 1944. The Stratocruiser did not provide Boeing's hoped-for financial windfall, however. Instead, Boeing earned substantial profits by adapting its C-97 air freighter as both a propeller-powered troop carrier and the KC-97, an aerial fuel tanker.

In the meantime, wind-tunnel data discovered in Germany as the war ended helped Boeing engineers design the country's first multiengine, swept-wing jet bomber, the XB-47. After World War II, Boeing also applied the technology of jet bombers to revolutionize civilian passenger airline travel.

As early as the 1940's, Boeing 707-120B's used to transport government officials had been given the call sign *Air Force One*. Boeing 707-320B airframes later were adapted specifically for use by the U.S. president, designated VC-137C, and officially called *Air Force One*. VC-137C's served as presidential aircraft until 1990, when they were replaced by two new aircraft using Boeing 747-200 airframes.

Events in Boeing History

1916: Boeing is first incorporated by William E. Boeing as the Pacific Aero Products Company to develop the B & W seaplane. The company is renamed the Boeing Airplane Company the following year.

1929: After building air mail and military aircraft throughout the 1920's, the company is merged into the United Aircraft and Transport Corporation (UATC), a group of aircraft manufacturers and airlines.

1934: Federal antitrust regulations require the splitting of UATC into three separate companies: the United Aircraft Company, the Boeing Airplane Company, and United Air Lines.

1935: Boeing's Flying Fortress (B-17) bomber, which later plays a crucial role in U.S. success during World War II, is first flown.

1942: Boeing's Superfortress (B-29) bomber, which also contributes greatly to the U.S. war effort, is first flown.

1952: Boeing's Stratofortress (B-52) bomber, which will remain the primary U.S. bomber for the next four decades, is first flown.

1957: Boeing's first jetliner, the 707, makes its first flight, entering service the following year. The company subsequently develops a series of jetliners that are enormously popular worldwide.

1960's: Boeing participates in the U.S. space program by designing and manufacturing Apollo and Saturn rockets and lunar orbiters.

1970: The first wide-body jumbojet, Boeing's 747, with twice the passenger capacity of any previous jet, enters service.

1980's: Boeing develops both the air-launched cruise missile and the MX intercontinental ballistic missile (ICBM).

1996: During a period of reorganization in the aerospace industry, Boeing purchases divisions of Rockwell International involved in aerospace and defense electronics.

1997: Boeing merges with the McDonnell Douglas Corporation.

Role in Space Exploration

In 1961, U.S. president John F. Kennedy committed the United States to landing a person on the Moon before the end of the decade. At that time, the far side of the Moon remained a mystery. Because Boeing president William Allen believed in the space program, he loaned 2,000 executives to the National Aeronautics and Space Administration (NASA) to coordinate activities. Boeing also provided overall systems integration for the entire Apollo project.

Boeing-built orbiters circled the Moon and sent photographs of the Moon's surface back to Earth, so NASA could select safe landing sites for the astronauts. Boeing also built the Lunar Roving Vehicle (LRV), which astronauts used to explore the Moon on the last three Apollo missions. Boeing often shared space-program construction responsibilities with other large aerospace companies. For the Saturn launch vehicles, for example, Boeing built the S-1C's first stage, North American Rockwell built the second, and McDonnell Douglas the third.

Despite the success of the space program, Boeing was buffeted during the mid-1960's by the loss of several crucial defense contracts. The company also launched its new 747 jumbojet on the eve of a depression in the airline industry. The company's workforce, once numbering more than 100,000, declined by more than 60,000 workers during the ensuing "Boeing Bust." A billboard erected in early April, 1971, teased, "Will the last person leaving Seattle turn out the lights."

Boeing's Influence

On August 1, 1997, Boeing and McDonnell Douglas merged and began operations as a single company with more than 220,000 employees. Phil Condit remained as chief operating officer and chairman of the new Boeing board of directors. Harry C. Stonecipher, formerly McDonnell Douglas president and chief executive officer, became president and chief operating officer of The Boeing Company.

Boeing announced on March 21, 2001, that its headquarters, employing about 1,000 people, would depart Seattle, the city that had been its corporate home for eighty-five years. However, many other Boeing manufacturing plants in the area would remain there. Dallas, Chicago, and Denver were listed as likely new Boeing headquarters locations before Chicago was chosen in early May. The surprise announcement came as a shock to many Seattle families that had sent several generations to work in Boeing's assembly plants in the Puget Sound area. Despite the loss of Boeing's headquarters, nearly 80,000 company jobs would remain in the state of Washington, but it was feared that some of those would leave as well. A few weeks after announcing the headquarters move, Boeing said it would move the assembly of its 757 jet fuselage to Wichita, Kansas, from Renton, a suburb of Seattle, transferring five hundred jobs.

Before the founding of Microsoft, Boeing was the Seattle area's signature, and singularly dominant, industry. Employees of the aircraft manufacturer influenced the city's traffic patterns, housing prices, and even department store sales, which coincided with Boeing's holiday bonuses. The famed World War II icon Rosie the Riveter was a Seattle-area Boeing assembly-line worker before her image was featured nationally on war posters.

Boeing is also a large-scale defense contractor as well as a commercial aircraft manufacturer. During 2001, the company competed with Lockheed Martin to build the Joint Strike Fighter. At an expected worth of about $300 billion, the defense contract was the most lucrative in history. Each of roughly 3,000 aircraft was expected to cost $25 to $30 million.

Boeing employees also have irrigated an eastern Oregon desert, managed housing projects for the federal Department of Housing and Urban Development, built a desalinization plant that converted sea water to fresh water for a resort in the Virgin Islands, and built voice scramblers for police departments. The Boeing Company also produced light-rail vehicles for the cities of Boston, Massachusetts, and San Francisco, California, introduced personal rapid transit in Morgantown, West Virginia, and built three gigantic wind turbines in the Columbia River Gorge.

Future Boeing Projects

For sale after 2007, Boeing planned to build a new 700-mile-per-hour Sonic Cruiser, which will reduce the current seven-hour transatlantic airline journey by one hour. Boeing also planned to increase aircraft speeds significantly with an entirely new engine technology using a mixture of conventional jet fuel—derived from oil, a fossil fuel—with clean-burning hydrogen. Prior to Boeing's new tests, the top speeds of commercial aircraft had been stagnant since 1970, when the record for the fastest civilian aircraft (1,600 miles per hour) was set by a Russian Tupolev Tu-144. Typical jet aircraft speeds (500 miles per hour) had not changed since the 1950's.

In 2001, Boeing unveiled a prototype superfast aircraft that could fly passengers between London and New York in forty minutes. In May, the Hyper-X, "a flying engine that looks like a surfboard with fins," designed jointly by Boeing and NASA, was tested over the Pacific Ocean 75 miles off Los Angeles.

In the engine test, the Hyper-X was bolted beneath the wing of a B-52 bomber. The B-52 released the "flying surfboard" at 20,000 feet, as a conventional booster rocket drove it to about 2,000 miles per hour. Revolutionary scramjets then cut in and, for ten seconds, the hypersonic plane reached a maximum speed of 5,000 miles per hour, making it the fastest aircraft in history.

Ordinary jet engines are propelled by blades that drag air into a chamber, compress it, mix it with jet fuel, and explode it out of the rear to create forward momentum. Scramjets have no blades, but depend on previously generated speeds to force air through an oval-shaped mouth into a copper chamber, where it mixes with hydrogen to produce a much more powerful explosion.

The Hyper-X can fly at speeds of up to 5,000 miles per hour, more than three times as fast as the next-fastest airliner, the thirty-year-old Concorde, which had become technologically obsolete by the year 2000. Other tests were foreseen with prototypes able to fly as fast as 7,000 miles per hour. Such vehicles could circumnavigate the earth in fewer than four hours. Boeing intended initially to design such aircraft for the U.S. military and then to build a bigger version for cargo operators. After all tests were completed, Boeing would build a version for commercial customers, such as British Airways, starting in 2016.

Boeing's hypersonic aircraft would be much smaller than the jumbojets that comprised parts of many airline fleets during the late twentieth century. The bigger planes lack the structural integrity required to withstand vastly accelerated speeds. The development of hypersonic aircraft also has been made possible by advances in the strength of manufactured metals. For structural reasons, the new airliner probably will have no windows. Passengers will be protected from a gravitational force of 6 g's by a highly pressurized cabin. The aircraft also will accelerate and decelerate slowly to lessen the effects of changing gravity. Such aircraft also will produce sonic booms as they accelerate, so routes will need to be configured to avoid large population areas at the point of transition to hypersonic flight.

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See also: *Air Force One*; Airplanes; Bombers; Hypersonic aircraft; Jumbojets; Manufacturers; McDonnell Douglas; National Aeronautics and Space Administration; Orbiting; Seaplanes; 707 plane family; Spaceflight; United Air Lines; X planes

Bombers

Definition: Military aircraft designed with the primary mission of dropping bombs.

Significance: Before the advent of effective missiles, bombers were the weapons used by air forces to attack enemy nations. Following World War I, bombing enthusiasts predicted that strategic bombardment could force an enemy to surrender and thus change the way nations would fight wars.

Bombers are generally classified by the type of bomb they deliver (a torpedo-bomber delivers a torpedo), their size (light, medium, or heavy), or their mission (fighter-bomber). While World War II saw a wide variety of bomb-dropping aircraft, the number of distinct bomber types produced has dwindled, as newer aircraft, such as fighters that are tasked with bombardment missions, perform multiple roles.

Development

The first military aircraft were used for reconnaissance. Only after trench warfare began did generals come to see airplanes as platforms that could carry ordnance beyond enemy lines to strike specific targets. In order to successfully bomb targets, bombers had to carry bomb loads that were heavy enough to inflict significant damage, to fly both high and quickly enough to bypass enemy defenses, and to deliver bombs accurately enough to hit the desired targets.

In order to build successful bombers, aircraft manufacturers had to overcome many technical difficulties that limited aircraft capabilities and performance. It is difficult, for example, to drop a bomb from a moving airplane so that it arrives on target, especially if the target is obscured or camouflaged. Bombs must be able to penetrate deeply enough or must carry enough explosive force to destroy the target. Bombers must be capable of flying high enough or quickly enough to avoid enemy fire or must be armored well enough to render enemy fire ineffective. Although defensive armor increases a bomber's odds of survival, its greater weight limits speed, range, and bomb load. Better accuracy is found at lower speeds and altitudes, where bombers are more vulnerable. A longer range allows bombers to hit a greater variety of targets but requires more fuel and, thus, a lighter bomb load. Finally, bombers require defensive armaments, or weapons, to avoid being shot down by fighters.

World War I

World War I saw experiments with almost every possible bomber mission. The first bombs were simply grenades tossed at enemy positions. Because these weapons were too light and inaccurate to cause serious damage, heavier bombs were designed. Early bombs that were released over the side of an airplane were often inaccurate. The first

Major Bombers of World War I

Name	*Date*	*Country*	*Speed (miles per hour)*	*Range (hours)*	*Ceiling (feet)*	*Number of Machine Guns*	*Bomb Load (pounds)*	*Wingspan (feet)*	*Weight (pounds)*
Airco D.H.4	1917	Britain	143	7	23,500	4	460	42.33	3,742
Blackburn Kangaroo	1918	Britain	100	8	10,500	2	930	74.83	8,017
Breuget Br.M.5	1917	France	88	5	14,110	2	661	29.67	4,235
Breuget B14B2	1915	France	110	3	19,030	2	661	47.08	3,892
Caproni Ca.30	1917	Italy	85	3.5	13,451	4	1,000	72.83	8,400
Caproni Ca.42	1918	Italy	78	4	13,451	8	3,197	98.08	14,793
Caudron R.11	1918	France	114	3	19,520	5	265	58.75	4,775
Friedicshafen G.III	1917	Germany	85	5	14,765	3	3,307	77.75	8,646
Gotha G.V	1917	Germany	88	6	21,325	3	1,102	77.75	8,745
Handley Page V/1500	1918	Britain	97	6	10,000	5	7,500	126.08	24,700
Short	1916	Britain	77	6	9,500	1	920	85.00	6,800
Sikorsky Ilva Mourometz V	1916	Russia	75	5	9,840	7	1,150	97.75	10,117
Vickers Vimy	1918	Britain	103	9	10,500	4	2,476	67.16	12,500
Voisin 5	1915	France	65	3.5	11,485	1	132	48.33	2,516
Zep Staaken R.VI	1917	Germany	80	8	12,467	7	4,000	138.41	25,269

bombers were observer aircraft converted for bombing missions. To inflict serious damage, many bombs were needed, so bombers began to fly in groups. Enemy fighters also forced bombers to fly together to mass their defensive firepower. By 1917, both sides had introduced specialized, bomb-carrying aircraft. The German Gotha G-IV, for example, was designed to attack enemy cities or port facilities far behind the battle lines. Fighters or observation planes were assigned to attack frontline headquarters or troop concentrations. Britain's Royal Navy Air Corps also experimented with launching planes from ships and, thus, introduced the aircraft carrier.

World War II

Although World War I bombers flew many varied missions, these operations were more ad-hoc responses to opportunities or threats than they were planned innovations. After the war, airmen began to develop theories about how aircraft could change the nature of war. The most famous of these was Italian general Giulio Douhet, who predicted that bombers could fly over battlefields to avoid costly ground battles. Bombers could attack specific cities, which Douhet termed a nation's "vital centers." Bombing would result in such damage and terror that citizens would force their governments to sue for peace. This terror bombing was justified as being more humane and less costly than the losses and suffering caused by a protracted war such as World War I. Essential to Douhet's theory was his claim that bombers would always perform as well as fighters, would carry more armament, and could thus always get though to their targets.

In the United States, General William "Billy" Mitchell, a strong advocate of air power, embraced Douhet's ideas, because they seemed to justify the creation of a separate branch of service. Mitchell believed that only a new and independent organization would be free from traditional preconceptions and could, thus, be innovative in utilizing new technologies.

Improved engines and metallurgy allowed aircraft designers to create weapons tailored to suit Douhet's predictions. Especially significant was the United States' adoption of the Norden bombsight, a complex instrument that was, in effect, an early analog calculator linked to an autopilot that determined the appropriate bomb release point using altitude, speed, and bomb type. Once the bomber was situated over the target, the bombsight automatically released the bombs at precisely the correct point, which could easily be missed by a pilot's human error.

Naval aviators perfected dive-bombing as another method to increase accuracy. A bomber would dive toward the target and release the bomb at the last possible instant before the aircraft pulled out of the dive, so that the bomb's trajectory was an extension of the dive. Dive-bombing was very accurate and was especially useful against maneuvering ships.

During World War II, many specialized types of bombers were used on missions that included strategic bombing, air superiority, interdiction, and tactical air support. In each case, bombers proved useful but neither as invulnerable nor as decisive as Douhet had predicted. Airframe and power plant developments resulted in fighters of great speed and heavy armament. Massed fighter attacks against bomber formations inflicted terrible damage on bombers that had to fly straight during their final bomb runs.

Technological advancements also increased the lethality of antiaircraft artillery. By 1945, antiaircraft defenses had been developed that used radar to determine the altitude and bearings of incoming aircraft, and proximity fuses ensured airbursts near the bombers. To avoid the more potent antiaircraft defenses, bombers were flown at higher altitudes that rendered them less accurate. During the war, more than one-half of the bombs dropped landed more than 1,000 feet from their targets.

Bomber enthusiasts failed to anticipate the effectiveness of what are now called passive defenses. Camouflage, decoy targets, smoke screens, and blackouts obscured targets and often rendered bombing raids ineffective, and civil defense measures reduced damage. Civilian morale proved more resilient than expected; terror attacks angered rather than intimidated civilians. Modern, organized national economies could thwart strategic bombing attacks by utilizing more civil defense personnel and replacement laborers or by dispersing factories to make them less vulnerable. These tactics made the concept of vital centers too vague to be useful. Throughout the war, airmen sought to destroy specific enemy industries, such as ball-bearing plants or petroleum refineries, which when destroyed, might cripple the enemy's ability to continue the war. Although these efforts inflicted terrible damage and chaos, enemy economies did not collapse.

Strategic bombardment also suffered from dispersal of effort. Anglo-American airmen such as U.S. general Henry Harley "Hap" Arnold faced continued demands for the diversion of bombers to other missions. Navies wanted long-range bombers for extended antisubmarine or reconnaissance missions. Theater commanders called for air assets to be used to interdict the movement of enemy troops and supplies, while battlefield commanders cried for tactical air support. After the war, air power theorists would claim that their lack of success was driven by these diversions.

The German experiences in World War I and the Spanish Civil War indicated that strategic bombardment alone would not bring victory. Many German airmen had been infantrymen in World War I and saw bombardment and observation as great force multipliers for ground attacks. As a result, German doctrine demanded heavy attacks on enemy air bases after which most of the bombers would support battlefield actions instead of attacking enemy cities. German bombers also tended to be of medium range and tended to use dive-bombing for accuracy. Early in the war, the Germans were successful with this strategy, but as the Allies introduced improved fighters and tactics, German bomber losses began to climb. Nevertheless, the German tactics, based upon a combination of mobile ground units and tactical air support, proved very potent. By 1943, the British and American air forces began to develop their own methods of tactical air support, which, by the summer of 1944, had proven to be a crucial factor in Germany's defeat.

World War II saw the invention of many technologies that would shape bombing missions and capabilities into the twenty-first century. Germany's emphasis on ground attacks led to improved communications between the bombers and ground forces. Specialized ground-attack bombers were created, and standard bombers such as the Stuka were modified for improved ground-attack lethality. To improve accuracy, the Germans introduced guided bombs, which were successful on numerous occasions. The V-1 rocket was a pilotless rocket-driven bomb that anticipated the American cruise missiles of the 1980's and 1990's. Germany fielded the world's first operational jet bomber when it introduced the Arado 234 Blitz Bomber.

Allied designers also introduced groundbreaking bomber technologies, inventing effective radar guidance systems to overcome the difficulty of finding targets. In order to stifle German antiaircraft defenses, the British invented what became known as chaff, thin strips of aluminum foil, which, when dropped in bundles, reflected aircraft-sized radar images that confused German gunners and night fighters. The Allies also introduced faster and more powerful bombers, including very-long-range strategic bombers, the most well known of which was the U.S. B-29 Superfortress.

Specialized bombs, such as the "Tallboy," which was designed to maximize penetration of hardened targets and used on German U-boat pens, were created. Ultimately, the greatest and most complex bomb used was the atomic bomb. Although some historians argue that the Japanese surrender was due to more than just the dropping of the atomic bombs, atomic weapons came closer than any other weapon to realizing Douhet's vision.

Postwar Developments

At the end of World War II, the United States investigated the effectiveness of bombing in a study called the United States Strategic Bombing Survey. According to the survey, bombing achieved a mixed record. Although strategic bombardment had not induced a complete collapse of the enemy, it had clearly played a major role in the Allied victories. Reflecting these results, postwar air forces became more balanced organizations. The U.S. Air Force, for example, divided bombing duties between Strategic Air Command (SAC), which operated long-range bombers armed with atomic bombs, and Tactical Air Command (TAC), which provided close air support for ground forces.

Throughout the second half of the twentieth century and into the twenty-first, bombers continued to play an active role in conflicts around the globe. New technologies made bombers increasingly powerful and more difficult to destroy. Some developments, such as jet engines and radar guidance systems, offered significant improvements over technologies introduced during World War II. Others, such as stealth technology, were entirely new. Stealth technology uses special aerodynamic shapes, radar-absorbing paint, and specially textured surfaces to render planes nearly invisible to radar.

The effectiveness of such technology was shown during the 1991 Persian Gulf War and the brief 1999 air campaign over Kosovo, where stealth aircraft penetrated enemy air defense zones. The effectiveness of bombers has also been enhanced by the development of powerful missile armaments and precision-guided munitions. In the 1982 Falkland Islands War, for example, French Exocet air-to-ground missiles sank a destroyer and damaged a number of British ships. In both the Gulf War and Kosovo, air-launched smart missiles guided by either infrared or radar inflicted considerable damage.

Both conventional bombers, such as the B-52, and stealth bombers can launch precision-guided munitions. The success of operations over Kosovo has resurrected the debate over the use of strategic bombardment as an alternative to ground warfare. While some claimed Kosovo was history's first successful independent air campaign, evidence indicates that bomb damage was not as extensive as claimed and that diplomatic factors were as decisive as bomb damage in Serbia's decision to surrender.

Kevin B. Reid

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See also: Air Force, U.S.; Airplanes; *Enola Gay*; Fighter pilots; Flying Fortress; Gulf War; Korean War; Luftwaffe; Manufacturers; Military flight; Royal Air Force; Stealth bomber; Strategic Air Command; Stratofortress; Superfortress; Tactical Air Command; Vietnam War; World War I; World War II

Boomerangs

Definition: A curved, multiwinged projectile which, when properly thrown, returns near the original starting point.

Significance: Used as a toy and in sport, the boomerang's unique wing configuration generates forces in flight which return the projectile back to the original point from which it was thrown.

Evolution of the Boomerang

The boomerang originated in Australia and was used as a hunting tool by the Aborigines. Although the boomerang is often thought of as a weapon, it has primarily served as a recreational and sport toy.

The killer-stick, believed to be the predecessor of the boomerang, was used for both hunting and fighting. The killer-stick has a similar shape and shares many of the boomerang's properties with one important difference: the killer-stick does not return to the thrower. The stick was smoothed, sanded, and shaped to provide an airfoil cross-section like a wing and could be thrown fast, far, and with great accuracy. Like many other sports projectiles, such as the discus, the killer-stick was thrown with rotational spin stabilizing its flight path.

The boomerang, which is smaller, lighter and has a more pronounced separation of wings than the killer-stick, was not used to kill game, but to trap birds. An Aboriginal hunter would imitate a hawk's call and throw the boomerang over a flying bird flock. To evade the hawk, the flock would swoop down into the hunter's waiting nets.

Shape and Construction

The boomerang is composed of two connected wings. The point of connection is called the elbow. There is a front, or leading, wing and a rear, or trailing, wing. The elbow separates the two wings at an angle generally ranging between 105 and 110 degrees.

Each of the boomerang's wings has a traditional airfoil cross-sectional shape with a leading and trailing edge. As with any other flight vehicle, the leading edge strikes the air first and the air flows over the top and bottom of the wing, past the trailing edge.

Unlike a bird's or aircraft's wings, the two boomerang wings are not mirror images of one another. Thus, there are right-handed and left-handed boomerangs. When thrown vertically into the wind, the upper wing's leading edge is located on the inner concave portion of the boomerang. The lower wing's leading edge is on the outer convex portion. Air first strikes the upper leading edge. As the boomerang rotates, this allows the lower wing's leading edge to meet and strike the air.

Aerodynamic Forces and Stability

Common to all sports projectiles, the aerodynamic forces acting on the boomerang are lift, drag, and gravity, or the boomerang's own weight. The spin imparted to the boomerang stabilizes the flight path. When a boomerang is thrown correctly, these forces cause the boomerang to circle around and return.

As the boomerang flies through the air, each wing produces lift. Although the shape of the wing generates lift, the lifting force is not enough to sustain the boomerang's flight. A boomerang is thrown with a spin similar to that of a discus. Without spin, a boomerang will wobble and fall to the ground; the boomerang's flight is not stable. Airplanes and birds have tail configurations that provide stability, while the rotational spin of a boomerang stabilizes its flight and produces a curved flight path. Stabilizing effects of spinning also are observed in a toy top and a bicycle wheel.

The turning force produced is a result of the unequal airspeeds over the spinning wings. The wings of a stationary, spinning boomerang produce the same amount of lift. When launched with a forward velocity, the forward-moving wing experiences more lift than the retreating wing. The net result is a force which turns the boomerang.

As with anything flying through the air, a boomerang is subject to drag and its own weight. The drag slows the boomerang down, limiting the flight time. However, given enough spin and initial velocity, the boomerang might circle above the thrower's head a few times before landing.

Boomerang Throwing Technique

A boomerang is launched almost vertically, based on the speed of the wind. The boomerang incurs a continuous turn throughout the duration of its flight, which causes the boomerang to lay down as it turns. Thus, the boomerang returns to the thrower in a horizontal hover. If a boomerang were thrown horizontally, it would climb until the wings stalled and simply fall to the ground.

The boomerang is launched at an angle to the wind. The thrower faces the wind and turns approximately 50 degrees to the right or left, depending on whether the person is right handed or left handed. Thrown at the proper angle, the boomerang will return.

Modern Designs

Simple and sleek in design, the boomerang's unique motion utilizes complex aerodynamics and physics. Based on these same scientific principles, some modern boomerangs have advanced technical or artistic designs. Several wings may be joined at a centralized hub. Modern boomerangs may be constructed to resemble letters of the alphabet or birds, for example. Some boomerangs are constructed so that the wings' tips are slower, making the boomerang easier to catch. All boomerangs use the same basic aerodynamic and physical principles to return to the thrower at the end of their flight.

Jani Macari Pallis

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See also: Aerodynamics; Airplanes; Birds; Forces of flight; Wing designs

Richard Branson

Date: Born on July 18, 1950, in Shamley Green, Surrey, England

Definition: Founder and chairman of the Virgin group of companies that includes Virgin Atlantic Airways.

Significance: British entrepreneur and venture capitalist Branson's Virgin empire melds fun and business, reflecting his "people-first" policy. His upstart Virgin Atlantic Airways has succeeded despite competition from more established airlines.

Richard Charles Nicholas Branson is the driving force at the center of a web of more than 200 companies employing more than eight thousand people in twenty-six countries. His web of interest in travel, retail, hotels, consumer goods, financial services, computer games, radio, television, cinema, and publishing makes Branson a regular entry into *Forbes* magazine's lists of the richest people in the world.

In 1970, the twenty-year-old Branson founded Virgin Mail Order Records and shortly thereafter opened a record shop in Oxford Street, London. He established his own record label, Virgin Records, in 1973, building a recording studio in Oxfordshire, where the first Virgin artist, Mike Oldfield, recorded *Tubular Bells* (1973). Another Virgin act, the Rolling Stones, helped make Virgin Records one of the top six record companies in the world.

In 1984, Branson became the majority backer of an airline he renamed Virgin Atlantic Airways. An upstart in a fiercely competitive field of established carriers, Virgin Atlantic eventually became the second-largest British long-haul international airline, with a fleet of Boeing 747 and Airbus A340 aircraft flying routes to New York, Miami, Boston, Los Angeles, Orlando, San Francisco, Hong Kong, Athens, and Tokyo. The airline is founded on the concept of offering competitive, high-quality upper class and economy service. It holds many major awards, including several Airline of the Year awards from *Executive Travel Magazine*.

Since 1985, Branson has been involved in a number of world record-breaking attempts. In 1986 he and a teammate made the fastest ever-recorded crossing of the Atlantic Ocean in his powerboat *Virgin Atlantic Challenger II*. A year later, Branson crossed the Atlantic with Swedish aeronaut Per Lindstrand in the hot-air balloon *Virgin Atlantic Flyer*, which was not only the first hot-air balloon to cross the Atlantic but also the largest ever flown, at 2.3 million cubic feet. The two men crossed the Pacific Ocean in 1991. Branson has also been a member of three teams that made unsuccessful attempts at transglobal hot-air balloon flights during the late 1990's. On the third attempt, in December, 1998, the team traveled 8,200 miles (13,200 kilometers), becoming the first hot-air balloonists to cross the entire Asian continent.

A child of a revolutionary 1960's, Branson has forged a unique synthesis of the youth revolution's values and the needs of a modern business. He captivates the public and employees by the unexpected prospect of making the gray world of work come alive with fun, excitement, and challenge.

Lori Kaye

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See also: Air carriers; Balloons; Transatlantic flight; Transglobal flight; Virgin Atlantic

Wernher von Braun

Date: Born on March 23, 1912, in Wirsitz, Germany; died on June 16, 1977 in Alexandria, Virginia

Definition: German-American rocket engineer who developed the first practical space rockets and launchers and became known as the father of the space age.

Significance: Von Braun designed the first ballistic missile, led the research team that put the first American satellite into orbit, and designed the Saturn rockets that sent humans to the Moon.

As a young man, Wernher von Braun became intrigued with the possibilities for space exploration, joining the Verein für Raumschiffahrt (Society for Space Travel) in the spring of 1930. In 1932, he went to work for the German army to develop rockets and missiles. After earning his doctorate in physics in 1934, von Braun was appointed the director of Germany's military rocket development program. Under pressure from German chancellor Adolf Hitler, Wernher subjugated his dreams of space travel to Germany's demand for weapons. Operating at a secret laboratory along the Baltic Coast, von Braun and other German scientists built and tested the V-1 cruise missile and the V-2 ballistic missile. When the German war machine collapsed in 1945, von Braun hid all of the classified rocket documents in an abandoned mine in Germany's Harz Mountains.

On May 2, 1945, the German rocket team surrendered to American forces. Von Braun and his research team were transferred to Fort Bliss, Texas, along with the German rocket documents and approximately 150 captured V-2 missiles. At the U.S. Army's Redstone Arsenal in Huntsville, Alabama, during the 1950's, von Braun and his team built the Jupiter ballistic missile. Between 1952 and 1954, von Braun developed one of the first comprehensive space exploration programs in the world. He led the team that put the Explorer 1, the first American satellite, into orbit on January 31, 1958. After being transferred to the newly established National Aeronautics and Space Administration (NASA) in 1960, von Braun was given the mandate to build the giant Saturn rockets.

Von Braun was appointed the director of NASA's Marshall Space Flight Center in Huntsville, serving in that capacity from July, 1960, until February, 1970. In that position, he designed and oversaw the development of the Saturn I, Saturn IB, and Saturn V rockets. On July 16, 1969, a Saturn V launched the crew of Apollo 11 to their successful landing on the Moon.

In 1970, von Braun moved to Washington, D.C., to oversee the strategic planning effort of NASA. He was awarded the National Medal of Science by President Gerald Ford in early 1977. Von Braun was one of the world's first and foremost rocket engineers and a leading authority on space travel. His intense desire to expand man's knowledge through the exploration of space led to humans' setting foot on the Moon.

Alvin K. Benson

Wernher von Braun stands in front of the Saturn IB launch vehicle, designed by his team of expatriate German scientists, at the Kennedy Space Flight Center in 1968. (NASA)

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See also: Apollo Program; National Aeronautics and Space Administration; Rocket propulsion; Rockets; Saturn rockets; Spaceflight; World War II

British Airways

Also known as: British Overseas Airway Corporation (BOAC), British European Airways (BEA), British Caledonian Airways

Date: Founded in 1924

Definition: The United Kingdom's national airline since 1939.

Significance: British Airways is one of the world's largest international airlines. Along with Air France, it is one of only two airlines to fly the supersonic Concorde jet.

History

The origins of British Airways lie in the post-World War I era of civil aviation. On August 25, 1919, its forerunner company, Aircraft Transport and Travel (AT&T), began the world's first daily international scheduled air service flying between London and Paris. That initial flight, in a single-engine De Havilland DH-4A biplane carrying one passenger and a cargo of newspapers, Devonshire cream, and grouse, taking off from Hounslow Heath, made history. The first flight took two and one-half hours and was the inspiration for further growth of British companies, starting services to Paris and to Brussels. Instone, a shipping group, and Handley Page, an aircraft manufacturer, became pioneer air companies despite facing difficulties of few passengers, high fares, and the danger and unreliability of early air travel. For instance, it took one pilot two days to complete the two-hour flight to Paris, making thirty-three forced landings along the way. Pioneer British airlines faced undercutting from their Dutch and French competitors and suffered severe losses.

By 1924, Britain had four main airlines: Instone, Handley Page, Daimler Airways (a successor to AT&T, who succumbed to Dutch and French competition), and British Air Marine Navigation Company, all of which merged to form Imperial Airways. The following year, Imperial Airways was servicing Paris, Brussels, Basel, Cologne, and Zurich. Further service was introduced to Egypt, the Arabian Gulf, India, South Africa, Singapore, and West Africa. Cooperating with Qantas Empire Airways, which serviced Singapore and Australia, service between the United Kingdom and Australia was established by 1935. Smaller air transport companies also began business. In 1935, these smaller companies merged to form the original privately owned British Airways. By 1939, Imperial Airways and British Airways were nationalized to form British Overseas Airways Corporation (BOAC).

Postwar development of British Airways has been a substantial leap from its humble initial origins. Long-haul services were provided to many international routes. Continental European domestic flights were flown by a new airline, British European Airways (BEA). BOAC introduced services to New York in 1946, Japan in 1948, Chicago in 1954, and the West Coast of the United States in 1957. Domestic flights included service to Belfast, Edinburgh, Glasgow, and Manchester. By 1967, the government recommended that a holding board be responsible for two main airlines, BOAC and BEA. British Caledonian was born in 1970, when Caledonian Airways took over British United Airways. Two years later, BOAC and BEA combined under a British Airways board, and a separate airline emerged as British Airways in 1974. Defeating the odds against it, including severe financial challenges, in January, 1976, British Airways launched the world's first supersonic passenger service, simultaneously with Air France: the Concorde. In 1987, the British government began selling shares in British Airways and the company was completely privatized.

As of 2001, British Airways' fleet comprises seven Concordes, seventy-one Boeing 747's, thirty-eight Boeing 777's, twenty-one Boeing 767's, forty-eight Boeing 757's, and fifty-two Boeing 737's, as well as eighty-three Airbus A318's, A319's, and A320's in service or on order. British Airways is a member of the oneworld Alliance, along with American Airlines, Qantas, Cathay Pacific, Iberia, Finnair, Aer Lingus, and LanChile, and also has code-sharing agreements with Air Mauritius, America West, Crossair, Emirates, LOT Polish Airlines, and Malev.

Operational Structure

British Airways operates from two main bases, London's two primary airports, Heathrow (the world's largest international airport) and Gatwick. In the year 2000, forty-eight million people flew on 529,807 British Airways flights, or an average of eighty passengers checking in every minute around the clock, and a British Airways flight either taking off or landing safely every thirty seconds. British Airways maintains an enormous fleet capable of circling the globe, with flight crews trained to serve and protect business, royal, and vacationing tourists around the clock all year long. Maintaining a huge fleet of aircraft and maintenance support systems, the flagship of the British Airways fleet remains the Concorde; British Airways boasts more supersonic flying in one year than all of the world's air forces combined.

British Airways attributes its success to its behind-the-scenes activities, such as investor relations. On its World Wide Web site, the company provides comprehensive information regarding its financial performance, a presentation provided to the financial community, an online version of its own investor magazine, and even more information, including its history, in the British Airways Factbook. British Airways has also created partnerships and alliances with other airlines around the world to better serve its customers.

British Airways is involved in cargo service and tracking to support globalization, big business uniting the world. British Airways engineering services offer a wide range of technical and support services, individually tailored toward operational and financial efficiency of the business customer. British Airways also offers flight training in what are considered to be world-class facilities.

British Airways participates in Dreamflight, a British charity whose sole purpose is to transport seriously ill children on a holiday of a lifetime to Walt Disney World in Florida. British Airways provides information on the program through a Dreamflight Web site.

Ever mindful of its responsibility to protect the environment, British Airways maintains a program of corporate responsibility to maintain and improve the environment. In conjunction with this program, there is a community learning center in Waterside, Harmondsworth, promoting opportunities for young people and adults to develop knowledge and skills to enable them to grow in active, positive community participation. Furthermore, British Airways provides awards that encourage environmental awareness in the hospitality industry.

British Airways is today the world's biggest international airline, carrying more passengers from one country to another than any of its competitors. Because it is the world's longest-established airline, it bears the distinction as the industry leader.

Pamela M. Gross

Events in British Airways History

1939: Two British airlines, Imperial Airways and British Airways, are nationalized to form the British Overseas Airways Corporation (BOAC).

1946: A new British airline, British European Airways (BEA), is established to handle continental European and domestic British flights. BOAC introduces London-to-New York service.

1952: BOAC flies De Havilland Comet jets on service to Johannesburg, South Africa.

1954: After two crashes in one year, Comets are removed from service.

1958: BOAC makes the first transatlantic jet flights, between London and New York.

1974: British Airways is formed by the merger of BOAC and BEA.

1976: Cooperating with Air France, British Airways inaugurates supersonic travel on the Concorde.

1987: The British government privatizes British Airways through a public stock offering.

1993: British Airways enters into a partnership with USAir, which is dissolved four years later.

1999: British Airways joins the oneworld Alliance, a global network of airlines, also including American Airlines, Canadian Airlines, Cathay Pacific Airways, and Qantas.

2000: British Airways suspends its Concorde operations after an Air France Concorde crashes shortly after takeoff from Paris, killing all on board and four on the ground.

2001: British Airways modifies its Concorde fleet, restoring service later in the year.

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See also: Air carriers; Concorde; Supersonic aircraft

Buoyant aircraft

Definition: Aircraft, such as hot-air balloons and dirigibles, or airships, that fly because they are filled with lighter-than-air gases.

Significance: Balloons and airships played important roles in the development of aviation, serving as reconnaissance, battle, and commercial aircraft. They continue to be used for recreation and advertisement and may see future use in coast watching, scientific study, and short-haul transportation of heavy goods.

Development

The first buoyant aircraft was the hot-air balloon, invented in 1782 by the French brothers Joseph-Michel and Jacques-Étienne Montgolfier, who found that closed bags of hot air rose and stayed aloft until the air inside them cooled. The basis for hot-air balloon flotation is that hot air is less dense, or weighs less, than the volume of air it displaces, so a hot-air balloon is a lighter-than-air aircraft. It soon became clear that hot-air balloons could be kept aloft by hanging under them baskets holding firepots. In this way, gondolas that also carry passengers were created.

Modern hot-air balloons differ from early prototypes only in the fabrics and heaters used. Flammable hydrogen and safer helium are other fill gases, with helium replacing hydrogen in all modern balloons that do not use hot air. Hot-air balloons cannot be steered. Hot-air balloonists rise into the sky by throwing out ballast and descend by letting gas out. Destinations and arrivals depend on the winds. Helium-filled balloons can remain aloft for longer periods and can travel farther than can hot-air balloons. However, their flight methodology and limitations do not change. Recreational balloonists prefer hot air, and commercial balloons use helium.

In 1852, France's Henri Giffard ended the problems of uncertain destination and arrival times by adding a 3-horsepower steam engine and propeller to a cigar-shaped, hydrogen-filled balloon, allowing for a maximum speed of 6 miles per hour. This nonrigid aircraft and all that followed it were named dirigibles, from the Latin word *dirigere*, which means "to steer." Although Giffard's invention was impractical for prolonged flight, it was innovative in its cigar shape that reduced wind resistance and increased maneuverability. All following dirigibles have been constructed with a similar shape.

Throughout the late nineteenth century, increasingly better-designed buoyant aircraft were invented and used. In 1883, French aeronaut Gaston Tissandier built the first workable airship with an electric motor. From 1898 to 1905, Alberto Santos-Dumont, a Brazilian living in Paris, set airship records in nonrigid, powered airships. All these airships, however, had engines that made them too heavy for commercial flight.

Airships

There are three main airship types: nonrigid, semirigid, and rigid. Nonrigids are essentially large, streamlined cylindrical balloons, nicknamed "blimps," supposedly for the sound made by a finger thumping into the side of the envelope, or gas bag. Nonrigids, such as the Goodyear blimps, get their shape from the gas within a single gas bag or envelope. The engines and a car or a gondola hang below the gas bag.

The design of nonrigid dirigibles simplifies cost and minimizes structural weight, which in turn reduces the net lifting capability. However, nonrigids are limited in size, because an unsupported gas bag may bend unpredictably under heavy loads or strong winds. In a worst-case scenario, a partially deflated gas bag may flop over the gondola or propellers. Conversely, the gas bag cannot be filled too tightly, lest it burst. The one gas bag is a single point of failure that could cause a crash, although the large size of dirigibles means that operations could continue for some hours, even with significant leaks. Another method to compensate for pressure loss in the gas bag is the use of an inner ballonet, which can be inflated with outside air.

Semirigid dirigibles have a keel on the bottom to support a larger gas bag, and the keel can hold the gondola and engines, at the cost of additional weight. The risks associated with a single gas bag also apply to semirigid dirigibles. The most famous semirigid was the Italian semirigid airship *Norge*, which in 1926 was used by explorer Roald Amundsen to make the first transpolar flight, from Spitsbergen Island to Alaska.

Rigid dirigibles have a framework to support an outer skin and individual gas bags. In rigid dirigibles, an individual gas bag can fail without damaging the aerodynamic integrity of the craft, and there are usually sufficient reserves among the other cells to maintain buoyancy. Those advantages cost additional weight. However, greater weight can be compensated for by greater size. There is theoretically no limit to a rigid's size. The German passenger airship *Hindenburg* had an LTA gas capacity of 7,000,000 cubic feet, and designs of twice that size have been proposed.

During World War I, the French army used semirigids for reconnaissance, coast patrol, and to find submarines. Near the end of the war, the British armed forces began developing rigid airships, in response to the expected large-scale availability of nonflammable helium gas. The 643-foot-long *R-34*, with a gas capacity of 2,000,000 cubic feet, was put into service in 1919 and made the first transatlantic airship flight, from Scotland to Mineola, New York, and back in eight days. Both the *R-34* and its sister ship, *R-38*, were destroyed in 1921.

Count Ferdinand von Zeppelin, a German military officer, had spent time as a military observer for the Union Army during the American Civil War. While in the United States, he took some balloon flights and became fascinated with balloons before returning to Germany to continue his military service in the Seven Weeks and Franco-Prussian Wars. After his retirement from the military in 1890, Zeppelin devoted all his efforts to the construction of rigid airships.

Zeppelin worked to allay one of the main problems in airship design, that of maintaining a cigar-shaped gas bag and avoiding partly deflated bags that cannot be steered. He made steerable, unchanging shapes by designing rigid, strong, light frames that were mated to gas bags. In 1900, Zeppelin's first airship, *LZ-1*, flew for seventeen minutes. In 1908, the 446-foot-long *LZ-4*, with a gas capacity of 500,000 cubic feet, flew for one half-day at 40 miles per hour.

Soon, Zeppelin's airships, widely known as zeppelins, made practical air transport available. In 1910, the first commercial airline and dirigible manufacturer, Deutsche Luftschiffahrts Aktien-Gesellschaft (Delag), was established. Delag's luxurious dirigibles interconnected many German cities, carrying 15,000 travelers per year. By 1914, when World War I began, Delag had in service twenty-seven dirigibles, including the *Sachsen* and the *Deutschland*, that had achieved airspeeds of over 50 miles per hour. In the next five years, 1,600 dirigible flights carried more than 35,000 passengers over 200,000 miles. Although Zeppelin died in 1917, before transatlantic airship flight was achieved, Delag carried on.

Military Uses

The first military buoyant aircraft were French hot-air/hydrogen tethered reconnaissance balloons, crewed by *aerostiers*. From 1794 to 1799, reports from these balloons aided French armies in battle. Similar reconnaissance balloons were used in the American Civil War, but true military aviation began only with the perfection of navigable airships in the late nineteenth century. Airships were the most formidable aircraft before World War I. They were made of fabric-covered metal frames and gas bags full of hydrogen. Airships were used by the Allies for antisubmarine patrols during World War I. The German zeppelins were the most functional airships, used during World War I to carry five 110-pound bombs and twenty 7-pound incendiaries at a time when military airplanes carried no weapons. More than one hundred zeppelin bombers were used by the Germans to bomb Paris and London. The German dirigibles were so effective that, after Germany lost the war, they were all confiscated. Further German production of zeppelins was prohibited until the late 1920's.

Commercial Uses

Airship construction continued in Europe and the United States throughout the 1920's and 1930's. The British dirigible *R-34* made a round-trip transatlantic crossing in July, 1919. In 1926, Amundsen flew the Italian semirigid airship *Norge* in his expedition to the North Pole. In the late 1920's after Germany was again allowed to produce airships, Delag built the *Graf Zeppelin*, an outstanding zeppelin of the time. The *Graf Zeppelin* had an approximate length of 800 feet and a gas capacity of almost 4,000,000 cubic feet. The luxurious airship began its nine-year service in 1928, ultimately making 600 flights, including 144 ocean crossings, covering 1,000,000 miles. It crossed the Atlantic to North and South America 139 times and made a complete trip around the world in three weeks at a cruising speed of 71 miles per hour, faster than comparable train or boat transportation.

In 1936, Germany began regular transatlantic passenger service with a new Delag zeppelin, the *Hindenburg*, also known as *LZ-129*. The *Hindenburg* cruised at a speed of 78 miles per hour, held 7,000,000 cubic feet of hydrogen, and carried fifty passengers in luxurious style. The airship had been rushed into production by German chancellor Adolf Hitler to show off the greatness of his Reich and was successful in a number of transatlantic flights. However, on May 6, 1937, while docking at Lakehurst, New Jersey, the *Hindenburg* caught fire and exploded, killing thirty-six people in one of the greatest air disasters of all time. After this event, the reputation of dirigibles as air carriers was irretrievably damaged.

Airship Disasters

Although the wreck of the *Hindenburg* was the most notorious airship disaster, it was not the only one. Others had preceded it. For example, a U.S. purchase, the semirigid *Roma*, 400 feet long, with a gas capacity of more than 1,000,000 cubic feet, was lost in 1922. The USS *Shenandoah*, a Navy airship, became the first zeppelin built in the United States in 1923. Filled with helium, the airship was 700 feet long, with a gas capacity of more than 2,000,000 cubic feet. After making a few long trips, the *Shenandoah* broke apart in a thunderstorm and was wrecked in 1925.

The U.S. Navy's *Los Angeles*, a German war reparation, was a bright spot in the airships' dark safety record. The 650-foot-long airship, with a gas capacity of 2,500,000 cubic feet, carried thirty passengers on each of 250 long flights between 1924 and 1932. However, the success of the *Los Angeles* did not outweigh the failures of other airships, which continued to prove problematic around the world.

In 1926, Italy's semirigid *Norge* flew Amundsen's expedition to Alaska but had to be dismantled. A polar flight two years later in the closely related *Italia* was disastrous. Only German zeppelins seemed to survive for long time periods.

Elsewhere, though, airship catastrophes continued to occur. In England, the dirigibles *R-100* and *R-101*, with lengths of approximately 700 feet and gas capacities of 5,000,000 cubic feet and accommodating one hundred passengers, had short terms of service. The *R-100*, christened in 1929, crashed in 1930 and burned to cinders, killing forty-six people. After this incident, the *R-101* was immediately scrapped, and Britain gave up dirigible construction.

The U.S. Navy built two dirigibles, the USS *Akron* and the USS *Macon*, each of which was 785 feet long, with a gas capacity of 6,500,000 cubic feet. Both ships could carry five scout planes and release or take them aboard in flight. Each ship survived for only about two years before crashing into the sea during storms. After the destruction of these two ships, the United States discontinued the building of rigid airships. Despite their varied uses, airships were virtually abandoned in the late 1930's, due to their high production cost, low speed, vulnerability to storms, a series of airship disasters, and advances in heavier-than-air craft. In 1938, American military blimps were put under Navy control for World War II scout, convoy, and antisubmarine work. In peacetime, small blimps have provided aerial television views of sports events and advertising.

Future Uses

After World War II, the U.S. Navy continued for approximately twenty years to develop blimps for antisubmarine, research, and early warning use. The largest, ZPG-2 type, 324 feet long, with a gas capacity of 0.9 million cubic feet, could remain aloft for a week without refueling. The Navy stopped almost all airship use in 1961. During the late 1980's, there was renewed Coast Guard and Navy interest in airship use for early warning and electronic antisubmarine warfare, although not much came of it.

However, enthusiasts attest that blimps can be used for many tasks unsuited to planes. For example, because airships can move very heavy, large objects over short distances much better than planes can, blimplike airships are sometimes used for short-haul and heavy-lift operations in remote areas. This use may continue to increase.

Another proposed use of airships is for intraurban passenger service and other short-distance transportation. Here, low airship speed is not a problem and ability for vertical and short takeoff and landing (V/STOL) is a major advantage over planes. Another advantage of airships over airplanes is their low noise production and fuel consumption.

One final modern use of airships could involve making rigid airships from modern materials and adding contemporary flight instruments and computers. Such airships, it is thought, would be useful for military surveillance of the oceans and coastal areas or for the scientific study of the environment. Thus, it seems probable that in the future many blimps and dirigibles will again take to the air.

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See also: Balloons; Dirigibles; Goodyear blimp; *Hindenburg*; Lighter-than-air craft; Military flight; Montgolfier brothers; Reconnaissance; Alberto Santos-Dumont; Transatlantic flight; Vertical takeoff and landing; World War I; World War II; Ferdinand von Zeppelin

Richard E. Byrd

Date: Born on October 25, 1888, in Winchester, Virginia; died on March 11, 1957, in Boston, Massachusetts

Definition: Naval aviator and premier twentieth-century polar explorer.

Significance: Byrd claimed to be first to fly over the North and South Poles and led five Antarctic expeditions that called public attention to that part of the world.

Born in Virginia, Richard E. Byrd was the son of Richard Evelyn Bird, a lawyer, and Eleanor Bolling Flood. After graduating from the United States Naval Academy in 1912, Byrd received an ensign's commission and made his first airplane flight in 1914. During World War I (1914-1918), he was forced into retirement by continuing problems with an injured ankle but was recalled to active duty and won his wings as a naval aviator in 1918.

After the war, Byrd worked on NC flying boats, pioneering seaplane landings. He helped create a government bureau of aeronautics. In 1925, he commanded a naval unit on an expedition to northern Greenland sponsored by, among others, John D. Rockefeller and Edsel Ford. During this expedition, he flew over Ellesmere Island and the interior regions of Greenland.

On May 9, 1926, Byrd and Floyd Bennett flew north from Kings Bay, Spitsbergen Island, in a Fokker monoplane, the *Josephine Ford*. The two journeyed for more than fifteen hours and recorded that they had passed over the North Pole during their flight. Although their claim would later be disputed, both men returned to the United States as heroes and were awarded the Congressional Medal of Honor. In June, 1927, less than a month after Charles A. Lindbergh's transatlantic flight, Byrd and three companions crossed the Atlantic in a Fokker trimotor, crash-landing in France after a forty-two-hour journey.

Byrd turned his attention toward the South Pole, gaining private funding for his five visits to Antarctica, which included a flight over the South Pole in November, 1929, aboard a Ford trimotor plane, the *Floyd Bennett*. The round-trip flight, with three other fliers, took nineteen hours and earned Byrd a promotion to rear admiral. It departed from a base named Little America that was constructed on the Ross Ice Shelf, a flat area of ice fronting the Ross Sea.

From 1933 to 1935, Byrd conducted a second expedition, extending the exploration of Antarctica. He continued his exploration of territory that he had previously named Marie Byrd Land, in honor of his wife. He caused some controversy when he spent the winter of 1934 alone in a station hut and had to be rescued, frostbitten and sick with carbon monoxide poisoning.

After being named as head of the U.S. Antarctic Service by President Franklin D. Roosevelt, Byrd led a third Antarctic expedition in 1939 and 1940. He established two bases on the continent and discovered Thurston Island. During World War II, Byrd served on the staff of the chief of naval operations.

At the end of World War II, Byrd led his fourth Antarctic expedition, named Operation Highjump, which mapped and photographed more than half a million square miles of the continent. This massive operation involved approximately five thousand men and thirteen ships, including an aircraft carrier. During this expedition Byrd flew over the South Pole for a second time on February 16, 1947.

Byrd's fifth and final expedition, Operation Deep Freeze, was an exploratory and scientific project conceived to coincide with the International Geophysical Year (IGY) activities involving thirteen nations. Traveling to his base aboard the icebreaker *Glacier*, Byrd made his final flight over the South Pole on January 8, 1956. Skilled at applying technology to his explorations, Byrd employed helicopters, seaplanes, and skibased airplanes. His expeditions to Antarctica claimed thousands of square miles for the United States.

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See also: History of human flight; Navy pilots, U.S.; Seaplanes; Transatlantic flight; World War I; World War II

C

Cargo aircraft

Definition: Cargo aircraft are aircraft dedicated to hauling freight rather than transporting passengers. Any airplane, regardless of size, is considered a freighter if carrying cargo rather than people is its primary use.

Significance: In the Western industrialized world, most food, newspapers, and mail is transported by air. Because airfreighters often have separate terminals, fly primarily at night, or utilize different airports than passenger traffic, it is easy to overlook how vital air freight has become to the modern economy. Air freight companies, such as Federal Express, DHL, and United Parcel Service, operate thousands of cargo aircraft daily, most of which go totally unnoticed by the general public. DHL Worldwide Express alone operates 358 aircraft out of thirty-six regional hubs around the world.

Cargo aircraft, also called freighters, transport fresh flowers from Africa, grapes from Chile, and many other items that in previous decades would have traveled by ship or truck, or not at all. While much of the commercial freight traffic in many countries still travels by land routes, cargo aircraft handle ever-increasing amounts of material. In the United States and Europe, for example, catalog companies and Internet merchants rely on freight companies such as Federal Express to deliver orders to customers quickly. Without air freighters, the overnight delivery of packages and documents over thousands of miles, which is now taken for granted, would be impossible.

Although the general public often thinks of cargo aircraft as hauling freight that is small, light, or perishable, air freighters are just as likely to be hauling oversize materials as they are to be transporting perishable cargoes that must reach customers quickly. Items too large in weight, length, width, or height to be shipped by truck or rail are now flown to their destinations on oversize aircraft such as the civilian Super Guppy and the U.S. military's C-5. Until recently, railway freight cars could not carry items exceeding 60 feet in length. The C-5, in contrast, has a cargo bay 143 long.

The Beginning of Cargo Flight

Using aircraft for hauling cargo was not an immediate priority in the aviation industry. For the first several decades of the twentieth century, aircraft remained relatively small. Following the Wright brothers' success in 1903, aviation pioneers focused first on increasing speed, distance, and number of passengers before contemplating using aircraft to carry freight. Any cargo hauled was highly specialized and lightweight, such as medical supplies. The United States Post Office began airmail service in 1918, but the service was limited almost entirely to letters. Writers were urged to use thin onionskin paper to reduce the weight of individual pieces of correspondence.

As the size and range of aircraft increased, however, aviation's potential for hauling freight became more apparent. In the mid-1920's, the U.S. military acknowledged the divergence of freighters from transport aircraft and began numbering the former with a "C" designation, to indicate cargo. The Douglas C-1 was the first airplane so designated, in 1925. The airplane, a single-engine biplane, had an enclosed passenger compartment that could transport six people. With the seats removed, it became a freighter. This remains typical of military freighters, as many aircraft bearing a "C" designation are used as troop transports as well as for carrying cargo.

On the civilian side, United Parcel Service (UPS), founded in Seattle in 1907 as a messenger firm, began shipping packages by air in 1929. For many years, however, the company restricted that service to the West Coast. In 1953, UPS expanded its air delivery system nationally. Companies such as UPS generally use conventional aircraft that have been converted for use as freighters. This is nothing new in aviation history. Many aircraft designed for transporting passengers have been pressed into service as freighters, while numerous passenger aircraft carry some freight in addition to their human cargo. The rear bulkhead in the main cabin of many aircraft is movable, which gives airlines the flexibility to increase or decrease the size of the passenger compartment and the baggage compartment behind it if necessary. Most commercial airlines, for example, have contracts with the U.S. Postal Service to transport mail. Ironically, one of the aircraft most closely associated in the public's mind with long-distance passenger transport, the Boeing 747, was designed originally to maximize its cargo capacity.

Passenger/Cargo Craft

When Boeing company aerospace engineers began planning the 747 in the early 1960's, industry analysts believed the future of air passenger service would lie in the area of supersonic transports (SSTs), such as the Concorde airliner then being developed in Europe. Although the 747 was initially designed as a jumbojet with a double-decker passenger compartment, the price of aviation fuel in the 1960's was so low—barely 10 cents per gallon—that many experts believed SSTs would be economical to operate despite their high fuel requirements and relatively small passenger cabins. The Concorde, for example, has a maximum passenger capacity of 144 persons, in comparison with the 747's high-density 624. The energy crisis of the 1970's combined with public concerns about negative side effects of SSTs, such as noise, proved the experts' predictions wrong. With the 747 being highly useful for either passenger transport or as a freighter, it is not surprising that by the twenty-first century, the SST had become a curiosity, while the Boeing 747 dominates international air traffic. Boeing ultimately chose not to use the double-deck concept for the passenger cabin of the 747. Instead, they placed the cockpit above the main cabin, giving 747's used as freighters an exceptionally roomy cargo compartment. When configured as a passenger plane, a 747 will seat passengers in rows of ten persons across. When configured as a freighter, two 8-foot wide cargo containers can be placed side by side.

Noted cargo aircraft over the years have included the Ford Tri-Motor and the Douglas DC-3. Both aircraft were developed primarily for use in transporting passengers, but were quickly pressed into service as freighters. The Ford Tri-Motor, introduced in 1926, was notable for its all-metal construction, an aviation first. One of the first aircraft designed to be inherently stable, the Tri-Motor could fly well on only two engines and maintain a level flight path with only one. The aircraft was manufactured for only seven years, from 1926 to 1933, with a total of 199 being built. The Tri-Motor was a rugged aircraft capable of surviving a great deal of rough use. As recently as 1998, a few Tri-Motors remained in service, including one being used by a sightseeing company in Ohio to fly daily tourist excursions.

The venerable DC-3 made its debut in 1935. Within a short time it gained a reputation for being virtually indestructible. It has been estimated that by 1944, over 90 percent of the aircraft being used by commercial airlines were DC-3's. The Douglas Aircraft Company built a total of 18,000 aircraft before discontinuing production. During World War II, the military version of the DC-3, the C-47, saw wide use in both the European and Pacific theaters. General Dwight D. Eisenhower was quoted as saying that the DC-3 was one of the four "weapons," which also included the jeep, the bazooka, and the atomic bomb, that helped the Allies win the war. Over one thousand DC-3's remained in service as of 200l, with the majority being used for transporting cargo.

Specialized Freighters

The DC-3 was typical of many freighters in that it was designed initially to serve as a passenger plane. In 2001, many commercial freighters are civilian aircraft, such as Boeing 737's or McDonnell Douglas DC-10's, that have exceeded the maximum number of hours allowed for use as a passenger plane, although a few specialized cargo aircraft have emerged in the civilian market. These specialized freighters include the Super Guppy, a modified Boeing Stratocruiser, developed by Aero Spacelines in the early 1960's. The diameter of the upper portion of the fuselage was increased, giving the aircraft the ability to transport oversized items such as sections of the Saturn rockets used in the U.S. space program. The rocket sections were too large in diameter to be transported via rail or truck. The resulting rather bloated profile earned the Super Guppy its nickname. The Super Guppy has a sideways-hinged nose for straight-in loading. Other freighters may be hinged so the nose swings up, or feature a large rear cargo door with a ramp. The military's C-5 Galaxy has both a hinged nose and a ramped rear cargo door.

Some military freighters do share an airframe design with a civilian equivalent, but the manufacturer modifies the aircraft at the factory with specialized cargo doors and other features. The C-131 used for many years by the U.S. Air Force was a cargo transport version of the Convair 340 used by civilian airlines. Military freighters, such as the C-5 Galaxy developed by Lockheed, are generally built specifically to be used as cargo aircraft. The C-5 is the United States' largest military freighter. The cargo hold of a C-5 is large enough to carry six Apache helicopters. The aircraft has a payload capacity of 270,000 pounds, which is less than that of its Russian counterpart, the Antonov AN-124, but still sufficient to transport two M-1 battle tanks weighing 135,000 pounds each. Fact sheets on the C-5 Galaxy point out that the aircraft's cargo bay, at 143 feet long, is a greater distance from end to end than that which Wilbur and Orville Wright covered in their first powered flight at Kitty Hawk. The C-5 is remarkable in its ability to land and take off from very short runways. The aircraft's landing gear has twenty-eight tires, giving it the high flotation necessary for landing on dirt runways. The landing gear are hydraulically hinged, allowing the plane to "kneel" to bring the level of the cargo bay down to truck-bed height, making loading and unloading easier and faster.

Just as U.S. aerospace engineers developed the C-5 to transport oversized military equipment such as tanks, engineers in the Soviet Union designed the Antonov AN-124. The AN-124 made its first public appearance outside the Soviet Union at the May, 1985, Paris air show. The aircraft has a maximum payload of 330,700 pounds. Like the C-5, the AN-124 is notable for its twenty-four-wheel landing system, which enables it to land on dirt runways and even hard-packed snow, despite being possibly the heaviest aircraft in the world.

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See also: Airplanes; Airline industry, U.S.; Airmail delivery; Apache helicopter; Boeing; Commercial flight; DC plane family; Lockheed Martin; Manufacturers; Military flight; 707 plane family

Sir George Cayley

Date: Born on December 27, 1773, in Scarborough, Yorkshire, England; died on December 15, 1857, in Brompton, Yorkshire, England

Definition: Early nineteenth century theoretician and experimenter who laid the foundation for heavier-than-air vehicle design.

Significance: Cayley was the first to conceive and publish the modern idea of the airplane: namely, the concept that an airplane should consist of one or more fixed wings, a fuselage, and a tail. He also designed and flew model gliders complete with control surfaces, was the first scientist to perform detailed tests of lift and drag as a function of angle of attack, and championed powered airplanes during the age of balloons.

George Cayley was born in Yorkshire, England in 1773 to a wealthy landowning family of noble lineage. He was privately tutored, with emphases on the scientific and mechanical arts, at which he excelled.

Although his official duties revolved around the administration of Brompton Hall, his baronial estate, Cayley applied his inquisitive mind to a wide range of practical issues affecting early nineteenth century English society. He devised a hot-air engine in 1799, more than a decade before the engine built by the Reverend Robert Stirling, whose name has since been attached to the concept. He directed the Polytechnic Institution in Regent Street, London, from its inception in 1839 to showcase technical achievements. He contributed improvements to railway carriage safety during the fledgling years of the railroad industry. He carried out experiments on ballistics and airships. He also invented several versions of an articulated mechanical hand to replace a lost limb.

Despite these many and varied achievements, Cayley is chiefly commemorated as the father of aerial navigation, a title first bestowed on him by the unsuccessful airplane designer William S. Henson, in an 1846 letter to Cayley. The appellation has since been reinforced by the discovery and publication in 1933 of Cayley's experimental notebooks, which along with his published writings, convey a sound knowledge of the dynamics of heavier-than-air flight almost a century before the Wright brothers applied themselves to the topic.

As early as 1799, Cayley had engraved on a small disk the force balance on a rudimentary aircraft. By 1804, he was performing whirling-arm experiments on the lift and drag characteristics of thin plates at low angles of attack and had noted the benefits of camber. In 1809 and 1810, he published seminal articles in *Nicholson's Magazine* that examined power requirements, structural issues, and aerodynamics for airplanes that could carry human passengers, given a sufficiently large lifting surface and a suitably light prime mover, or propulsion system. His sketchbooks show model vehicles with a movable rudder and tail, a variable center of gravity, and a dihedral angle for lateral stability.

Late in life, Cayley designed a remarkable vehicle that was described in an 1843 article in *Mechanics' Magazine*. It featured airscrews for vertical liftoff that converted to flat planes for horizontal flight under the impetus of a propeller. In 1849, Cayley published the results of model glider experiments and by 1852 had designed a vehicle with a 500-square-foot lifting surface, weighing 300 pounds and capable of supporting a person on board. It appears that he did oversee some manned glider experiments on his estate in or around the same year. Active almost to the end of his life, Cayley died at home on December 15, 1857, just short of his eighty-fourth birthday.

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See also: Aerodynamics; Gliders; Heavier-than-air craft; History of human flight

Cessna Aircraft Company

Definition: Wichita, Kansas-based company specializing in the manufacturing of small planes.

Significance: Cessna became a market leader in the general aviation field before World War II. After the war, the company continued its success by branching out into the production of business jets, eventually selling more business jets than any other company.

The Early Years

Cessna Aircraft Company had its inception in 1911 when founder Clyde Cessna attended an air show in Oklahoma City. Aviation so enthused Cessna that he moved to New York and spent three weeks working on an aircraft assembly line to learn all he could about flight. After returning to Oklahoma, Cessna purchased a monoplane and began making demonstration flights. Cessna also hoped to use his new monoplane as a blueprint for his own planes. Despite having no formal engineering training, Cessna produced several airplanes over the next seven years, first on his farm west of Wichita and after 1916 in Wichita itself. The United States' entrance into World War I in 1917 stifled Cessna's hopes to build a successful flight training school, and he was unable to secure any government manufacturing contracts. Cessna left the aircraft business in 1918 and did not return for seven years. Cessna focused on farming until 1925, when two Wichita aircraft builders, Walter Beech and Lloyd Stearman, asked Cessna to join them in establishing a new company, TravelAir. Cessna and Stearman designed the TravelAir 5000, which won the 1927 Dole Race to Hawaii. Other TravelAir designs also became very popular. However, Cessna was not content at TravelAir, and he sold his stock in 1927 to start Cessna Aircraft Company.

The Depression

Cessna enjoyed success during the late 1920's. The United States was in love with aviation, particularly after Charles A. Lindbergh's transatlantic flight in 1927. Cessna did well with two production models, the AW and BW, as well as specialized racing planes, but the good times did not last long. The Great Depression crippled the American economy, and aircraft manufacturers went bankrupt as their market disappeared. Cessna closed its doors in 1931, and Clyde Cessna never returned to the company he founded, though he did produce several highly successful racing aircraft during the 1930's. Cessna's nephews Dwane and Dwight Wallace resurrected the company in 1934. The Wallace brothers immediately set to work on a new aircraft, the C-34. The C-34 was designed for efficiency and long-term service, hoping to attract businessmen looking for reliable and cost-effective air transportation. The new plane boasted a cruising speed of 143 miles per hour and a range of 550 miles, while consuming only five gallons of fuel per hour. The single-engine C-34 and its descendants became known popularly as Cessna's Airmaster line. The company also produced a twin-engine plane, the T-50, nicknamed the Bobcat. The first T-50 flew in 1939 and boasted such features as retractable landing gear, hydraulic brakes, and a 1,000-mile cruising range. Though not as luxurious as some of its competitors, the T-50 cost considerably less. During World War II, the T-50 saw extensive service as a trainer aircraft, redesignated as the AT-17.

Wartime Production

As World War II loomed, Cessna's established reputation made the company an important part of the nation's preparedness efforts. The firm received its first order from Canada, which ordered five hundred modified T-50's and two hundred extra engines. The U.S. government soon followed with its own orders. As a result of this new demand, Cessna's employment increased from 200 in 1940 to 1,500 by the spring of 1941. After the United States entered the war, Cessna diversified its production to meet wartime demands. The company built subassemblies for the massive Boeing B-29 bomber. Cessna also designed a cargo plane, the C-106, but the craft never went into production. Cessna built 6,111 planes for the U.S. war effort, including 750 CG-4A-CE gliders. Production lines ran twenty-four hours a day, seven days a week, beginning early in 1942. Employees could make use of their own club, with a gym and a lounge. The company was among only 3 percent of U.S. manufacturers to earn the prestigious Army-Navy "E" rating, awarded to manufacturers that met production goals, five times during the war.

Postwar Hopes

Aviation enthusiasts envisioned a postwar United States that would take to the air in great numbers. The idea of providing families with safe, affordable airplanes as an alternative to automobile or rail travel attracted many within the aircraft industry. Cessna's production capabilities and experience positioned the company to take advantage of this new opportunity in the general aviation sector. Cessna produced the Model 120 in 1946, at a price of $2,695. This would be as close as any U.S. aviation manufacturer would come to producing an aircraft suitable for the needs and budgets of American families. The 120 could cruise at 100 miles per hour and promised durability with less maintenance. The company also produced a more expensive, upgraded version known as the Cessna 140. Cessna promoted its new product line by establishing distributorships around the world. In December, 1946, Cessna produced almost as many small planes as all of its competitors combined. The company built on the success of the 120 and 140 by introducing three new models, the 190 and 195 in 1947, and the 170 in 1948. The 190 and 195 were designed for greater luxury, and the 170 could carry four people, as opposed to only two in the 120 and 140. Despite these new designs, Cessna struggled through the end of the 1940's. The United States' economy sagged as it readjusted to peacetime production, and aircraft companies had to find other ways to make profits. Cessna's Wichita competitor Beech investigated automobiles and prefabricated housing. Cessna looked to somewhat more mundane products including furniture, hydraulics, and aluminum lockers. The furniture-making enterprise proved the most profitable, particularly after the company won a contract from the Army Quartermaster Corps. After the Army contract expired, Cessna tried to market its furniture line through Chicago-based department store Marshall Field's. Finally, the demand for aircraft increased to the point that Cessna could eliminate its furniture operation in 1951. In the 1950's, Cessna continued expanding its offerings. In 1953, Cessna debuted the Model 180 and the 182 Skyline which promised greater performance, though at a greatly increased price of $13,000. The company also introduced the 172 Skyhawk in 1956 as an improved version of the 170. Cessna diversified its product line even further in 1954 by entering the luxury twin-engine market with the Model 310, which would be immortalized in the television program *Sky King* (1951-1952, 1956-1962). Cessna's 2,489 planes sold in 1958 made the company the world's largest private-plane manufacturer.

The Jet Age

Cessna continued its advancements in design with the 1961 production of the Model 336-337 Skymaster. The Skymaster boasted two engines, but rather than placing one on each wing, Cessna put one on the nose and the other between twin tails. This configuration eliminated the dangerous situation of unequal thrust in case of engine failure. The Skymaster won excellent reviews from aviation experts, but it did not attract buyers due to its unconventional appearance. In fact, the Skymaster failure did not seriously damage the company because Cessna and Dwane Wallace had already turned to the jet market. Originally, company officials hoped to design a high-end turboprop plane that would fit the market niche between small private planes and the expensive business jets then making their first appearance. Wallace soon saw that a turboprop model was not the solution. Responding to the success of Wichita-based Learjet, Cessna produced the Citation in 1972. In designing the new plane, Cessna stuck with its established formula of offering the customer a safe and efficient aircraft at a reasonable price. The Citation offered quiet and reliable performance with less maintenance and better fuel economy. The plane had room for comfortable accommodations for six people at about half the price of its competitors. The new jet did, however, have its drawbacks. Its cruising speed of 400 miles per hour was 150 miles per hour slower than the Learjet models, and the Citation had a somewhat strange appearance, with its straight wings and blunt nose. Critics felt that the Citation stood little chance of success, and early sales favored the competition. The company stood behind its design, and by 1978, the Citation was the world's fastest-selling corporate jet. The company expanded its offerings by following up the original Citation with the Citation I and II models. Cessna hoped to move into new market territory, however, and began development on a larger, faster, and more luxurious jet, the Citation III. The first prototype of the Citation III flew in 1979 and Cessna delivered the first production models in 1983. The Citation III cruised at 509 miles per hour and could fly 2,500 miles. The cost of the jet in 1984 was $6,120,000, but that did not deter customers who purchased fifty of the planes that year, far above the totals of Cessna's competition. The company redesigned the Citation III extensively in 1990, giving the plane a new avionics package, an improved interior, and changes in the airframe. Cessna completed the evolution of the original Citation line with the VI and VII models. The Citation VI was a lower-priced version of the Citation III, which Cessna delivered in 1991. The Citation VII was a larger and more powerful model, delivered in 1992.

Corporate Changes

The economic pressure of developing the Citation line stretched Cessna's resources. Customers complained that their planes did not function reliably and the company's maintenance and repair services did not always meet expectations. Cessna sent out more than one hundred service bulletins addressing problems, publicly highlighting the shortcomings of the early Citations. The company also faced stiff competition from other firms. These problems made it impossible for Cessna to remain an independent company. In 1985, General Dynamics acquired Cessna and promised to continue and improve the Citation line. In 1992, Textron purchased Cessna from General Dynamics for $600 million in cash. These changes in corporate structure did not change Cessna's focus, however. The company remained the world's largest seller of business jets through the end of the century.

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Octave Chanute

Date: Born on February 18, 1832, in Paris, France; died on November 23, 1910, in Chicago, Illinois

Definition: An experimenter in glider flight and design, a communicator who helped early experimenters exchange information, and an author who inspired many aviation pioneers.

Significance: Chanute's experiments in gliding flight near Chicago, Illinois, in the late 1800's and his correspondence with other experimenters in the United States and Europe led him to publish many articles on flight. His 1894 book, *Progress in Flying Machines* inspired many of the first American aviators, including Wilbur and Orville Wright, to begin their flying experiments.

Octave Chanute was born in France but emigrated to the United States in 1938 and studied civil engineering through an apprenticeship program. Working with railroads, he became one of the most successful engineers in the United States and designed the first bridge across the Missouri River. Chanute became interested in the challenge of flight in the 1870's and corresponded extensively with aviation experimenters, such as Otto Lilienthal in Germany. During the 1890's, he designed, built, and tested his own gliders in hundreds of flights on the shore of Lake Michigan.

Although Chanute learned much from his own experiments, he is best remembered for the encouragement he gave to others and for his role as a communicator. He pub-

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lished many articles on flight in engineering journals and magazines of the time, as well as a book, *Progress in Flying Machines*, in which he reviewed the work of past and then-current flight researchers. Through his personal correspondence, he led many aviation pioneers into the field. Wilbur and Orville Wright read Chanute's book and corresponded frequently with him as they worked on their glider and airplane designs. Chanute visited the Wrights at their camp at Kitty Hawk, North Carolina, and gave them advice and encouragement as they chased the goal of powered flight.

It was Chanute who, in Paris in 1903, first revealed to European aviation researchers that the Wright brothers were on the verge of success. He published detailed accounts of that success within a few weeks of their first flights. A couple of years later, in an apparent effort to motivate the Wrights toward a more public exhibition of their success, Chanute informed Orville and Wilbur that the Europeans were nearing success in building a flying machine. The Wrights, who had been somewhat secretive about their post-1903 experiments in hopes of selling profitable airplanes to the military, rejected his advice, responding that there was no one in the world, not even Chanute himself, who was capable of building a flying machine within the next ten years. The first successful European flight took place the following month.

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See also: Airplanes; Gliders; Heavier-than-air flight; History of human flight; Otto Lilienthal; Wright brothers

Jacqueline Cochran

Date: Born c. 1910, in Muscogee, Florida; died August 9, 1980, in Indio, California

Definition: Pioneer in aviation who paved the way for future female American pilots.

Significance: At the time of her death, Cochran held more speed, altitude, and distance records than any other pilot in aviation history. She was the first woman to break the sound barrier and the first living woman to be inducted into the American Aviation Hall of Fame.

Born near Pensacola, Florida, sometime in 1910 (although she claimed her birth date was May 11, 1912), Jacqueline "Jackie" Cochran spent her early years in poverty. Orphaned while still an infant, she was raised by a foster family of sawmill workers. Her formal education did not go beyond the second grade. During her teens, she moved to Alabama to work as a beautician and enrolled in a three-year nursing program. Although she completed her training, Cochran, fearing failure, did not take the written examination and instead became a doctor's assistant near the sawmills where she had been raised.

Depressed by the poverty of the sawmills, however, Cochran returned to work as a beautician. This work took her from Pensacola to Philadelphia, and finally to New York City, where she worked at the Saks Fifth Avenue department store. On a business trip in 1932, she met Floyd Odlum, a wealthy investor who enjoyed aviation. Following their conversation, Cochran enrolled in flight school. She quickly completed the courses, becoming one of only a few women to have a pilot's license. Thereafter, she received a commercial pilot's license, bought her own plane, and began competing in air races.

Cochran opened a beauty shop and started a cosmetic manufacturing business. In 1936, she married Floyd Odlum; the couple settled on a ranch near Indio, California. Marriage allowed Cochran to concentrate most of her time on flying. During the next year, she set three speed records and was awarded the Harmon trophy as the outstanding woman aviator of the year. In 1938, she won the Bendix Transcontinental Race by setting a new speed record, and the following year set an altitude record of 33,000 feet while winning the New York to Miami air race.

During the early 1940's, Cochran used her aeronautical skills to help the Allied war effort. In 1941, she became the first woman to ferry a B-17 bomber to Britain, and thereafter recruited other female pilots to continue ferrying operations for the military. As a result of this success, in 1943 the military appointed her as the head of the Women's Airforce Service Pilots (WASPs). Under her direction, over one thousand women completed important missions across the Atlantic. In 1945, the Army awarded Cochran the Distinguished Service Medal for her accomplishments as head of the WASPs. Following World War II, she worked as a reporter for *Liberty Magazine*. As a journalist she covered the Nuremberg war crimes trials, was the first American woman to enter Japan after the war, and interviewed Chinese leaders Chiang Kai-Shek and Mao Zedong.

Following the war, Cochran returned to the skies to set new records. In 1948, she set an altitude record of over 55,000 feet, and in 1953, she flew an F-86 Sabre jet faster than the speed of sound (Mach 1), becoming the first woman to break the sound barrier. Her aviation records continued, as she became the first female pilot to land a jet on an aircraft carrier and the first woman to pilot a jet across the Atlantic Ocean. In 1964, she logged a record-setting flight at 1,429 miles per hour, over twice the speed of sound (Mach 2) and the fastest for a female pilot.

In 1970, Cochran retired from the U.S. Air Force Reserve with the rank of colonel, and the next year she became the first living woman to be inducted into the American Aviation Hall of Fame. She died in 1980, leaving behind more than two hundred flying records. In addition to holding more records for altitude, speed, and distance than any pilot in history, her pioneering efforts made it possible for women to serve their country as pilots, astronauts, and military officers.

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See also: Air derbies; Flying Fortress; Military flight; Women and flight; Women's Airforce Service Pilots; World War II

Cockpit

Definition: The area within an aircraft from which pilots operate the aircraft's controls.

Significance: Cockpits provide a central point from which airplane performance can be commanded and monitored.

The term "cockpit" originated with the ancient sport of cockfighting. Early pilots had to control unstable airplanes through control levers positioned without regard to one control's effect on another. Pilots stayed busy, their motions reminiscent of the frenzy in the gaming floor's cockpit.

Although early airplanes accommodated pilots, they had no cockpits by modern definition. The Wright brothers' *Flyer* pilot lay prone, having controls in reach but little else. No flight instruments existed until about 1911. In his underpowered, box-kite-like *14-bis*, Alberto Santos-Dumont stood erect while becoming Europe's first airplane pilot. By their first decade, airplanes had evolved cockpits as effective yet inefficient workstations.

By World War I, fighter cockpits gave their seated pilots a control stick, a rudder bar and precious few instruments. Open cockpits were a hallmark of pre-1920 airplanes—rarely were cockpits enclosed. As enclosures became prominent in the 1920's, some pilots disliked them, wanting the wind on their faces to indicate slips or skids. By the 1930's, most airplanes featured enclosed cockpits, although efficient pilot motion stayed a low priority.

The layout of cockpits only slowly became logical, with their instruments and installations sometimes cumbersome. Lockheed's prewar Model 14 Hudson is an example of cockpit inefficiency; its Royal Air Force (RAF) version was a handful for its single pilot. In his 1972 memoir, H. A. Taylor recounted the difficulties of solo flight in the Hudson, beginning with starting the engine. It was a procedure that "was preferably done with three hands, each with more than the usual number of fingers and thumbs," and involved simultaneously pressing buttons for both the starter motor and booster coil while holding a spring-loaded, three-position switch that selected the engine to be started. Meanwhile, an engine-doping pump and a wobble-pump had to be worked, and as soon as the engine fired, the idle cut-off lever had to be released and the throttle manipulated while the booster button was continually pressed. The layout of these vital mechanisms added to the challenge: "The buttons, switches and doper were on a fore-and-aft electrical panel to the pilot's right; the wobble-pump handle was at the rear of the throttle pedestal; and the cut-off levers sprouted, among a dozen or more others, from the top of this pedestal."

Not all 1930's manufacturers spurned pilot efficiency. By the early 1930's, Germany's Junkers Aircraft built its Ju-52/3m, called "Tante Ju" ("Auntie Junkers") by her adoring crews. Its innovations included dual instruments, a series of mechanical devices to reduce distraction-induced pilot errors, and effective weatherproofing. Logic arranged its flight instruments, and the pilot and copilot could both reach the brake lever. By the climax of World War II, cockpit efficiency had become a manufacturing priority.

Modern Cockpits

Airplane cockpits range from the single-place, where the pilot is the sole occupant and performs all duties, to the multi-place, in which several crew members share duties such as flying, communicating, navigating, and systems monitoring. Cockpit designs demand unique considerations.

Accessibility means that the pilot's station must be easily reached upon entry and easily departed at flight's end. Restraints must counter turbulence, yet allow quick crew egress in emergencies. Once seated, pilots must be able to reach all of the flight and systems controls. The control sticks so favored by early designers provide an unencumbered view of the instrument panel, and fall to hand naturally. Control yokes, or wheels, create an automotive feel that comforts new aviators, but blocks pilot vision of parts of the instrument panel. Both amateur airplane builders and conglomerates, such as Europe's Airbus Industrie, have found value and pilot acceptance of side-sticks, joysticks mounted on the cockpit bulkhead, or side wall, where they can comfortably be reached by the pilot's hand. These controls can be reliably gripped, even in tense moments or in turbulence, when jolts and jostling fling a pilot's reaching hand from levers or dials.

From the 1920's through the 1950's, training airplanes tended to have tandem cockpits, in which the student and instructor sat on the airplane's centerline, one behind the other. Advantages included the students' ability to perform maneuvers in either direction with equal challenge, for their field of vision either way remained identical. Additionally, students tended to develop cockpit skills more quickly because their instructors remained essentially hidden. Disadvantages included the need for duplicate instrumentation and the instructors' inability to see nuances in student facial expressions. In the 1950's, as most trainer cockpits adopted side-by-side seating, designers strove for cockpit efficiency. Sometimes that goal is still unmet. Ten accidents occurring between 1972 and 1982 prompted development of what is known as cockpit resource management. Accidents underscored the need for physical changes in cockpits. Studies revealed surprising clues to the dangers induced by poor design.

By the twentieth century's close, newly produced airplanes had begun to incorporate cockpit ergonomics. Ergonomics considers the design of the human body, including its ranges of skeletal and muscular motion. Normal operation is the first consideration, but airplanes encounter strong turbulence, operate in daylight and darkness, and can climb in minutes from searing heat at the airport to subzero temperatures at altitude. Designers must consider these factors and more, plus incorporate characteristics to maximize crash survivability. Like the rest of the airplane, the cockpit is a compromise, for which designers cannot rely on tradition. Today's cockpit designers use recent and exhaustive studies to meet their goals. Despite its claustrophobic faults, the cockpit holds strong allure to millions. Depicting airplanes, artists usually focus on cockpits, for therein sits an airplane's humanity, and what many see as its ultimate office.

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See also: Airplanes; Flight control systems; Instrumentation; Manufacturers; Rudders; Alberto Santos-Dumont; Training and education; Wright *Flyer*

Bessie Coleman

Date: Born on January 26, 1893, in Atlanta, Texas; died on April 30, 1926, in Jacksonville, Florida

Definition: The first African American woman to fly an airplane and the first to earn an international pilot's license.

Significance: Coleman overcame racial barriers in the United States to achieve her dream of flying, becoming an inspiration to women and minorities.

Bessie Coleman, known to her fans as "Queen Bess," grew up caring for her thirteen younger siblings on a small farm near Waxahachie, Texas. Coleman's father left the family when Coleman was nine, and her mother supported the children by picking cotton and taking in laundry. Although at the top of her class, Coleman had to leave school at the end of eighth grade to work as a laundress. Finding domestic work humiliating, she left Texas in 1915 and went to live with her brother in Chicago, where she studied to be a manicurist.

During World War I (1914-1918), Coleman read accounts of brave aviators and decided that she wanted to become a pilot and open a flight school for African Americans. When no flight school in the United States would accept her as a student, she went to France. Coleman began her training at the École d'Aviation des Frères Caudron at at Le Crotoy in November, 1920. In June, 1921, she became the first black woman to receive a license from the Fédération Aéronautique Internationale. She returned to Chicago in September, 1921, hoping to further her flight training, but again no flight school in the United States would accept her. Undaunted, she returned to France in February, 1922, and completed an advanced course. She sailed for the United States in August, ready to begin her aviation career.

Coleman flew in her first air show, the first public flight in the United States by an African American, in New York on September 3, 1922, and went on to perform in air shows across the country. She was offered a role in a motion picture, but when she found that it required her to dress in ragged clothing, she refused, believing the role would perpetuate a negative image of African Americans. After this episode, several of her backers withdrew their support of her.

Coleman began a lecture tour hoping to inspire young African Americans but found that the meager sums she collected from her audiences would not allow her to achieve her dream of opening a flight school. The chewing-gum manufacturer Edwin W. Beeman helped her purchase a plane in which to fly in a celebration sponsored by Jacksonville's Negro Welfare League. On the day before the event, Coleman's mechanic, William D. Wills, took her up so she could survey the area. Coleman sat in the back of the plane without wearing her seatbelt, so she could boost herself up to see out of the cockpit. A wrench left in the airplane jammed the controls, causing the plane to flip and go into a tailspin. Coleman was flung from the plane and plunged 2,000 feet to her death.

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See also: Air shows; Safety issues; Training and education; Women and flight

Commercial flight

Definition: The transportation of passengers and freight by commercial airline companies.

Significance: Commercial flight has made possible a global economy, drastically reducing the amount of time and money that must be spent in transporting people and goods over long distances.

The emergence of relatively reliable and safe airplanes during World War I induced people to attempt the organization of an airline to operate those craft on a scheduled basis over a consistent route. The Deutsche Luftreederei began service from Berlin to Leipzig and Weimar on February 5, 1919, followed only three days later by the French Farman Company on the cross-channel crossing from Paris to London using a converted Goliath bomber of World War I provenance. In August, 1919, the first daily service was established on this route from Le Bourget Airfield in Paris to Hounslow in the United Kingdom. The oldest surviving airline, KLM, was organized in the Netherlands in 1919 and, jointly with a British company, began flying the route between Amsterdam and London the following year. Outside of Europe, the Queensland and Northern Territories Aerial Services (Qantas) was founded in 1920. This eventually became the Australian national airline.

Most of the airlines founded in the 1920's and 1930's were created at least in part to encourage the purchase of aircraft of domestic manufacture. However, the privately owned Swissair was the first European airline to purchase American aircraft. The intertwining of domestic aircraft manufacture and national airline operation was widely advocated as critical to national defense.

In the United States, airline pioneers were private operators, as were the aircraft builders, and there was no national policy concerning either operation. Throughout the 1920's there were no adequately financed airlines, and most lasted for only short periods before failing or merging. Given the large expanse of the United States, an airline with routes of national or even regional coverage was the exception. It was only in the late 1920's that any thought was given to the question of encouraging a domestic aircraft industry or the promotion of domestic airline companies.

International Transportation

In Europe, in particular, the colonial airline emerged as a factor in the overall evolution of commercial aviation. Britain, France, and the Netherlands all developed colonial airlines, with Belgium, Italy, and the United States joining the operation less extensively. Routes for national airlines were limited to destinations within a country or its possessions, except by agreement. The extensive colonial empires still in existence in the 1920's and 1930's became natural sites for extended airlines. Britain, for example, created Imperial Airways by first using bilateral agreements with other European countries to reach the Mediterranean, and once there, to project a continuation based on British colonies and protectorates in Malta, Cyprus, Palestine, Trans-Jordan, Iraq and the Persian Gulf protectorates, India, Burma, the Malay Protectorate, Australia, and New Zealand. China, Central Africa, and South Africa could be reached by other routes. Only the North Atlantic and the northern Pacific resisted a "British" national airline. France shaped a colonial airline from Provence across the Mediterranean to Algeria, the French Sahara, French Equatorial Africa, and Madagascar. Working out the landing rights between Belgium and France provided a route to the Belgian Congo. The Netherlands, through trades with Britain, shaped a colonial route for KLM to the Dutch East Indies (present-day Indonesia).

In the 1930's, these colonial routes were the main long-distance air routes available not only because a far-flung empire simplified the problem of securing landing rights but also because the operating stage, the maximum distance that might be flown without stopping to refuel, was then only about 500 miles. The Pacific and Atlantic oceans were the major water jumps that remained unconquered by civil aircraft in 1930. The American air routes showed the way to the solution. Pan American Airways was first organized to fly from Miami to Key West in Florida and to Havana, Cuba, and by the 1930's from Brownsville, Texas, to Mexico City and Panama. Pan American founder Juan Terry Trippe advocated the concept of the "chosen instrument" or the idea that international connections for the United States should be provided by a single American company flying only outside of the country. The American "empire" in this sense was Latin America, where American investment was extensive but political control was only indirect. Germany, which after World War I lost its colonies, similarly turned to South America, particularly Colombia, to shape an extensive system of air routes. In the American case, Pan American's ultimately extensive route structure in the Caribbean, on the east coast of South America, and in Central America provided experience in operating a long-distance international airline.

By the early 1930's, three airlines in particular were seeking to develop world-scale route patterns: Pan American, Imperial Airways, and KLM. Such a development called for a set of aircraft that were entirely new in concept from those that had been derived from the planes of World War I. Specifically, what was needed were seaplanes, which offered some advantages. They could fly stages of considerably greater length than could be flown with standard land planes because the sea-based plane enjoyed an almost infinite takeoff runway, a long stretch of water in a sheltered embayment. Several miles might be used at a time when a 1,000-foot runway was the norm. Long runways, either on land or on water, meant that planes could be quite large, use multiple engines, have large enough fuel tanks to fly an extended stage, and require less strength in the undercarriage.

The tradition of high-powered planes introduced between 1907 and 1909 by American aircraft builder Glen H. Curtiss continued. In addition to the Curtiss Company, Martin and Sikorsky each produced large, four-engine seaplanes with the potential for stages of more than 500 miles. Because of its size, the United States showed a concern for lengthening the stage even of land-based planes. When Pan American adopted the seaplane in the early 1930's, the Sikorsky S-42 flying boat had four engines that permitted it to fly to Buenos Aires, Argentina, by making a series of water crossings between Puerto Rico and the Rio de la Plata.

Airmail Service

After World War I, another factor contributed to airline development, namely the desire for an air service to speed up delivery of mail. Unlike Europe, where the nationalized airlines carried the mail, in the United States the Army Air Corps was assigned the job, with generally poor results. The problems of flying in a country the size of the United States were considerable. Particularly in the East, with the broad band of the Appalachian Mountains lying athwart the main routes, bad flying conditions were endemic and crashes were frequent. The introduction of aircraft beacons helped, but the low altitude at which most contemporary planes operated continued to plague service. Commercial flying began in earnest in 1925 when, under the Air Mail Act of 1925, also known as Kelly Act, the United States Post Office Department established contracts for carrying mail over assigned routes. Payments were made in return for the weight of mail carried. This practice often generated earnings that made the difference between marginal operation and flying at outright losses. Later, the method of airmail payments was revised. Instead of paying for the weight of mail carried, the Post Office paid instead for the space reserved for airmail, were it to be offered to the airline company to transport. The result was an incentive to the companies to increase the size of the planes that they normally flew.

Growth of the Aviation Industry

Competition for the airmail routes led to the formation of several large American aviation companies. William Boeing, who during World War I was a lumber producer in Seattle, Washington, had built planes from Sitka spruce, a wood with fibers of great tensile strength. Boeing bid on what came to be called the "Columbia Route" (New York City to California's San Francisco Bay Area), winning the western segment from Chicago to Oakland. Henry Ford, who for several years had been building a trimotor plane, secured the route linking Cleveland and Chicago. To serve the western section, Boeing experimented with new and larger planes built by the Boeing Aircraft Company, which in the following sixty years became the world's largest and most comprehensive civilian aircraft manufacturer. United Aircraft & Transport joined with National Air Transport (which later became United Air Lines) and others to create a second aviation company that secured the contract for the eastern segment of the Columbia Route, linking Chicago and New York City, and for the north-south route on the west coast from Vancouver, Canada, to Los Angeles. A further recipient of an airmail contract was the Aviation Corporation (North American and Curtiss aircraft builders), which became American Airlines. The General Motors Corporation held major ownership in Transcontinental Air Transport (TAT) as well as Eastern Transport on the north-south airmail route on the East Coast. With Pan American, which was assigned several foreign routes, these aviation companies constituted the "Big Five" airlines, which survived as the dominant U.S. carriers until the 1990's.

Improvements in Aircraft Operation

In the late 1920's, airlines were stymied by two problems: night flying and high-altitude flying. Both were still too dangerous for passenger transportation. In the United States, crossing the Appalachians was possible, as the operating ceiling of the planes exceeded the necessary 3,000 to 4,000 feet. In the Rocky Mountains and the western Coast Ranges, however, there were 8,000- to 10,000-foot passes. Continuous flight over a major part of the United States could not be accomplished during daylight hours.

In 1929, Transcontinental Air Transport and the Pennsylvania Railroad joined forces to solve, at least in part, these altitude and darkness problems. They organized a rail-plane route between New York City and Los Angeles. The "Airway Limited" departed New York's Pennsylvania Station at 6:05 P.M., using a Pullman sleeper to reach Port Columbus, Ohio, a new landing field outside of the Ohio capital. There, passengers boarded a Ford Trimotor plane at 8:15 A.M., which carried ten passengers to Waynoka, Oklahoma, by 6:24 P.M., in time to board a second Pullman sleeper on the Santa Fe Railway at 11:00 P.M. This was to arrive in Clovis, New Mexico, at 8:10 A.M., when the passengers boarded a second plane to fly to Los Angeles, and, for through passengers, on to San Francisco by 7:45 P.M. The route avoided most night flying and any mountains over 5,000 feet.

Such an arrangement demonstrated the need for planes better than the Ford Trimotor, the workhorse of American carriers in the late 1920's. By 1928, Ford had improved speed on his plane, from 100 miles per hour on the 1926 model to 120 miles per hour on the 1928 model, through the introduction of stronger radial engines that were coming into use in the United States. By 1929, the United States was building 5,500 aircraft, up from only 60 five years earlier. The Vega of 1927 had increased cruising speed up to 150 miles per hour.

In 1930, Boeing's Monomail demonstrated the virtues of all-metal planes with the installation of retractable landing gear. Most experts view the Boeing 247 of 1933 as the first modern commercial aircraft. It showed that twin-engine planes were safer than trimotors because they could be maneuvered more easily and might be flown on a single engine. So many of the planes were ordered that when Transcontinental and Western Airlines (TWA) sought to order some, Boeing declined. TWA turned to a smaller builder, the Douglas Company, and commissioned a similar plane as a trial. The prototype was the DC-1. In its developed form as the DC-2 and DC-3, it proved to be the most significant commercial plane ever constructed.

The DC Planes

The plane was first introduced as a prototype (the DC-1) in 1933 and put into production as the DC-2 (and in evolved form as the DC-3 in 1936). The first DC-2 was put in service on the Newark-Pittsburgh-Chicago run, after only 11 months development time. In an era when American engine builders were introducing new and more powerful engines at a regular and rapid rate, the Wright Engine Company had been able to substitute an improved and more economical engine by the time that quantity production began. American Airlines asked for a slight enlargement of the DC-2. When fitted out with seats, this enlargement held twenty-one passengers and was called a DC-3. As such, it was the first airliner to operate at a profit with a reasonable load factor. The DC-3 had a ceiling above 5,000 feet, could fly on only one engine, and with a stressed aluminum sheathing, was a strong plane with a retractable landing gear. In the ten years of its production life, the DC-3 became the unrivaled master airliner, carrying the majority of American traffic. It was found in the fleets of most of the world's airlines, was used for military cargo (as the C-47 in the United States and as the Dakota in Britain), and was constructed in a run of more than 13,000 planes. Undoubtedly the greatest contribution of the DC-3 was that it demonstrated with great clarity the feasibility of safe, reliable, affordable, and profitable flying. Flying was a curiosity when the DC-3 was first built but had become standard transportation by the time of its last manufacture.

Between 1927 and 1939, the smaller aircraft engine rapidly advanced in its technology. Before World War I, the Russian aeronautical engineer Igor Sikorsky had constructed a twelve-engine flying boat. In the progression from DC-1 through DC-3, knowledge secured from earlier expressions of a basic design was used to enlarge that design so as to gain size, speed, and economy. Certain general qualities were standardized. The typical DC plane had a squarely rounded fuselage, a low wing, a particular way of carrying engine pods, and other features that had become standard. For example, if a larger passenger load was sought, the fuselage would be lengthened rather than widened. A longer plane required no other changes than enlarging the engines. Engines could be made more powerful by turbocharging them (supercharging them using centrifugal blowers driven by exhaust gas turbines), enlarging the cylinders, and making other mechanical elaborations. American aircraft builders became very adept at securing more power to go faster, farther, or cheaper.

The Four-Engine Plane

During the 1930's, American airline operators increasingly sought ways of constructing and operating four-engine planes, recognizing that such aircraft could potentially fly above altitudes normally characterized by turbulence. Consequently, the Boeing Stratoliner was introduced in 1940. Equipped with a pressurized cabin and capable of flying at 14,000 feet at a speed of 200 miles per hour, the Stratoliner had just begun service during the second year of World War II. Development of this pioneering four-engine plane was taken over by the U.S. government for the duration of that conflict. The Stratoliner was the only commercial aircraft able to be flown directly from Newfoundland, Canada, to Northern Ireland during World War II. With its powerful supercharged engines, the Stratoliner could navigate not only above weather but also over mountains, rather than around them. Thus, routes could be chosen because they formed parts of great circles on the earth's surface and were therefore the shortest possible distances between two points.

A second four-engine plane was designed just before World War II when the general configuration of the DC-3 was transformed into a four-engine size. Unlike the Stratoliner, this was not a pressurized plane, so it represented the last phase of one line of advance rather than the beginning of a postwar design. The enlarged DC-4 was flown throughout the war, becoming the main transatlantic aircraft in the form of the United States Army's C-54 troop transport.

Postwar Developments

After World War II, air transportation was quickly restored to civilian life. The Stratoliner and the DC-4 began immediate service on the longer routes, even across the Atlantic and Pacific Oceans. Even more important was the introduction of a plane that for one decade became the principal competitor of the DC-4, the Lockheed Constellation. The rapid growth in the power produced by American aircraft engines encouraged TWA to turn to the Lockheed company in search of a plane that would add more than 100 miles per hour to the speed of the DC-3 (175 miles per hour) rather than the marginal 25-mile-per-hour increase of the DC-4. In addition, TWA engineers sought to lengthen the stage of planes so that a single-stop transcontinental flight was possible in either direction. When it entered service, the Constellation had an 80-mile-per-hour speed advantage over the DC-4. When the Super Constellation went into service in 1957, it weighed twice as much as its precursor, was considerably faster, and carried a much increased payload.

The very rapid growth of air traffic in the ten years after 1945 called for a number of different planes to deal with extended routes and enlarging markets. In large part, this expansion could transpire because there was a market for used aircraft. As airlines strove to fly faster and with lengthened stages, more people switched from trains or ships to planes. By 1953, the DC-7 was put in service, with a stage of up to 3,000 miles and a speed reaching 300 miles per hour. By 1957, the number of passengers crossing the Atlantic by air was greater than by sea. Once jet planes came into service at the end of the 1950's, flying the Atlantic accelerated to the point that little more than a decade of steamship service remained before the end of the Atlantic Ferry.

The Jet Era

The realization that planes of varying size and purpose could carry jet engines had a profound effect on commercial flight. It was anticipated that the jet would revolutionize the speed of air travel. What was rather unexpected was that it could sharply reduce its cost when provided by a jetliner large enough to carry an economical load. The Boeing 707 was so economical when it was placed in service by Pan American on October 26, 1958, that it played the role for commercial jets that the DC-3's had played for piston planes. When the fan jet was substituted for the simple jet engine, the family of Boeing jets earned a reputation for economical working just as the DC-6 had in the last generation of piston planes. Within a few years, Boeing had developed specialized jets for nearly the full range of commercial flying. The Boeing 727 became an intermediate-range jet carrying more than one hundred passengers, rivaling in size the largest piston planes. Later, the Boeing 737 became the workhorse of North American airlines. When it was discovered that the cost of operating jets was considerably less per passenger mile than the cost of operating even the best piston-engine planes, flying grew rapidly and became quite common over considerably longer distances. The Boeing Company began planning what came to be known as a jumbojet, the 747. When placed in service in 1970, the 747 was capable of carrying up to about five hundred passengers, but most models were fitted out for about four hundred, with substantial space allocated for baggage, mail, and freight.

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See also: Airline industry, U.S.; Airmail delivery; Airplanes; American Airlines; Boeing; Cargo aircraft; DC plane family; Jet engines; Jumbojets; KLM; Lockheed Martin; Manufacturers; Pan Am World Airways; Qantas; 707 plane family; Swissair; Transatlantic flight; Transcontinental flight; Turbojets and turbofans; United Air Lines

Communication

Definition: The practice of exchanging safety and operating information between aircraft in flight and ground stations.

Significance: Communication enables aviation to serve society more completely by expanding the conditions and geographical areas of its operations.

Because they were few, underpowered, and only slightly engaged in commerce, airplanes before 1914 needed no communications between themselves or with ground-based stations. As World War I progressed, airships and specially equipped airplanes carried Morse code radio equipment for military purposes. It was not until the 1930's, however, that civil aviation communications radio became a truly useful appliance. Fledgling airlines in the United States began to install radios aboard their airplanes and at their dispatch hubs to monitor each airliner's progress. This practice brought about the earliest, most rudimentary form of what has become the air traffic control (ATC) system. Early pilots considered radios an unwelcome intrusion in the cockpit, and some pilots refused to use them. Despite these protests, aviation communications provided undeniable benefits to safe and efficient operation, so the system expanded. Following World War II, aviation radios had become widespread in all but the smallest airplanes, as airspace around major cities became congested. By the 1960's, radios were familiar even in small airplanes. By the 1970's, air travel had become sufficiently pervasive that medium-sized and smaller cities attracted enough air traffic to make communications important to safety. The number of control towers rose accordingly, and radio communication frequencies soon became congested. Few pilots could realistically consider their airplanes as operating apart from the air traffic system, but standardization of communications procedures and phraseology lagged behind hardware technology.

International Standardization

Standard phraseology is essential for several reasons. Flying is increasingly an international venture, for even those pilots who never venture far from their home airports encounter fliers from other lands. At the end of World War II, industry leaders of various nations recognized aviation's international tendency and formed the International Civil Aviation Organization (ICAO). The ICAO established English as the standard aviation language; international aviation communication was and is to be conducted in English. Pilots from non-English-speaking countries must be able to read, write, and speak English sufficiently to use the aviation system, but at the beginning of the twenty-first century, reliably judging that ability in every corner of the industry was still uncertain. The twentieth century's worst aircraft accident, the Tenerife, Canary Islands, collision of two loaded Boeing 747's, hinged solely on unclear communications. Responding to these deficiencies, the ICAO's Proficiency Requirements In Common English Study Group (PRICESG/2) completed its second meeting and final report in May, 2001. The ICAO's goal is to implement an English language proficiency standard for aviation in the twenty-first century. That standard is to address pronunciation, stress and intonation, grammar and syntax, vocabulary, fluency, comprehension, and interaction. The group suggested a list of items to be included in ICAO guidance material. These included the full ICAO scale with a glossary of terminology, elaboration of each level, and examples; an English language competencies chart specifying language performance objectives appropriate to the air traffic controller and pilot work domain; an introduction to English language acquisition and learning theories and methodologies; a manual describing the characteristics and attributes of sound English language training programs; a discussion of the importance of "extended" English, relevant to a controller and pilot's ability to handle unusual aviation circumstances and emergencies; and approaches to testing English language speaking and listening proficiency.

Aviator's Alphabet

At the beginning of the twenty-first century, aviation was largely dependent on radio communications for both safety and efficiency. Air traffic control has developed from what was basically a trial-and-error experiment in the 1930's to an essential segment of the aviation industry. It works best when all participants understand the system and use it properly. Understanding is the most important commodity in pilot-controller communications. To establish a solid basis for understanding, in the early 1970's the Federal Aviation Administration (FAA) of the United

States established a pilot/controller glossary. In that glossary, words and phrases to be used in flight have specific meanings.

Aviation communication relies on these standardized meanings. The FAA calls this "phraseology," and sets forth these words, phrases, and their meanings in the Aeronautical Information Manual (AIM). The AIM divides its treatment of communications into a user-friendly general discussion, placing the pilot/controller glossary handily at the end of the book. The FAA also had to deal with the issue of letters and numbers spoken over aviation radios. Each nation registers its airplanes using letters and numbers or letters alone; these tail numbers establish an airplane's identity in radio communication.

To facilitate this, one segment of the AIM displays a phonetic alphabet wherein individual letters are pronounced as specific and familiar words. The AIM treats numbers just as thoughtfully, rendering easily confused numbers with distinct sounds. For example, in conversational use, the numbers "five" and "nine" can be impossible to distinguish in noisy environments or when accents blur them. Aviation pronounces "five" as "fife" and "nine" as "niner." Number sets such as "fifteen" and "fifty" are easily misheard even in the quiet of casual office conversation. Aviation addresses this by instructing pilots to, in most cases, speak each number separately. "Fifteen," therefore, becomes "wun fife" and a correctly speaking pilot or controller says "fifty" as "fife zero." On the other hand, the AIM instructs pilots and controllers to speak airliner call signs and airways in the more conversational format. Airway V12 would be spoken "viktah twelve." Airliner 523 (the assigned flight number, not the tail number) would be spoken "Airliner fifetwenty-tree."

Aviators accepted the phonetic alphabet as they did the radio: Some loved it, some ridiculed it. As aviation brought regions, states, and nations into ever closer contact, the existing hodgepodge of dialects and accents justified the FAA's wisdom in detailing even phonetic pronunciation. This practice bolsters understanding between pilots and controllers, making the aviation system far safer than it was before standardization had become a goal.

Pilot/Controller Glossary

Even pilots native to English-speaking countries may have widely diverging accents, and syntax differs from region to region in many countries. In the United States, after 1972 the FAA established a pilot/controller glossary in the AIM that put forth words and phrases that were largely compatible with those of the ICAO. These words had developed by trial and error since the 1930's, and the FAA found them both efficient and effective. Common words include "Affirmative" to answer a question "yes," while "negative" answers such a question with "no." Flight students soon learn that on the radio, monosyllabic words such as "yes" or "no" might not transmit over the radio. Within the United States alone, different regions say "yes" in fashions confusing to the inhabitants of other localities. A commonly misused aviation word, "Roger," means simply that the hearer has received all of the last transmission. It does not indicate compliance with an instruction, nor understanding of information. When pilots or controllers do not understand a transmission, they should ask the sender to "Say again." Because radio communications frequencies are usually very busy, the ATC system has words that en-

AIM Phonetic Alphabet

Letter	*Word*	*Pronunciation*
A	Alpha	al-fah
B	Bravo	brah-voh
C	Charlie	char-lee *or* shar-lee
D	Delta	dell-tah
E	Echo	eck-oh
F	Foxtrot	foks-trot
G	Golf	golf
H	Hotel	hoh-tel
I	India	in-dee-ah
J	Juliet	jew-lee-ett
K	Kilo	key-loh
L	Lima	lee-mah
M	Mike	mike
N	November	no-vem-ber
O	Oscar	oss-cah
P	Papa	pah-pah
Q	Quebec	key-beck
R	Romeo	row-me-oh
S	Sierra	see-air-rah
T	Tango	tang-go
U	Uniform	you-nee-form *or* oo-nee-form
V	Victor	vik-tah
W	Whiskey	wiss-key
X	X ray	ecks-ray
Y	Yankee	yang-key
Z	Zulu	zoo-loo

capsulate entire sentences into a single word, easily understood by anyone without regard to their first language, accent, or any impediment. One example would be "Wilco," which the AIM defines as meaning, "I have received all of your last transmission, I understand it, and I will comply with it."

Spoken altitudes, radio frequencies, and headings have traits that mesh with the basic rule of pronouncing numbers. Pilots in the United States speak altitudes as thousands and hundreds of feet. In aviation English, the phrase "Two thousand, five hundred" spoken alone only refers to altitude; any other subject would follow the numbers, such as "two thousand, five hundred RPM" if discussing engine or propeller speed, or "two thousand, five hundred miles" when discussing range. The AIM also admonishes U.S. pilots to address radio frequencies by speaking the numbers individually, and to use the word "point" to define tenths and hundreds of a frequency allocation. Internationally, non-U.S. pilots use the three-syllable word "decimal" instead of the single-syllable "point," which the Americans find clearer and more succinct. A common ground control frequency is spoken as "wun too wun point seven" (121.7). Controllers and pilots use good procedure when they speak aircraft headings (the direction in which the aircraft travels in a straight line) by enunciating each number separately. To head east, therefore, is spoken as "zero niner zero." This system, properly used, allows the person familiar with it the ability to understand a message because the more it uses specific, meaning-rich words or phrases, the less aviation is encumbered by ambiguous, nonstandard ones. The result is increased safety (saving lives and property) and efficiency (saving money and resources). For pilots and controllers, the pride of professionalism should be a third benefit.

Benefits of Standardized Communication

Not all pilots agree with the principle of standard phraseology. To teach standard phraseology takes time, and its benefits are not readily apparent with each use. Articles in aviation magazines occasionally have derided established phraseology, some authors belittling aviators who used it or instructors who taught it. Many of these too quickly embraced the AIM's allowance that, should a pilot's understanding of phraseology fail, he might simply speak conversational English. Others retorted that every pilot's public duty is to learn the system and be a fully functioning part of that system, which includes established communications standards.

Within the aviation community, as in most others, effective communication remains elusive. Yet while other industries tend to have codes or jargon for internal use, the decades have forged aviation's communications system into an English-based specialty language. As such, aviation-speak is inefficient for face-to-face conversation but very succinct for time-critical communications in a fluid environment. That fact and its implications are only just beginning to make inroads into the flight training environment. Flight schools still concentrate on teaching aerodynamics, airplane systems, maneuvers, regulations, weather, or myriad other subjects that at the time seem far more immediate than communications. Overall, the aviation industry continues to awaken to communications as a serious public safety issue.

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See also: Air traffic control; Airline industry, U.S.; Federal Aviation Administration; Pilots and copilots; Safety issues

Concorde

Also known as: Supersonic transport (SST)
Date: First flight in 1969; placed in service in 1976
Definition: Name assigned to an Anglo-French fleet of supersonic passenger transport airplanes.
Significance: The Concorde was the first supersonic aircraft used for regularly scheduled passenger service, built jointly by British and French aircraft manufacturers and later operated by two carriers, British Airways and Air France. The Concorde, which crosses the Atlantic in a scheduled time of three hours and fifty minutes, reduces both flight times and the effects of jet lag.

Supersonic Flight

The laws of physics are absolute and mysterious, as aviators in the 1940's discovered when their planes approached the speed of sound: about 760 miles per hour at sea level and about 660 miles per hour at 50,000 to 60,000 feet. As pilots accelerated toward these speeds, they found their planes shaking violently and running up against some sort of invisible wall, later referred to as the sound barrier.

When a vehicle achieves a speed exceeding the speed of sound, it is said to be traveling at Mach 1. At twice the speed of sound, it enters Mach 2. Mach numbers refer to the ratio of an aircraft's speed to the speed of sound at the altitude of the vehicle. Speeds from Mach 1 to Mach 5 are designated supersonic; speeds above Mach 5 are hypersonic. When a plane travels at exactly the speed of sound, its speed is described as transonic. Speeds below the speed of sound are considered subsonic.

During World War II (1939-1945), before U.S. Air Force test pilot Chuck Yeager first achieved supersonic speeds in the Bell X-1 rocket plane in 1947, numerous pilots unwittingly achieved such speeds during dives. Under such conditions, they could not control their vehicles, because shock waves built up around the controls, locking them in place and rendering them useless. Some pilots ejected under such circumstances; others died when their planes plowed into the earth at supersonic speeds.

Following World War II, U.S. Air Force designers sought to develop supersonic aircraft for the military. Engineers had to cope with the effects of the shock waves that occur as the sound barrier is being breached. They also needed to devise ways for aircraft to endure the extremely high temperatures generated by friction on the craft's outer surface, as speeds of Mach 1 and higher are achieved. Such heat-resistant metals as titanium were employed to replace the aluminum that covered the exteriors of most subsonic aircraft.

The work of these engineers and designers had broad implications for the commercial aircraft industry. By the 1970's, both the United States and the Soviet Union had planes, notably the Soviet MiG-25 Foxbat interceptor and the U.S. SR-71 spy plane, that could fly at speeds higher than Mach 3.

Supersonic and hypersonic aircraft create shock waves because of sudden changes in air pressure. Although people on the ground experience sonic booms when supersonic and hypersonic craft fly overhead, people within them do not, because the vehicles fly faster than the sound their planes create and remain well ahead of it. Because sonic booms are destructive and annoying, often shattering both windows and the nerves of people on Earth, most supersonic flights are routed over oceans. When supersonic commercial aircraft fly over land, they usually fly at subsonic speeds.

Commercial SSTs

The commercial aviation industry passed through several stages before the 1960's. Single-engine planes from the first decade of flight gave way to more powerful and safer dual-engine planes. As airmail routes expanded, the size of aircraft also expanded to assure larger payloads and accommodate passengers. As early as 1914, regular passenger service was available between St. Petersburg and Tampa, Florida, a distance of about 25 miles.

World War II brought about considerable advances in aviation, including the development of jet planes, which, after the war, gradually became used as commercial passenger vehicles. These planes flew faster than propeller planes, often cruising close to 600 miles per hour but still not approaching the sound barrier. The next major development in commercial passenger service was the supersonic transport plane that reduced the transatlantic crossing time from eight or nine hours to three and one-half hours or fewer.

Four major world powers, the United States, the Soviet Union, France, and Great Britain, began to consider developing supersonic commercial air transport. It was presumed that SSTs would carry passenger loads comparable to those carried by existing jet planes, and that SSTs would offer the same two or three classes of service (coach, business, and first classes) typically available on most long-distance subsonic planes, thereby making supersonic air travel economically feasible.

While the actual SST prototypes were being developed, it became evident that they could not comfortably carry

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more than about one hundred passengers, although some configurations would permit a maximum capacity of 144. At fares averaging 20 percent more than those of full-fare first class, approximately eleven thousand dollars for a round trip, supersonic air travel attracted an elite class of transatlantic passengers. These fares, however, did not begin to cover the high cost of flying supersonic aircraft. The Concorde, which accommodates about one hundred passengers, requires three times more maintenance than does a 747, which accommodates about four hundred passengers. The Concorde also burns 50 percent more fuel.

During a quarter-century of supersonic air service, Concordes incurred huge deficits for Air France and British Overseas Airways Corporation (BOAC). Keeping the Concordes aloft, however, became a matter of national pride for the French. Britain's contractual agreements with France prevented its withdrawal from participation, although there was a public outcry from the British public and members of Parliament to do so.

The Anglo-French Alliance

In the 1950's, once it had become clear that supersonic transport was the next logical step in the development of passenger air transportation, the four major powers began to look into developing SSTs. The British hoped to join with the United States in developing such planes, but the Americans were cool to entering into such a partnership. Finally, in November of 1962, the British and French, realizing it made economic sense to merge forces in the development of this project, agreed to proceed with SST research and development.

These nations had their own reasons for wanting to proceed with the Concorde, which cruised at 60,000 feet with an average speed of 1,320 miles per hour over water. For the British, the project would keep design teams employed when the economy was lagging. It might also enhance British attempts to join the European Community. For the French, the project would result in enhancing the image of France's national aircraft industry.

The estimated cost of the Concorde project was between $420 and $480 million. By the time the first Concordes were aloft, however, the cost had reached more than ten times the earlier estimates. Nevertheless, the prototypes, 001 and 002, were ready in September, 1968.

The initial flight of 001 from Toulouse, France, occurred in March, 1969. The following month, 002 flew in

Concorde Problems Between 1979 and 2000

Between its first commercial flight in 1976 and the crash of Air France Flight 4590 in July, 2000, Concordes carried more than four million passengers over many millions of miles. Its safety record is impressive. Concordes log fewer than one thousand hours per year, whereas Boeing 747's log many times that number. Heavy overhauls on Concordes occur with three times the regularity of overhauls on other passenger planes.

Concordes registered the following major problems between 1979 and 2000:

1979-1981: Tires blow out four times on Concordes during takeoffs in this period.

May, 1985: A London-to-New York flight encounters engine problems and makes an emergency landing in Boston.

March, 1992: On a London-to-New York flight, a Concorde loses a section of its rudder but lands safely at John F. Kennedy International Airport.

February, 1997: On a London-to-New York flight, a Concorde develops engine trouble and lands at Halifax, Nova Scotia.

January, 2000: Two Concordes are forced to make emergency landings within twenty-four hours of each other, one for engine failure on landing, the other for the sounding of a fire alarm in the cockpit.

July 25, 2000: Air France Flight 4590 crashes just after takeoff from Charles de Gaulle Airport outside Paris, killing 113. All Concordes are consequently grounded pending investigation.

Bristol, England. Both prototypes were displayed at the Paris Air Show in June, 1969. By April, 1970, after various design changes, the production of sixteen Concordes was confirmed. BOAC ordered five. Air France ordered four.

Both Trans World Airlines (TWA) and Pan American had taken options to buy Concordes. However, as environmentalists began to rally against permitting these noisy planes to fly into the United States, both TWA and Pan American dropped their options. When the first commercial Concordes were launched in January, 1976, the British Concorde flew the London-to-Bahrain route, and the French Concorde flew from Paris to Rio via Dakar.

In February, 1976, the Concordes won their battle to fly into both New York's John F. Kennedy International Airport and Washington's Dulles International Airport. Regular New-York-to-London and Washington-to-Paris service began, continuing until July, 2000, when, after Concorde's long accident-free history, Air France Flight 4590 to New York crashed after takeoff from Charles de Gaulle Airport outside Paris. The death toll was 113. All Concordes were grounded pending a thorough investigation and modification of the remaining aircraft. Air France resumed Concorde flights on November 7, 2001, and British Airways followed suit two days later.

American and Soviet SSTs

In December, 1966, the United States commissioned Boeing to build a swing-wing aircraft with General Electric engines capable of carrying three hundred passengers at a cruising speed of about 1,800 miles per hour, or Mach 2.7. In early 1971, this project, for which the U.S. Congress had appropriated about $425 million between September, 1966, and October, 1967, was well under way, with both presidential and congressional support. In March, 1971, however, the House of Representatives voted to discontinue all SST funding. The Senate lacked sufficient votes to pass an amendment to restore this funding.

The Soviet Union was far ahead of the other three national powers that were directly involved in the development of passenger SSTs. The Soviet Tupolev-144 (Tu-144) was shown at the Paris Air Show in June, 1965. The first prototype flew in December, 1968, exceeding Mach 1 for the first time the following June. In May, 1970, shown off at Moscow's Sheremetyevo Airport, it exceeded Mach 2 for the first time.

A production model of the Tu-144 crashed at the Paris Air Show in June, 1971, killing all on board. The crash was attributed not to mechanical problems but to other factors. The Soviets, however, did not give up. By December, 1975, scheduled freight and mail flights were instituted between Moscow and Kazakhstan. Regular Tu-144 passenger service began between Moscow and Kazakhstan in November, 1977, lasting until June of the following year, while modifications were made in the aircraft. The route reopened in June, 1979, and continued to function until August, 1984, when Aeroflot discontinued such service.

The present fleet of Concordes is expected to operate until 2007. Meanwhile, research is afoot to produce an entirely new generation of SSTs, most of them capable of carrying relatively large numbers of passengers at speeds approaching Mach 3.

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See also: Accident investigation; Aeroflot; Air France; British Airways; Mach number; Sound barrier; Supersonic aircraft; Transatlantic flight; Andrei Nikolayevich Tupolev; X planes; Chuck Yeager

Continental Airlines

Definition: A large U.S. air carrier of passengers and cargo based in Houston, Texas.

Significance: Continental is the fifth largest airline in the United States, despite two bankruptcies.

From very humble beginnings, Continental has risen to become the fifth largest air carrier in the United States. Born in scandal, Continental survived the deregulation of the airline industry in 1978 only to face two bankruptcies that would leave the company's employees demoralized and its customers angry over poor service. In one of the industry's most successful turnarounds, a new management team came onboard in October, 1994, and returned the carrier to profitability and award-winning service.

Early Days

Walter T. Varney learned to fly in the U.S. Army during World War I. He learned about the airline industry flying mail under contract to the U.S. Postal Service. A scandal involving the postmaster general, Walter Folger Brown, resulted in President Franklin D. Roosevelt canceling all airmail contracts on February 9, 1934. The new postmaster general, James Farley, called for new bids on April 20, 1934. Varney's recently formed airline, the Southwestern Division of Varney Speed Lines, bid on one of these routes. The Pueblo, Colorado, to El Paso, Texas, route was not as long or as profitable as the routes awarded to the large U.S. carriers such as United Airlines, Trans World Airlines, American Airlines, and Eastern Air Lines, but Varney and his financial backer, Louis H. Mueller, planned to use the mail revenues to support their first air route from Denver to Pueblo, stopping in Las Vegas, Nevada, Sante Fe and Albuquerque, New Mexico, and finally, El Paso. Unfortunately, Varney and Mueller found that the sparsely populated areas of western Texas did not generate a high level of passenger traffic.

The Robert Six Years

On July 5, 1936, Robert F. Six paid Mueller $90,000 for a 40 percent share of the company now called Varney Air Transport. On Six's initiative, Varney Air Transport purchased the majority of the Wyoming Air Service network, moved the company's headquarters to Denver, and changed its name to Continental Airlines. Six was elected president of the airline on February 3, 1938. He saw the passage of the Civil Aeronautics Act (1938), which created the Civil Aeronautics Authority (CAA) and gave it authority to issue permanent route certificates, as an excellent opportunity for Continental to expand. In order to do this, the company needed aircraft. To raise the money, Six arranged for Continental's first stock offering in late 1938.

The United States' entrance into World War II in 1941 interrupted Six's plans for Continental. Six himself joined the Army Air Transport Command, where he devoted most of his time to administration and logistics planning. Meanwhile, Terry Drinkwater, who had joined Continental in 1938 as a legal expert, assumed the job of temporary president of the airline. Following the end of the war, Six returned to Continental determined to expand the airline. Unfortunately, the only major expansion during the early postwar years was to Houston, Texas. On July 15, 1949, Continental became one of the first carriers in the United States to offer a promotional low fare to expand its passenger traffic. This Skycoach service and a reputation for technical excellence earned Continental the respect of its fellow air carriers, but respect did not translate into the expansion that Six envisioned.

All of this changed with the adoption by the Civil Aeronautics Board, which had replaced the Civil Aeronautics

Authority, of a new concept, interchange service. In the spring of 1951, Continental signed an agreement with American Airlines and Braniff. American agreed to provide service in California to San Francisco, Los Angeles, and San Diego, as well as to Phoenix, Arizona. Continental provided service in Texas from El Paso to San Antonio. Braniff initially flew the San Antonio-to-Houston segment. When Braniff withdrew from the agreement, Continental assumed this route as well. On February 1, 1952, Continental signed a second interchange agreement with Mid-Continental Air Lines to serve St. Louis. A third interchange agreement was worked out with United Air Lines in September, 1953. Under this agreement, Continental would fly between Denver and Tulsa, Oklahoma, while United would continue the route on to Seattle, Washington, and Portland, Oregon. During the period of the interchange service agreements, only Delta became involved in more agreements than Continental.

On July 22, 1958, Continental was authorized to operate service from Dallas-Fort Worth to El Paso, Lubbock, Midland-Odessa, Amarillo, Abilene, Albuquerque, and Santa Fe. This award, combined with the 1953 acquisition of Pioneer, gave Continental a full range of service in the state of Texas. Following Continental's acquisition of its first true jet, the Boeing 707, Six was now ready for further expansion. Continental became the first U.S. airline to introduce economy class fares in December, 1961. They also introduced a system of progressive maintenance in which aircraft maintenance was broken down into self-contained work periods and then spread out at regularly scheduled times over the operating life of the aircraft. This system was later adopted by the airline industry as a whole.

During the 1960's, Continental experienced three more firsts. On August 3, 1961, a Continental flight from Los Angeles to Houston became the first U.S. jetliner to be hijacked. On May 22, 1962, Continental recorded its first fatal accident in twenty-five years when what was presumed to be a bomb exploded in the lavatory of the same 707 that had been hijacked the previous year. A happier event occurred in May, 1964, when Continental entered the international market with a contract from the Military Airlift Command to fly troops to the western Pacific. Continental created a wholly owned subsidiary, Continental Air Services, in September, 1975, which served Vietnam, Laos, and Thailand. The service closed in December, 1975, when the Communists took over the entire region. In another Pacific venture, Continental invested in the newly formed Air Micronesia, holding 31 percent of its shares. Air Micronesia was to provide local service to the islands of the central Pacific.

By the late 1970's, Continental had grown to become the tenth largest domestic carrier in the United States. Unfortunately, its size did not protect it from the results of airline deregulation following the passage of the Airline Deregulation Act in 1978. The Airline Deregulation Act freed carriers to enter new routes and charge fares based on "market considerations." In other words, airlines were free to select routes based on their judgment of its potential profitability and to charge competitive fares that would attract necessary customers. The result was an expansion of low-cost, no-frills service that seriously weakened the higher cost, prederegulation carriers such as Continental.

Frank Lorenzo Takes Over

In 1972, Frank Lorenzo purchased a debt-ridden regional carrier named Texas International. With deregulation, Texas International, which had introduced its Peanut Fares in 1977 as a way of appealing to cost-conscious leisure passengers, was set for new growth and prosperity. After the creation of Texas Air Corporation in 1980 as a holding company for Texas International, Lorenzo formed New York Air to compete in the northeast markets of New York and Washington. Lorenzo began his takeover bid for Continental in 1981. The takeover was bitterly opposed by the management and unions of Continental, who finally conceded on November 25, 1981, when Texas Air assumed control of 50.8 percent of the stock. The two airlines agreed to merge in July, 1982, and the headquarters was moved to Houston, Texas. Amid mounting losses, the machinists union went on strike on August 13, 1983. After failing to reach agreement with the striking union, Lorenzo and Continental declared bankruptcy on September 24, 1983, and ceased all domestic operations. The company furloughed two-thirds of its workforce and resumed operation three days later. The pilots and flight attendants joined the striking machinists on October 1, 1983; however, Continental continued flying a reduced schedule. The old labor contracts were declared void and employees were given a "take it or leave it" option to work at reduced salaries and forfeit all seniority rights. These cost savings helped Continental to emerge from bankruptcy on September 2, 1986.

Intent on expanding, Texas Air took over Eastern Air Lines and People Express in 1986. People Express and New York Air were merged into Continental on February 1, 1987. Eastern Air Lines continued to fly under its own name, filing for bankruptcy in March, 1989, and ceasing operations on January 18, 1991. Stressed by these acquisitions and plagued with service problems, Continental was again in financial difficulty. In the summer of that year, Frank Lorenzo sold all of his assets in the company. Continental filed for bankruptcy a second time in December, 1990.

The Road to Recovery

Continental again reduced service and began to sell assets to raise cash, including its Seattle to Tokyo and Australian routes. However, it was not until Air Canada and a group of private investors headed by David Bonderman, of Air Partners, agreed to invest $450 million in the company that Continental was able to emerge from bankruptcy in April, 1993. Unfortunately, by the fall of 1994, Continental was once again faced with a serious shortage of cash. Earlier that year, Gordon Bethune had left the Boeing Aircraft Company to become the president and chief operating officer of Continental. He assumed the duties of chief executive officer in October, 1994. Under his leadership, Continental began what was called the “Go Forward Plan.” The plan called for Continental to review its flight schedule and eliminate money-losing routes, restructure its balance sheet, improve its service performance, and restore employee morale. The plan was a tremendous success. By July, 1995, Continental had posted the largest quarterly profit in its history. In January, 1997, it was named the Airline of the Year by the industry journal *Air Transport World*.

In 1998, Continental announced the beginning of an alliance with Northwest Airlines. The agreement called for code sharing on all Continental destinations from Cleveland, Newark, Houston, and Los Angeles and on all Northwest destinations from Detroit, Memphis, Minneapolis, and Tokyo. A code-sharing agreement occurs when two airlines offer a flight under the flight designation of a single carrier. Each carrier agrees to fly one segment of the larger route. For example, on a route from Houston to Tokyo, Continental would fly the segment from Houston to Minneapolis while Northwest would fly the segment from Minneapolis to Tokyo. In effect, code sharing allows an air carrier to offer flights to destinations that it does not serve directly by placing its passengers on the aircraft of another airline. They also agreed to consolidate ramp, cargo, and ticketing activity in selected cities. In a more controversial move, Northwest also purchased the stock interest of David Bonderman, giving the airline a 14 percent share of Continental stock. Because the deal would have given Northwest a 51 percent share of Continental’s voting stock, a trust was established for this stock and Northwest agreed to retain only a veto over any potential merger of Continental with another carrier. It was announced in 1999 that Continental would join the Wings Alliance, whose major partners were Northwest and the Dutch carrier KLM.

Although Northwest agreed to sell its controlling interest back to Continental in an effort to settle a lawsuit filed by the U.S. government, the marketing aspects of their alliance continue and have helped Continental to expand to serve over 220 destinations worldwide. Continental also continues to rank as one of the best airlines in the United States in terms of on-time performance, baggage handling, and customer satisfaction, while posting some of the best financial performances in its

Events in Continental Airlines History

1934: Continental Airlines’s predecessor, Varney Speed Lines, makes its first flight, from Pueblo, Colorado, to El Paso, Texas.

1937: The name of Varney Speed Lines is changed to Continental Airlines, and the new airline’s headquarters are moved from El Paso to Denver, Colorado.

1941-1945: Continental modifies B-17 and B-29 bombers for the United States during World War II.

1953: Continental merges with Pioneer Airlines, expanding its services further into Texas and New Mexico.

1959: The airline makes its first jet flights, with a small fleet of Boeing 707’s.

1963: The airline moves its headquarters to Los Angeles, California, and transports U.S. troops to Asia during the Vietnam War.

1969: Continental inaugurates service to Hawaii.

1970’s: The airline undergoes a period of extensive expansion, including service to Australia and New Zealand.

1982: After deregulation of the airline industry, Continental experiences a period of turbulence, merging with Texas International.

1983: The airline reorganizes under Chapter 11 of the Federal Bankruptcy Code.

1986: Continental reemerges from Chapter 11 and, a year later, becomes the third-largest U.S. airline, with the consolidation of Frontier, New York Air, and People Express.

1987: The airline introduces its OnePass frequent flier program.

1993: Continental purchases ninety-two new Boeing 737, 757, 767, and 777 aircraft.

1999: Continental’s jet fleet, with an average age of about seven years, becomes the youngest of those of the ten largest U.S. airlines.

history. Despite financial crises and bankruptcy, Continental has become the transcontinental and international carrier that Robert Six dreamed of creating.

Dawna L. Rhoades

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See also: Air carriers; Airline Deregulation Act; Airmail delivery; Boeing; KLM; Mergers; Northwest Airlines

Corporate and private jets

Definition: Jets owned wholly or in part by corporations or private individuals.

Significance: Corporate and private jets provide corporations and individuals greater freedom and luxury in planning their air flights and have other significant business advantages over commercial flight.

In the general scheme of air travel, corporate and private jets are considered general aviation. Having a private jet is a status symbol of some magnitude. In Africa, for example, Swaziland's King Mswati III became a member of the jet-owning club in 1999. In southern Africa alone, the presidents of Namibia, Zimbabwe, and Botswana each have their own private jets. In common with other world leaders and corporate executives, these leaders note that having one's own jet saves time and money.

Corporate and private jets have become more comfortable and safe over time and come in various degrees of luxury and comfort. Some companies tout that they have their own private jets. Other corporations and individuals buy shares in private jets, depending on how much time they wish to use the jet.

Jet Manufacture and Ownership

The major manufacturers of corporate jets are Cessna, Piper, and Beech, each striving to provide businesses with speed, comfort, and safety. In overall safety, corporate jets, if not all private jets, have an equivalent rank with the airlines.

A new trend in corporate jet ownership is fractional ownership of business jets, a time-sharing application. Richard Santulli of Executive Jet is one of the leaders in this trend. Shared ownership provides the comfort and convenience of owning a plane with the economy of time-share. An eight-passenger Raytheon Hawker, for example, sells for $12.4 million plus the cost for personnel and servicing. To make its purchase economical, a business would have to fly four hundred or more hours.

Time-sharing allows eight customers to buy a single plane and for each to use it for one hundred hours of flying. Executive Jet guarantees a plane to be ready with six hours of notice. The company has about six hundred jets, giving it 40 percent of the world's business jet market. FlexJet and TravelAir offer similar plans.

There is also a flourishing market in used planes. The maintenance of private planes tends to be well done, because of both federal standards and the general culture of business regarding its planes.

Whether conventional business jet or time-sharing jet, planes are being designed to operate in many different terrains while still offering passenger comfort. Thus, the Cessna Citation Excel has more headroom and other amenities than did earlier jets, but it is also able to land and take off on sod, dirt, and other difficult runways. It also has greater range and speed than earlier business jets.

Manufacturers are engaged in a continual effort to improve corporate and private jets. For example, Cessna Aircraft, based in Wichita, Kansas, which has sold more than three thousand Citations in more than thirty years, will upgrade to a larger Model 680 Sovereign to increase its market share of the super-midsize business market. There are other efforts to expand the private jet market. Eclipse hopes to make the world of the private jet affordable for business and first class customers through building a plane with a smaller, more efficient engine. It has had a number of design breakthroughs, including a digital avionics system. In most private planes, avionics are largely analog. This system requires that each gauge on the instrument panel has its own box of electronics and wiring, adding a great deal of weight. The Eclipse system will combine all the display instruments in one system. Eclipse is also counting on automation to cut its costs. Laser welding is one of its options, as is the use of robotic painters.

Safety Concerns and Issues

The 1999 crash that killed golf champion Payne Stewart has, however, led to serious questions regarding the safety of private and corporate jets. The National Transportation Safety Board (NTSB) has determined that the accident was most likely caused by the flight crew's incapacitation following the loss of cabin pressure. A flight data recorder, which could have prevented the accident, was not required on the twenty-five-year-old plane.

Between 1990 and 2000, the number of business jets in the United States virtually doubled. That means that in 2001, there were about seven thousand small jets flying for either charter companies or private businesses. About half of the passengers on private jets are middle management personnel. It is important to note that federal regulations for commercial airlines do not always apply to private and corporate jets. Business jets have had safety records that stand up well in comparison with commercial airlines. However, with the growth of fractional ownership, there is growing concern that this type of corporate-owned plane operates under less stringent rules than do charter flights. Business spokespeople, nevertheless, argue that business has an excellent culture of training and maintenance.

Practical Aspects of Private Jets

There are a number of advantages to corporate airlines or private jets in any form. Passengers of private jets are able to land at the airport of their choice, many of which are not serviced by scheduled commercial airlines. Moreover, these flights do not require connecting flights and can avoid clogged airports. Business planes offer the convenience of flexible scheduling, so that travelers are able to leave on their own schedules and often can return the same day. All this convenience, moreover, can take place out of the public's sight. No time is wasted, since travelers choose virtually all details of the schedule and destination, and can change flight plans as needed. These private corporation planes tend to be under rigid safety inspections.

Privacy is another reason for using these jets. Confidential meetings can be held on the plane, and work can be pursued. These private aircraft also send a message to one's business guests of their importance.

The luxury of private jets extends to their entertainment centers as well as other features. Pacific Systems, for example, has long supplied entertainment and communication systems for top-level corporate jets, planes that carry heads of state, and even personalized 747's for the extremely wealthy. The company is introducing its IntelliJet touch-screen cabin management system. It is an application of Pentium processors and touch-sensitive screens, putting all possible cabin systems that control its environment and entertainment at the touch of the jet's owner. Pacific Systems will give the buyer gold- or titanium-plated switches, a karaoke system, and state-of-the-art music and video systems that can be independently operated by each passenger.

The trade-off for convenience is money. These jets are quite expensive. A small six-seat Cessna or Learjet sells for about $5 million. A Falcon 900, Canadair Challenger 601, or a Gulfstream IV will cost $23 million or more. The new long-range Gulfstream V costs about $35 million, fully fitted, but has a nonstop range of 6,500 nautical miles.

In addition to the initial cost for the plane, operation expenses are heavy. There are pilot salaries, hangar fees, mechanics' fees, fuel, airport charges, mandatory Federal Aviation Administration inspections, and more. For example, a Gulfstream IV costs around $3,000 an hour to operate. A midsize Cessna Citation V costs about $1,500 per hour.

Advantages of Private and Corporate Jets

Athletes are often dependent on private jets for transportation to their various engagements. Not even the death of Payne Stewart, who crashed on a private jet en route to a professional golf tournament, could shake the confidence of players in their use. Golf champion Tiger Woods, for example, said that private jets have become the only sensible form of transportation for celebrity golfers, whether they seek privacy or convenience in their travel. Both Arnold Palmer and Jack Nicklaus not only use private jets but also own them. Moreover, Palmer is a licensed pilot, and Nicklaus hires pilots as part of his own company.

The main benefit of a private or corporate jet is savings in time. Private and corporate jets give those who use them control of their schedules. The private or corporate traveler can avoid the usual delays that plague commercial travelers. For example, Bill Cosby in his Gulfstream IV, Arnold Palmer in his self-piloted Cessna Citation VII, Disney's Michael Eisner, and many other CEOs can save time and aggravation through the use of private and corporate jets. Business executives with sufficient money say that the planes are worth the expense. Jack Nicklaus, for example, states that he could not run his current business, much less his still-flourishing golf career, without the use of his private jet. As a prolific golf-course designer, Nicklaus travels throughout North America and the rest of the world in his Gulfstream II *Air Bea*. Traveling without the constraints of commercial airline schedules allows him to double the amount of work he can accomplish without exhaustion.

Motion picture stars often own private jets. Arnold Schwarzenegger has a G-III. John Travolta has a G-II. In addition to the status, comfort, and convenience of private jets, movie stars own them because of the security they provide. However, the movie-star image is not one that the private and corporate jet companies wish to convey. They prefer to emphasize the convenience and businesslike nature of the private plane. They point out that a great deal of business can be conducted on these planes. These planes transport midlevel executives from place to place, not simply the CEOs. Xerox is but one corporation that flies its executives from small airports such as Westchester County, New York, to Rochester for business. The planes are also ideal for bringing customers to the company. Sales personnel often start their sales pitches on the planes.

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See also: Airplanes; Beechcraft; Cessna Aircraft Company; Flight data recorders; Piper aircraft; Safety issues

Crewed spaceflight

Date: Beginning April 12, 1961

Definition: Any flight that carries humans into space.

Significance: Crewed spaceflight has allowed humans to explore the solar system and to react to discoveries and problems encountered during space missions.

Development

The flight of humans into space had been the dream of science-fiction writers and explorers for more than a century before the first crewed spaceflight. Explorers regarded the first human step into space as the beginning of a new age of exploration, in which humans eventually explored the Moon, Mars, the asteroids, and all of the solar system.

Humans were preceded into space by robotic spacecraft containing instruments to monitor the earth and space environment and to explore the solar system. These uncrewed spacecraft frequently suffered from a lack of intelligence, or, the ability to adapt to unforseen circumstances. Thus, after a new discovery was made, it was frequently necessary to design a follow-on spacecraft, with new equipment intended to help scientists to understand more fully the measurements from the previous mission. Crewed spaceflight was expected to allow human intelligence and ingenuity to respond and adapt to discoveries or problems encountered during flight.

Neither the drive to explore the unknown nor the need for human intelligence in space provided the motivation for the vast expenditure of government funds needed to send humans into space. The real motivation was the intense political competition between the capitalist and communist political systems during the Cold War. The political leaders of both the United States and the Soviet Union saw success in space exploration as a way to demonstrate to their own citizens and to the rest of the world the superiority of one political system over the other.

The First Humans in Space

Following the launch of the world's first artificial Earth satellite, Sputnik 1, on October 4, 1957, both the United States and the Soviet Union began serious efforts to launch humans into space. The U.S. effort was called Project Mercury, and the Soviet program was called Vostok.

The formal selection process for the Mercury astronauts began in January, 1959, when the National Aeronautics and Space Administration (NASA) chose 110 military

U.S. Crewed Space Missions, 1961-1972

May 5, 1961:	Mercury Redstone 3	**December 4, 1965:**	Gemini VII	**March 3, 1969:**	Apollo 9
July 21, 1961:	Mercury Redstone 4	**December 15, 1965:**	Gemini VI-A	**May 18, 1969:**	Apollo 10
February 20, 1962:	Mercury Atlas 6	**March 16, 1966:**	Gemini VIII	**July 16, 1969:**	Apollo 11
May 24, 1962:	Mercury Atlas 7	**June 3, 1966:**	Gemini IX-A	**November 14, 1969:**	Apollo 12
October 3, 1962:	Mercury Atlas 8	**July 18, 1966:**	Gemini X	**April 11, 1970:**	Apollo 13
May 15, 1963:	Mercury Atlas 9	**September 12, 1966:**	Gemini XI	**January 31, 1971:**	Apollo 14
March 23, 1965:	Gemini 3	**November 11, 1966:**	Gemini XII	**July 26, 1971:**	Apollo 15
June 3, 1965:	Gemini IV	**October 11, 1968:**	Apollo 7	**April 16, 1972:**	Apollo 16
August 21, 1965:	Gemini V	**December 21, 1968:**	Apollo 8	**December 7, 1972:**	Apollo 17

Source: Data taken from (www.nssdc.gsfc.nasa.gov/planetary/chrono_astronaut.html), June 4,2001.

test pilots from 508 candidates submitted by the Department of Defense. The 110 candidates were carefully screened for physical fitness, experience, skill, and size, to accommodate the small size of the Mercury spacecraft. On April 27, 1959, NASA announced the names of the seven astronauts chosen for Project Mercury: Navy lieutenant M. Scott Carpenter; Air Force captain Leroy Cooper; Marine lieutenant colonel John Glenn, Jr.; Air Force captain Virgil “Gus” Grissom; Navy lieutenant commander Walter Schirra; Navy lieutenant commander Alan Shepard; and Air Force captain Donald “Deke” Slayton. The Soviet Union was, at the same time, conducting its own selection process, although the Soviet selection effort received less publicity than did the U.S. effort. On March 14, 1960, the Soviet Union selected a group of twelve cosmonauts: Pavel Belyayev, Valeri Bykovsky, Yuri Gagarin, Viktor Gorbatko, Yevgeny Khrunov, Vladimir Komarov, Alexei Leonov, Andrian Nikolayev, Pavel Popovich, Georgi Shomin, Gherman Titov, and Boris Volynov.

The Soviet Union’s second artificial satellite, Sputnik 2, launched on November 3, 1957, demonstrated the technology that was required for humans to fly in space. Sputnik 2 carried an 11-pound dog named Laika into orbit. Monitors on Sputnik 2 demonstrated that the interior temperature could be maintained in a range suitable for human survival and that a suitable atmosphere could be maintained using a system of reactive chemicals that give off oxygen and another chemical system to absorb exhaled carbon dioxide.

During the spring of 1960, engineers in both the United States and the Soviet Union were working to place the first human into space. The timetable for the U.S. program was highly publicized, whereas little information about the Soviet Union’s effort was released. A series of uncrewed test vehicles preceded the crewed flights. The first flight of the Vostok capsule, on May 15, 1960, failed after the capsule did not reenter Earth’s atmosphere. The second Vostok flight, in August, 1960, carried two dogs who were recovered successfully after reentry. The third flight, in December, 1960, suffered a failure to reenter the atmosphere, and the dog carried on board was killed. In March, 1961, the final Vostok test flight successfully carried a dog into orbit. The United States made successful suborbital flights of the Mercury spacecraft in December 19, 1960, and January 31, 1961. The January, 1961, flight carried a chimpanzee named Ham, the first primate to fly into space, on a 15-minute spaceflight to an altitude of over 100 miles.

At 9:07 A.M. Moscow time on April 12, 1961, the era of human spaceflight began with the launching of Vostok 1, carrying cosmonaut Yuri Gagarin, into orbit from a launch pad at the Baikonur Cosmodrome in Kazakhstan. Gagarin completed one Earth orbit and landed near Smelovka, on the Volga River, 108 minutes after liftoff.

Only three weeks later, the first crewed flight of the U.S. Mercury project was launched. At 9:34 A.M. on May 5, 1961, a Redstone rocket carried astronaut Alan Shepard from the Cape Canaveral Air Force Station. Five minutes after liftoff, Shepard’s spacecraft, *Freedom 7*, reached its peak altitude of 107 miles above Earth’s surface. Shepard’s flight lasted 15 minutes and 22 seconds and carried him 290 miles over the Atlantic Ocean.

On May 25, 1961, fewer than three weeks after Shepard’s successful suborbital spaceflight, President John F. Kennedy publicly committed the United States to the goal of landing a man on the Moon and returning him safely to the earth before the end of the 1960’s. Recognizing that Shepard’s suborbital flight did not match either the orbital flight conducted by Gagarin or the Soviet Union’s leadership in space exploration, Kennedy established a more long-term goal for the space race.

On August 6, 1961, the Soviet Union launched cosmonaut Gherman Titov, the backup pilot for Gagarin's flight, on a seventeen-orbit spaceflight lasting 25 hours and 18 minutes. During his flight, Titov suffered severe space sickness in response to weightlessness, demonstrating that human flight into space would present physiological problems.

The United States matched Gagarin's orbital flight on February 20, 1961, when astronaut Glenn was launched into space. Glenn completed three orbits before returning to Earth after 4 hours and 55 minutes. During the flight, the ground controllers received a signal that the heatshield, which proctected Glenn and his *Friendship 7* capsule from burning up during the extreme heat of reentry, had come loose from the spacecraft. Ground controllers instructed Glenn to override the planned separation of the retrorocket package from the spacecraft and to use the straps that held the retrorockets to the spacecraft to hold the heatshield in place. Although the difficulty turned out only to be a faulty sensor, Glenn's intervention could have been vital to the successful completion of the mission if the heatshield had indeed come loose.

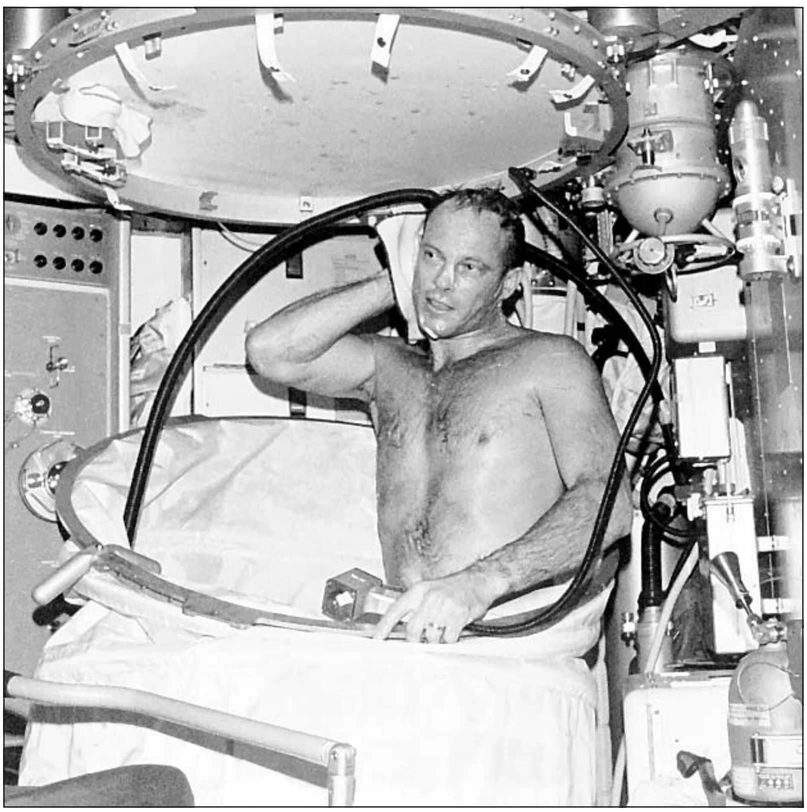
The Soviet Union followed its Vostok program with the Soyuz program, using a spacecraft that could carry up to three cosmonauts on spaceflights lasting several days. The nation also developed a series of space stations, called Salyuts, which were visited by cosmonauts carried aloft in the Soyuz spacecraft.

The U.S. Mercury project was followed by the Gemini Program, in which two astronauts flew in a single spacecraft. In the Gemini missions, astronauts demonstrated orbital rendezvous and spacewalking techniques that would be required for lunar landings. The Gemini Program was followed by the Apollo Program, which had the goal of landing astronauts on the Moon. A total of twelve Apollo astronauts walked on the Moon, beginning with astronauts Neil Armstrong and Edwin "Buzz" Aldrin, who landed on the Moon on July 20, 1969. Leftover Apollo hardware was used to launch the first U.S. space station, called Skylab, and to perform the first joint U.S.-Soviet spaceflight, Apollo-Soyuz.

On April 23, 1967, cosmonaut Vladimir Komarov became the first human to die in space. Komarov was piloting the first test flight of Soyuz 1. On the spacecraft's eighteenth orbit, its maneuvering system began to malfunction, and Komarov attempted to make a landing. However, he could not control the spacecraft, which became entangled in the cords of its parachute and hit the ground at more than 200 miles per hour, killing its pilot.

In June, 1971, three cosmonauts, George Dobrovolsky, Vladislav Volkov, and Viktor Patsayev, were killed when the Soyuz 11 spacecraft returned to Earth after a twenty-three-day stay at the Salyut 1 space station. A valve, designed to open after the spacecraft reentered the atmosphere, opened while the Soyuz was still in space, allowing the spacecraft's air to escape and suffocating the crew.

The United States has also suffered human losses in its development of spaceflight. On January 27, 1967, during a preflight Apollo test, a fire swept rapidly through the Apollo Command Module, killing all three astronauts participating in the test, Roger Chaffee, Virgil "Gus" Grissom, and Edward White. After the fire, NASA officials



By the time Skylab 3 was launched in 1973, astronauts were able to dispense with their heavy spacesuits once in orbit and could even take showers while in space. (NASA) designated the test as Apollo 1, honoring the crew. An extensive investigation revealed numerous design flaws, and manned launchings were postponed for more than a year while an extensive redesign was conducted.

On January 28, 1986, the space shuttle *Challenger* exploded shortly after liftoff. It carried a crew of seven astronauts: Francis Scobee, the commander; Michael Smith, the pilot; Judith Resnik, Ellison Onizuka, and Ronald McNair, all mission specialists; Gregory Jarvis, a payload specialist; and America's first schoolteacher in space, Sharon Christa McAuliffe. Below-freezing temperatures had hardened the O-ring seals between the segments of the solid-fueled rocket boosters causing one joint in the right solid rocket booster to develop a leak. After liftoff, hot gases cut through metal on the shuttle, and seventy-three seconds into the flight, the *Challenger* disintegrated, and all seven astronauts were killed.

More recent developments have been more positive. On February 20, 1986, the Soviet Union launched the Mir Space Station, which would be almost continuously occupied by a succession of crews for fifteen years before being deorbited on February 23, 2001. In 1999, NASA, working with a group of international partners including Canada, Japan, Russia, and the European Space Agency (ESA), began construction of the International Space Station (ISS). By 2001, after forty years of human exploration of space, more than 400 astronauts and cosmonauts had flown into space.

Risks Versus Benefits

Because space is not a natural environment for humans, sophisticated life-support systems are required to maintain atmospheric composition, temperature, and other features within a range suitable for human survival. The failure of any critical system can result in death for the crew.

Crewed spaceflight is also inherently more costly than robotic spaceflight, because the crew and its life-support systems must be carried into orbit at a cost of about $10,000 per pound. During the 1970's, NASA officials had decided that the space shuttle would carry all future payloads into space, even simple satellites that required no human intervention. NASA began to phase out rockets, such as the Delta, that had been used to launch uncrewed satellites. A highly focused debate developed over the next two decades over the relative merits of crewed versus uncrewed spaceflight. Critics of crewed spaceflight specifically targeted NASA's planned space station as a high-cost project whose scientific return would be less than if an equivalent amount of money were spent on robotic spacecraft. Following the *Challenger* accident, NASA officials decided that the crewed space shuttle fleet would be used only to launch satellites that required human intervention, and a fleet of new booster rockets was developed to launch robotic satellites.

However, in crewed spaceflight, humans can accomplish many tasks that may not be performed by robotic spacecraft. For example, when thrusters on his Gemini spacecraft began firing, causing the craft to rotate rapidly, astronaut Neil Armstrong was able to regain control of the spacecraft and return it safely to Earth. After an explosion on board the Apollo 13 mission to the Moon, astronauts modified the spacecraft's air-purification system so that they could survive the return to Earth. Cosmonauts overcame damage from an onboard fire and the leaks and damage caused by the impact of a resupply spacecraft, keeping the Mir Space Station operational. Space shuttle astronauts have repaired the Hubble Space Telescope, salvaged the improperly orbiting Westar-VI and Palapa-B2 satellites, and assembled large structures, including the International Space Station.

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See also: Apollo Program; Neil Armstrong; Astronauts and cosmonauts; Yuri Gagarin; John Glenn; Gemini Program; Mercury project; National Aeronautics and Space Administration; Russian space program; Alan Shepard; Space shuttle

Crop dusting

Also known as: Agricultural aviation

Definition: The aerial application of dusts, granules, sprays, and other materials for agricultural purposes.

Significance: Crop dusting allows the rapid, even dispersal of pesticides, fertilizers, seeds, and other materials over wide areas without the compaction of soil or crushing of vegetation commonly caused by tractors and other heavy farm machinery.

Early History and Development

The first patent relating to the use of aircraft in agriculture was granted to Alfred Zimmermann in 1911 by the Imperial Patent Office in Berlin, Germany, for an invention allowing the aerial application of lime water to control moth damage to pine forests. In practice, neither Zimmermann's invention nor other sporadic efforts succeeded until two Americans, C. R. Neillie and J. S. Houser, controlled *Catalpa sphinx* caterpillars by dusting them with lead arsenate from a Curtiss JN-6H Jenny biplane near Troy, Ohio, on August 31, 1921.

Types of Aircraft

Agricultural aircraft are designed or equipped to enhance visibility in all directions, to avoid pilot exposure to chemicals with special ventilation, to reduce pilot fatigue, to ensure pilot safety, to protect the aircraft and equipment from corrosive chemical mixtures, and to ensure high performance at slow speeds with heavy loads. The types of aircraft employed in crop dusting include specially designed agricultural monoplanes and biplanes, ex-military and ex-civil aircraft, and helicopters. Specially designed agricultural aircraft, such as the Cessna Ag-Truck, Turbo Thrush, and Ag-Cat and the Skyfarmer T-300A, tend to be more expensive than nonspecialized aircraft that can be adapted to agricultural use. Both ex-military aircraft, such as the Grumman Avenger and the Boeing Stearman, and ex-civil aircraft such as the Douglas DC-6, DHC Beaver, Piper Aztec, Russian Antonov AN-2M, and Pilatus Turbo Porter, have been used as agricultural aircraft.

The use of helicopters in crop dusting has increased worldwide because of helicopters' many advantages over fixed-wing aircraft, including their superior efficiency as sprayers due to their greater downwash at slower speeds, their ability to land almost anywhere without the need for an airstrip, their greater maneuverability, and their superior visibility. Helicopters' advantages may be outweighed by their disadvantages, however. Helicopters are far more expensive to purchase, and their operation is much more affected by changes in temperature and humidity than that of other types of aircraft. In addition, helicopters have more moving parts than other aircraft, requiring more maintenance, and they also have smaller centers of gravity, necessitating more careful loading.

Crop-Dusting Equipment

During the 1920's, hand-cranked and horse-drawn ground dusters had been employed with some success against boll weevil infestations devastating the cotton crops of the American South, but application rates were too slow for control. Early crop-dusting airplanes were equipped with sheet metal containers, called hoppers, mounted behind the pilot in the rear seat. An assistant balancing behind the hopper was required to turn the hopper's feeder crank, causing calcium arsenate to be discharged through a tube in the bottom of the fuselage. Dusting from aircraft proved successful for pest control over large areas.

Experience taught crop dusters that the pesticide dusts had to be constantly agitated and sifted in order for them to be dispersed evenly, leading to hopper designs incorporating rotating paddles or sweeping, windshield-wiper-like blades. Hoppers centrally mounted under the fuselage and equipped with pilot-operated levers eliminated the need for assistants. Tanks suitable for carrying liquid applications, accurate gauges to measure loads, and efficient filters and pumps evolved through trial and error.

Dispersal equipment also evolved, the most popular being the boom and nozzle for spraying liquids and the spreader for dispersing dry materials. The boom, a long, rigid pipe usually attached behind or below the wing of an airplane, supports movable nozzles that can be variably spaced along the boom and rotated to point in any direction to vary the spray pattern. In addition, the size and shape of the orifices on the nozzle can be changed like those on a showerhead to vary droplet size and spray intensity. The most frequently used spreader is suspended beneath the hopper and the fuselage so that the airstream can help blow the hopper contents out through the opening gate of the hopper to be deflected by the spreader. Some spreaders are fan- or wing-shaped, whereas others have divided outlets or rotating disks to disperse materials.

Application Materials and Methods

Applications of insecticides, fumigants, herbicides, fungicides, and defoliants are most often associated with crop dusting, but many other materials are commonly applied, including fertilizers, trace elements, and poison bait dropped over wide areas for the control of animal pests such as rabbits and mice. Even seeds for crops such as rice, grass, and vetch are sown from aircraft.

The usual practice in crop dusting is to fly back and forth in straight, parallel lines across the field being treated. If the area is too steep or irregular, the flight lines should follow the contours of the land. Coverage should begin downwind, so that the aircraft can make each swath without passing through an already-sprayed area. Flags are often posted at each end of a field to mark the spacing for each swath.

Turnarounds are the most likely maneuvers to cause accidents and must be made carefully, to prevent both crashes and the accidental dispersal of chemicals over adjoining areas. Maintaining a constant speed and height is important for even distribution. Speed and height of the aircraft are determined by atmospheric conditions and by the material to be dispersed. Controlling drift is necessary to prevent the exposure of humans, livestock, water sources, adjacent crops and pasture, and structures to contamination by hazardous materials. Drift is influenced by many factors, including weather conditions, particle size, specific gravity, evaporation rate, height of release, horizontal and vertical air movement, and aerodynamic effects of the aircraft. These factors lead to concerns about the potential use of crop dusters to disperse hazardous biological or chemical material in a terrorist attack. These planes were grounded temporarily following the hijackings of September 11, 2001.

Sue Tarjan

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See also: Airplanes; Biplanes; Helicopters; Jennys; Pilots and copilots

Glenn H. Curtiss

Date: Born on May 21, 1878, in Hammondsport, New York; died on July 23, 1930, in Hammondsport, New York

Definition: The most prolific aeronautical inventor and manufacturer of airplanes and airplane engines in the United States well into the 1920's.

Significance: Curtiss developed ailerons for flight control, designed the first American amphibious airplanes, and built the first airplane to cross the Atlantic Ocean. He was also the first U.S. licensed pilot and the first to make a public flight.

Born in 1878, Glenn Hammond Curtiss, a champion bicycle racer, developed gasoline engines to power his bicycles, and he set international speed records on bicycles powered by engines with up to eight cylinders. It was Curtiss's engine expertise that led him to join Alexander Graham Bell's Aerial Experiment Association (AEA) in 1907 as its director of experiments. In the AEA, Curtiss quickly became instrumental in the design of a series of successful airplanes. The Curtiss White Wing became the first American airplane to take off on wheels instead of skids and the first to use ailerons for roll control in turns. His June Bug made the first "public" flight that was filmed and witnessed by the press in 1908. This flight would win Curtiss the *Scientific American* prize. The French press proclaimed Curtiss the "Champion Aviator of the World" after he set new speed records in winning the Gordon Bennett trophy in France in 1909.

Curtiss was sued by Wilbur and Orville Wright, who claimed that his use of ailerons violated their patents for controlling the roll of an airplane. Although many experts believed that ailerons were different from the Wrights' use of wing-warping, the courts were harder to convince. Repeated lawsuits kept Curtiss tied up in the courts for years, until the government intervened in the national interest, as the country entered World War I.

Curtiss further angered the Wrights when, at the request of the Smithsonian Institution, he agreed to prove that Samuel Pierpont Langley's aerodrome, an uncrewed flying machine driven by a gasoline-fueled, steam-powered engine which had crashed in the Potomac River twice in attempting the first airplane flight, was actually capable of flight. Curtiss made significant modifications to Langley's design, and when it flew, the Smithsonian proclaimed the aerodrome to be the first heavier-than-air craft capable of flight. The Wrights never forgave Curtiss for trying to usurp their rightful claim as the first to fly.

Curtiss established flying schools throughout the country and contracted to train Navy and Army aviators as he continued to develop newer airplanes. His Curtiss JN-4, or Jenny, a trainer aircraft, was the best American-designed plane to come out of World War I, and surplus Jennys became the airplane of choice for hundreds of aspiring pilots after that war.

A prolific designer of land-and-water-based airplanes for the Navy, Curtiss designed the NC-4, the first airplane to fly across the Atlantic, in 1919, and a series of racing planes that set world speed records in the early 1920's. His OX series of airplane engines were dominant in the U.S. market. Curtiss died in Hammondsport, New York, on July 23, 1930, of a pulmonary embolism suffered after a bout with acute appendicitis.

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See also: Airplanes; Jennys; Heavier-than-air craft; History of human flight; Samuel Pierpont Langley; Transatlantic flight; World War I; Wright brothers

D

DC plane family

Date: Beginning in 1933

Definition: The most widely used passenger airplane series between the 1930's and the 1970's.

Significance: From the 1930's through modern times, the DC series of planes made air travel possible for most Americans by introducing such innovations as sleeper cabins, nonstop coast-to-coast flights, pressurized cabins, and ever-expanding fuselages to allow for more passengers per plane and to allow airlines to fly profitably.

The Beginning of the DC Series

The greatest contributor to the expansion of domestic and international air travel was the family of planes known as the Douglas Commercials or DC series. Built by the Douglas Aircraft Company, the DC's became the dominant brand of commercial passenger plane starting in the 1930's, and later served the needs of the American military beginning in World War II. The first DC model, the DC-1, was built in 1933. Capable of carrying twelve passengers, the two-propeller plane could travel coast-to-coast in a little over eleven hours. The DC-1 took passenger comfort into account in comparison to its main rivals. To combat the noise from the propeller-driven plane, the company used carpeted floors, sound-absorbing fabric, and rubber supports for the seats. The only DC-1 built was purchased by TWA, which saw the plane as the one that would allow it to compete with the more established air carriers. Within a year of the DC-1 rolling off the assembly line, the Douglas company built the DC-2, also for use in passenger flight by TWA. Known as the Sky Chief, the DC-2 could carry fourteen passengers, and in terms of physical size it had 2 feet more space in the fuselage and nearly 6 feet more in the wingspan. While it had a limited range of 1,000 miles, the DC-2 proved to be a workhorse, with 134 produced between 1934 and 1937. The third of the line was appropriately known as the DC-3 and was first flown as a passenger plane in 1935. This was the best known and the most popular of the DC series and is frequently called the greatest cargo plane ever built. American Airlines was the first to use the craft, after seeing its competitors tie up the other aircraft manufacturers with large orders of other passenger plane models. The airline sought a plane that would allow passengers to rest during the lengthy flight from New York to Los Angeles. The DC-3 had fourteen seats that folded into sleeping berths for passengers. The plane could carry fourteen passengers on an extended coast-to-coast flight or use all of the seats to fit twenty-eight passengers per flight for a shorter trip. The DC-3's larger capacity, its sleeping berths, and its nearly 1,500-mile range provided a boon for the passenger airline business and more importantly for the Douglas Aircraft Company. By the 1940's, approximately 90 percent of all passenger planes flying in the United States were either DC-2's or DC-3's. Some 455 DC-3's were built for commercial use, but the start of World War II saw a surge in the need for military transports that the DC-3 also filled. Over 10,000 DC-3's were produced for the military to carry both men and matériel to the European and Asian war zones. Even after the war and the end of production in the 1940's, the DC-3 continued to influence the passenger and freight airline markets and it continued to be flown in both capacities at the turn of the century.

From DC-4 to DC-8

The highly popular and profitable DC-3 was followed by a less successful version, the DC-4. Nearly twice the size of its predecessor, the DC-4 could carry up to forty-two passengers, but its size made maintenance and flight expensive, relegating the DC-4 to use almost exclusively as a military transport. In this role, the DC-4 was known as the C-54 Skymaster. The DC-4's were used mainly to fly supply missions across the North Atlantic. The four-engine plane proved to be reliable in this task and was used as a cargo carrier for civilian purposes at the end of the war.

In 1939, the DC-5 made its first flight. However, only five DC-5 aircraft, with seven more as R-3D military transports, were ultimately built.

The next in the series, the DC-6, was best known as the first regular aircraft to make around-the-world flights. Flying for the first time in 1946, the DC-6 was used by American, United, and Pan American airlines. Featuring the first pressurized cabin in the DC series, the DC-6 was able to fly at 20,000 feet while keeping passengers comfortable within the fuselage. The new DC-6 was a considerable improvement over its predecessors, carrying 102

A DC-3 in flight in 1959. (Library of Congress)

passengers and traveling at a speed of 308 miles per hour, a full 90 miles per hour faster than the DC-4. The DC-6 became the workhorse for the airlines in their extended international flights. In 1951, the DC-6B, with modifications of the original DC-6, became first official presidential airplane. Known as the *Independence*, it was first used by President Harry S. Truman to allow him to travel quickly across the country or around the world. The DC-6B was also adapted for use as a cargo carrier in the Korean War. Over seven hundred of them were built for military and civilian use, and by end of the century, scores continued to be used.

The DC-7 proved to be the last propeller-driven plane in the DC series. It represented the greatest increase in range among the models, with each plane able to fly 5,135 miles. By increasing the distance it could fly, the DC-7 became the first passenger plane to fly nonstop from New York to Los Angeles. Because the DC-7 did not have to stop for refueling, the flying time of the trip was reduced. This reduced flying time increased profits and lowered the ticket price for the flight, while the shorter flying time made a cross-country trip less burdensome for most people. The DC-7 was also known as the Seven Seas because its long range allowed for flights around the world. The DC-7 was introduced in 1953 and it could carry 110 passengers, a small improvement over the DC-6. There were 338 of the planes built and a few continued to operate a half-century later.

The DC-8, introduced in 1959, was the first jet-powered plane of the DC series. The four jet engines allowed the plane to reach speeds exceeding 600 miles per hour. The DC-8 became the first commercial jet to break the sound barrier. Along with its speed, the DC-8 had an expanded fuselage that doubled the passenger load to 260. While the plane had a slightly shorter range—4,500 miles—than its predecessor, its passenger capacity and freight-hauling abilities made it one of the largest commercial planes at that time. Over 550 of the planes were built, with more than 350 continuing to fly through the 1990’s. Three different models of the DC-8’s were built: the DC-8-61, the DC-8-62 and the DC-8-63.

The Modern DC’s

The DC-9 has the distinction of having the largest number of commercial airplanes produced of any of the DC series.

Some 976 planes were built, of five different types, each one extending the fuselage and allowing for more passengers. The DC-9-10 was the smallest version, carrying only ninety passengers and used primarily for shorter range flights. The DC-9-20 also had a smaller fuselage, carrying fewer than one hundred passengers while utilizing larger engines to create greater thrust and carry larger payloads. The DC-9-30 added 15 feet to the fuselage and carried 115 passengers. The plane was specifically designed for rapid takeoff, allowing it to be used on smaller air fields. This made the DC-9-30 the most frequently used of all the aircraft. The DC-9-40 added another 6 feet to the fuselage and expanded passenger cargo to 125. The DC-9-50 was the largest plane in the family, with 8 more feet of fuselage beyond the DC-9 40, a passenger capacity of 139, and more space for cargo. Each of the DC-9's was introduced in the 1960's and many continued to fly both passengers and cargo at the turn of the century.

The DC-10 was the last of the series to be produced. While many of the features of the series would be found in its successor, the MD, the merger of Douglas Aircraft with McDonnell Aircraft led to the end of the name DC. The first model DC-10 flew in August, 1971. The DC-10-30 and the DC-10-40 were both extended-flight airplanes, with ranges of 5,900 and 5,800 miles, respectively. Three other types of DC-10's were used, mainly for carrying freight. The DC-10 Convertible was able to carry passengers or freight, though it was mainly a cargo carrier. The DC-10-15 resembled the original DC-10 but had a longer range of approximately 6,000 miles. The last of the DC-10's was the 30F. It was used exclusively as a freight carrier and became one of the standard planes for package delivery companies. The 30F was renamed the KC-10 cargo plane for the U.S. Air Force. When DC-10 production was halted in 1989, approximately 380 planes were flying commercially, while 60 more were being used as cargo carriers for the Air Force. Yet even with this commercial success, the DC-10 had a mixed safety record. A 1974 crash near Paris killed 346 people and was blamed on a cargo door blowing open in flight. Similar problems were discovered in other DC-10's. In a six-month period in 1979, some five hundred people died in three DC-10 crashes. This was attributed to structural fatigue, with one crash caused by a pylon collapsing in flight. In July, 1989, in Sioux City, Iowa, the most spectacular crash occurred, when a DC-10's hydraulic system failed. Over one hundred people died, although more than twice that many survived. These safety problems gave the DC-10 a bad reputation but it continues to fly in many airline fleets.

The DC series ended with the DC-10. In 1967, the Douglas Company, suffering from severe financial losses caused by problems in the production of DC-8's and DC-9's, merged with the McDonnell Corporation to form McDonnell Douglas. The next series of DC planes were renamed the MD series, and when McDonnell Douglas merged with Boeing in 1997, the planes took on the 700 family name associated with that company.

The Legacy of the DC's

The DC series of planes may have been the most important of all families of passenger carriers. With their start in the 1930's, the DC series helped make air travel affordable for the individual and profitable for many airlines. The DC planes also established such innovations as nonstop flights across the United States, larger fuselages to carry ten times the passengers of the original DC models, and a dependability that sees many DC's flying local routes to smaller airports and others longer routes across countries or continents. While the DC line ended with the DC-10 and the original company that developed the model was merged into oblivion, the plane series continues to strike the imaginations of both those who study passenger airlines and those who fly them.

Douglas Clouatre

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See also: Airplanes; Boeing; Cargo aircraft; Commercial flight; Jet engines; Manufacturers; McDonnell Douglas; MD plane family; Military flight; 707 plane family; Trans World Airlines; Transatlantic flight; Transcontinental flight; Turboprops; World War II

Delta Air Lines

Definition: The world's first crop-dusting company, which became one of the world's foremost passenger airlines.

Significance: One of the world's most successful airlines, the history of Delta Air Lines spans the aviation era. From the beginnings of commercial flying, Delta has been a presence in aviation, first as the original aerial crop dusting company and later growing to become a leader in passenger carriers.

Crop-Dusting Beginnings

As an official incorporated entity, Delta Air Lines dates from 1945, when what was then the Delta Air Corporation changed its name. The organization actually dates back some twenty years earlier to the first aerial crop-dusting company. In the early years of the twentieth century, boll weevil depredations on cotton crops forced the Bureau of Entomology of the United States Department of Agriculture to establish its Delta Laboratory in Tallulah, Louisiana, to research methods of controlling the pest. Dr. Bert R. Coad directed the research, often assisted by Collett Everman Woolman, a district agent of the extension department of the Louisiana State University. Powdered arsenates were effective against the pest but an efficient, broad-scale delivery method was required. Coad decided to try aerial dusting from airplanes. With surplus Curtiss Jenny airplanes acquired from the Army, he and Woolman began to perfect aerial crop-dusting procedures.

In 1923, mechanical problems with his airplane forced George Post, an executive of the airplane maker Huff Daland Manufacturing Company, to land in Tallulah. Excited by the prospects for crop dusting, Post convinced his company to form a new division, the Huff Daland Dusters. Huff Daland then began building the first airplanes specifically designed for crop dusting.

The forerunner of Delta Air Lines, Huff Daland Dusters began operations in Macon, Georgia, in 1924 but cotton farming in the area was insufficient to support activities and, at Dr. Coad's suggestion, operations were shifted to Monroe, Louisiana, for the next year.

Woolman then joined the company as vice president and field manager. Because crop dusting is seasonal, the company soon sought ways of generating off-season revenues. Their first effort was to continue crop dusting through the winter, shifting operations to Peru, where the seasons are the reverse of those in the northern hemisphere. Additionally, Woolman acquired airmail service rights for a 1,500-mile route between Peru and Ecuador.

The company's operational base at the time was the Mississippi Delta. Accordingly, the word "delta" appeared in the company name for the first time when ownership changed in 1928. Huff Daland sold the division to a group of Monroe businessmen. Woolman remained as vice president and general manager of Delta Air Service. The new company continued crop-dusting operations under that name until 1966.

A political revolution in Peru forced the closing of crop dusting and airmail operations there in 1928. The planes were sold to what later became Peruvian Airlines; the airmail route went to Pan American Grace. Delta Air Service used the money to purchase three five-passenger TravelAir monoplanes and, on June 17, 1929, began 90-mile-per-hour passenger service on a route from Dallas, Texas, to Jackson, Mississippi, with stops in Shreveport and Monroe, Louisiana. Strictly a passenger operation without any associated airmail contracts or revenue, this was an ambitious step into what was to be an increasingly important service.

Airline Regulation

The election of President Herbert Hoover brought important changes to the air industry. Hoover's postmaster general, Walter Folger Brown, was determined to use the awarding of airmail contracts to improve and streamline what he saw as a chaotic air carrier structure. On April 29, 1930, Congress passed the Air Mail Act of 1930, also known as the McNary-Watres Act, empowering Brown to do just that. Lacking night flying experience, Delta did not fit Brown's requirements and consequently lost its mail contracts in 1930. Delta was back to being merely a crop-dusting operation. In response, Dr. Coad was brought on as chief entomologist and dusting operations expanded. Passenger planes and routes went to Aviation Corporation (AVCO), a holding company whose most important asset was American Airlines, but crop-dusting rights and equipment were retained by Delta Air Services, which was then reincarnated as Delta Air Corporation.

Franklin D. Roosevelt won the 1933 presidential election, sweeping Hoover and his postmaster general out of office. Within months, the new administration cancelled all airmail contracts. After a disastrous attempt to use the Army Air Corps to fly the mail, a call was placed for new bids. In the bidding, Delta acquired the mail route from Charleston, South Carolina, to Dallas and Fort Worth, Texas, with stops along the way in Atlanta and Birmingham. Delta purchased trimotor Stinson-T planes, which could carry seven passengers and mail at 100 miles per hour, and resumed airmail operations on July 4, 1934.

The Great Depression of the 1930's was a time of often painfully slow development and consolidation for the American airline industry. Airlines made little or no profit. The Civil Aeronautics Authority was created to regulate and control the airlines and airline routes. Despite recurring difficulties, Delta gradually improved its routes and position. Delta also experienced its first passenger fatalities in 1935 when the propeller of a Delta Stinson-A broke in flight. The resulting crash in a cotton field near Gilmer, Texas, killed two passengers and the crew of two. In the next year, mechanical failure of another Delta Stinson-A seriously injured a veteran Delta test pilot. The pilot, Charles H. Dolson, eventually recovered and returned to work. He was a key figure in unionizing Delta pilots, bringing them into the Air Line Pilots Association in 1935, and he later replaced C. E. Woolman as president of Delta.

The Delta complex of routes increasingly passed through Atlanta, making it a natural home for the organization. Accordingly, when leases in Monroe came due for renewal in 1941, the Board of Directors moved Delta headquarters from Monroe to Atlanta.

With the entry of the United States into World War II, key personnel were lost to the war effort and vital matériel and supplies were in short supply. Nevertheless, the airline forged ahead. Air routes were added and the workforce increased. Assets, working capital, and passenger totals climbed. Delta undertook a major aircraft modification program for the military. Under a two-year contract, Delta personnel prepared bombers for conditions in the Pacific and European theaters and installed long-range fuel tanks on P-51 Mustangs.

As the war ended in 1945, Delta renamed itself Delta Air Lines. At this point, Delta had flown more than 300 million passenger miles in ten years without a passenger or crew fatality. In a major victory for Delta that year, the Civil Aeronautics Board (CAB), instituted in 1940, awarded it the lucrative Chicago-to-Miami route. Company fortunes continued to rise. By 1946, Delta had carried more than one million passengers.

Delta lost a number of key personnel in a horrifying and bizarre accident in 1947. On April 22 of that year, a Delta C-47 carrying seven major Delta executives and piloted by Delta's operations chief was approaching the runway at Muscogee County Airport in Columbus, Georgia, when a BT-13 flown by an experienced Civil Air Patrol pilot landed on the C-47. No one survived the ensuing crash and fire.

The Delta Fleet

Aircraft Type	*Total Owned and Leased*	*Average Age*
Boeing 727-200	74	22.4
Boeing 737-200	54	16.1
Boeing 737-300	26	14.1
Boeing 737-800	43	0.9
Boeing 757-200	120	9.5
Boeing 767-200	15	17.6
Boeing 767-300	85	10.9
Boeing 767-400	15	0.2
Boeing 777-200	7	1.3
Lockheed 1011-100	4	19.7
Lockheed 1011-250	4	18.1
MD-11	15	6.9
MD-88	120	10.5
MD-90	16	5.1
ATR-72	19	6.5
EMB-120	57	10.6
CRJ-100/200	155	2.8
Total	829	9.6

Source: Data taken from (www.delta.com/inside/investors/corp_info/fleet/index.jsp), June 5, 2001.

Mergers and Expanding Routes

Another benefactor of the 1934 bidding was Carleton Putnam's Pacific Seaboard Air Lines. Flying passenger routes in California without airmail contracts, the line was struggling until, like Delta, it captured an airmail contract. The new route, from Chicago to New Orleans, shifted its operations to the Mississippi Valley and inspired a change of name to Chicago and Southern Air Lines (C&S). With Delta's newly acquired Chicago-to-Miami route, C&S came quickly into Delta's purview and, in 1953, the two airlines merged. The new company went by the name Delta-C&S for about two years before reverting to Delta. The move significantly expanded Delta's range of routes and enhanced its competitive position.

A month after the merger, a Delta DC-3 flying from Dallas to Shreveport encountered a thunderstorm near Marshall, Texas. Unaccountably breaking Delta regulations, the pilot attempted to pass through the storm. Seventeen passengers and the crew of three perished when the plane went down. One passenger survived when her seat detached and landed upright.

Important improvements to company operations were made in the 1950's. In 1955, Delta pioneered the hub-and-spoke system. Shortly thereafter, weather-avoidance radar was installed in the noses of all Delta aircraft. Delta entered the jet age in 1959, becoming the first airline to introduce the new passenger jet aircraft, the DC-8. The greater maintenance needs of jet aircraft thrust Delta into a vast effort to upgrade training, inspection, and maintenance procedures. Air traffic control improvements were also introduced at this time, when Congress created a new safety regulatory agency, the Federal Aviation Agency, later called the Federal Aviation Administration (FAA). The agency was to develop and manage an air traffic control system to maintain safe separation distances between all commercial aircraft through all phases of flight.

Tragedy struck again when one of Delta's new Convair-880 jets crashed and burned during a 1960 training flight. It seemed to take off normally but almost immediately rose steeply, then banked left and right and crashed, killing the four crew members. The cause of the accident was never determined.

The 1960's were a time of intense competition for new routes and milestone changes. Bert Coad, still managing the crop-dusting division, died in 1966 and the division was soon closed down. Then, in September of that year, C. E. Woolman died following surgery for an aneurysm. He had only recently given up his position as president and general manager in order to become the chief executive officer.

Throughout the decade, Delta lost many route wrangles with the CAB. Although these efforts were a drain on energies and resources, company assets, revenues, and net income rose impressively. Delta's market share also rose steadily. The CAB did award Delta a few lucrative routes, such as the Dallas-Fort Worth-to-Phoenix route. Delta also gained access to the major North Carolina airports.

The route system continued to expand in the 1970's, both through CAB awards and also through the 1972 merger with long-ailing Northeast Airlines. The Atlanta-to-London route was established in 1978. Together with its New England and Northeast routes, Delta's route system now encompassed the entire eastern United States, with side routes to western cities as well as to the Caribbean and London. However, the merger with Northeast also brought equipment problems. In the 1970's, Delta had a dozen different types of planes in service, creating enormous maintenance headaches. The Northeast planes had not been made to Delta's specifications. A five-member crew and eighty-three passengers were all killed when one of the DC-9-31's obtained from Northeast hit a seawall while attempting to land in Boston in a thick fog on July 31, 1973. No single cause was identified, but a number of errors and failures of both the crew and ground control apparently combined to create the disaster. This accident followed the May 30, 1972 loss of the four crew members during the takeoff of a DC-9 training flight in Fort Worth caused by turbulence from the previous landing.

Deregulation

Deregulation of the air industry in 1978 created a host of opportunities and risks. Delta greatly extended its western routes in a merger with ailing Western Airlines in 1987. Then, in the greatest transfer of flights in airline history, Delta gained many additional transatlantic routes with the 1991 purchase of the routes of bankrupt Pan American. The former crop-dusting outfit had become a giant of global passenger flight. By 1998, Delta was the most-flown airline in the world, with 105 million passengers that year.

Delta suffered its most deadly accident on August 2, 1985. A Lockheed Tri-Star attempting to land at Dallas in a thunderstorm was caught in a microburst downdraft and landed more than a mile short of the runway, striking a car and killing the occupant. On board, 8 crew members and 126 passengers were killed.

Almost exactly three years later, on August 11, 1988, a Delta Boeing 727 crashed trying to take off from Dallas, killing two crew members and twelve passengers. Improper procedures and failures of discipline were cited as causes.

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See also: Accident investigation; Air carriers; Airline Deregulation Act; Airline industry, U.S.; Airmail delivery; Crop dusting; Jennys; Mergers; Safety issues

Dirigibles

Definition: Aircraft that float because of lighter-than-air gas and that have power sufficient to direct their course of flight.

Significance: Dirigibles were the leading edge of aviation from the 1850's until they were supplanted by airplanes and helicopters. Dirigible aviation developed many techniques that were later adopted for airplanes. In the twenty-first century, dirigibles may serve a number of niche functions, such as telecommunications repeaters, high-altitude science platforms, and heavy cargo transporters.

Nature and Use

Dirigibles, like balloons, are often referred to as lighter-than-air (LTA) craft, in contrast with airplanes and helicopters, which are heavier-than-air (HTA) craft. The term "dirigible" is a shortened form of "dirigible balloon," meaning directable, or steerable, balloon. Buoyancy is the key to dirigible flight. The ancient mathematician Archimedes stated that a body immersed in a fluid is buoyed up by a force equal to the weight of the displaced fluid. For dirigibles, two LTA gases, hydrogen and helium, are combined to provide the buoyancy that lifts the dirigible and any payload.

Typically, hydrogen lifts 60 pounds per 1,000 cubic feet. Helium lifts 14 percent less (53 rather than 60 pounds) per 1,000 cubic feet. Helium has a major safety advantage over hydrogen, in that it does not burn, whereas hydrogen can ignite explosively.

Unfortunately, helium did not become available until the 1920's, and even then, the U.S. government, which controlled most of the world's supply, was slow to allow exports. Consequently, dirigibles manufactured outside the United States flew using highly flammable hydrogen, which caused many catastrophic fires. A third LTA gas, hot air, has only one-third the amount of lift of hydrogen, meaning the propulsion unit must have proportionately more thrust.

Another dirigible concern is that the density and pressure of the surrounding air decreases with altitude. Hence, there is less lift available per unit volume, so the craft must be larger to carry a given payload to higher altitudes. Consequently, dirigibles with heavy payloads tend to be limited to low altitudes of a few thousand feet. For higher altitudes, designers can compensate for decreased lift per unit volume by using lighter payloads, such as remotely controlled instruments instead of people.

Types

Dirigibles are divided into three categories: nonrigid, semirigid, and rigid. Nonrigids are essentially large, streamlined cylindrical balloons, nicknamed "blimps," supposedly for the sound made by a finger thumping into the side of the envelope, or gas bag. Nonrigids, such as the Goodyear blimps, get their shape from the gas within a single gas bag or envelope. The engines and a car or a gondola hang below the gas bag.

The design of nonrigid dirigibles simplifies cost and minimizes structural weight, which in turn reduces the net lifting capability. However, nonrigids are limited in size, because an unsupported gas bag may bend unpredictably under heavy loads or strong winds. In a worst-case scenario, a partially deflated gas bag may flop over the gondola or propellers. Conversely, the gas bag cannot be filled too tightly, lest it burst. The one gas bag is a single point of failure that could cause a crash, although the large size of dirigibles means that operations could continue for some hours, even with significant leaks. Another method to compensate for pressure loss in the gas bag is the use of an inner ballonet, which can be inflated with outside air.

Semirigid dirigibles have a keel on the bottom to support a larger gas bag, and the keel can hold the gondola and engines, at the cost of additional weight. The risks associated with a single gas bag also apply to semirigid dirigibles. The most famous semirigid was the airship *Norge*, which made the first transpolar flight from Spitsbergen Island to Alaska.

Rigid dirigibles have a framework to support an outer skin and individual gas bags. Although the term "zeppelin" is sometimes used to describe any rigid dirigible, the name legally applies only to the type of craft manufactured by the Luftschiffbau Zeppelin company of Germany.

In rigid dirigibles, an individual gas bag can fail without damaging the aerodynamic integrity of the craft, and there are usually sufficient reserves among the other cells to maintain buoyancy. Those advantages cost additional weight. However, greater weight can be compensated for by greater size. There is theoretically no limit to a rigid's size. The German passenger airship *Hindenburg* had an LTA gas capacity of 7,000,000 cubic feet, and designs of twice that size have been proposed.

History

Beginning in the 1790's, balloons made true humankind's dream of the possibility to drift like clouds. Like clouds, however, balloons drifted wherever the wind blew. Thus, inventors realized their craft must be directable as well as lighter than air. The key to this directional ability was generating sufficient power while remaining light enough to fly. Repeated attempts in the first half of the nineteenth century showed that human power was insufficient against even slight winds. A number of inventors flew models powered by springs or clockworks during that time, but none of the models' mechanisms could be sufficiently scaled up to power a craft carrying a person.

Henri Giffard of France had the first partial success on September 24, 1852, with a dirigible powered by a steam engine. The engine, advanced for its time, produced 3 horsepower and weighed as much as two large men. Giffard's aerial steamer, as it was known, launched from the Paris Hippodrome and hissed sedately to a landing 17 miles away. In a later flight, Giffard circled around Paris. However, because his craft's top speed was only 6 miles per hour, it was not steerable against even a breeze.

Fortunately for dirigible designers, the development of metallurgy and power plants advanced in the second half of the nineteenth century. In 1886, an electrolytic process was invented for producing aluminum inexpensively enough so that it could be used to replace the heavier steel in dirigible support structures. In 1876, German engineer Nikolaus August Otto began marketing a four-stroke, internal combustion engine yielding more power per unit weight than the external-combustion steam engines. In 1885, another German engineer, Gottlieb Daimler, patented significant improvements to the internal combustion engine and offered it for use in dirigibles.

On November 12, 1897, an airship built by Austrian David Schwartz sported a 10-horsepower Daimler motor. Before it was ready to launch, a gust of wind pulled the craft loose from its moorings and toward nearby buildings. The pilot panicked and valved out so much gas that he crashed on the field. Despite its misfortune, this ship represented the first rigid dirigible, with a solid structure and a thin aluminum skin around the gas bag.

By this time, both airships and balloons had developed a bad reputation. Fortunately, public relations assistance and superb flying skill arrived from Brazil in the form of wealthy experimenter Alberto Santos-Dumont, who took a single-cylinder engine from each of two tricycle automobiles to make a single, 66-pound, two-cylinder engine delivering 3.5 horsepower, roughly five times the power-to-weight ratio that had been available to Giffard. Santos-Dumont launched this eighty-two-foot nonrigid craft with 64,000 cubic feet of gas volume, along with himself and a basket.

On September 20, 1898, Santos-Dumont began flying around Paris in his airship, usually flying low enough to greet people on the streets. As both his flying skills and his dirigibles became progressively more advanced over the next several months, he aroused tremendous public interest, especially because he commuted around Paris in his compact dirigibles, mooring his craft above the spots to which he traveled.

Santos-Dumont engendered so much interest in flying that a prize was offered to the aviator who could fly a seven-mile course to the Eiffel Tower and back within in thirty minutes. After several heroic attempts, Santos-Dumont won the prize. He became a global celebrity and inspired many others built nonrigid airships.

In Germany, Count Ferdinand von Zeppelin built a large rigid dirigible, *Luftschiff Zeppelin Number 1*, or *LZ-1*, which was 420 feet long and 42 feet in diameter with a gas volume of 400,000 cubic feet, sixty times greater than that of Santos-Dumont's model number 1. *LZ-1*, which first flew in July, 1900, had seventeen separate gas cells held together by an aluminum framework and covered with fabric.

However, the two 15-horsepower engines gave *LZ-1* a top speed of only 16 miles per hour, still insufficient to fly against moderate winds. Zeppelin raised more money to build *LZ-2* and *LZ-3*, both of which had two 65-horsepower engines. *LZ-2* was destroyed at its mooring by winds, but successful flights of *LZ-3* led the German government to offer payment for a still-larger craft, if it could stay aloft for twenty-four hours.

On August 4, 1908, the *LZ-4* began a majestic tour from its home base on the Swiss border, heading north along the Rhine River. People along the way cheered the giant airship. *LZ-4* flew for eleven hours, as far as Mainz, Germany,

Notable Airship Disasters

August 24, 1921: The U.S. *R-38* airship, built for high altitudes, maneuvers hard at a low altitude, breaks in half, and explodes.

December 21, 1923: The French airship *Dixmude* explodes in flight during a thunderstorm, killing fifty crew members.

September 3, 1925: The USS *Shenandoah* breaks apart in thunderstorm, killing fourteen of the forty-three crew members.

May 25, 1928: The Italian airship *Italia* loses buoyancy and crashes attempting to reach the North Pole.

October 5, 1930: The British *R-101* airship crashes and burns, killing forty-eight of the fifty-four total passengers and crew.

April 3, 1933: The USS *Akron* is driven into the sea by downdrafts in a storm, killing seventy-three of the seventy-six crew members.

February 12, 1935: After the fin of the USS *Macon* is ripped off in storm, the airship loses buoyancy and crashes at sea, killing two of the eighty-three crew members.

May 6, 1937: The German airship *Hindenburg* explodes while docking at Lakehurst, New Jersey, killing thirty-six of the ninety-eight passengers and crew.

and had begun its return when one engine failed. Rather than press on in the dark with only one engine, Zeppelin set *LZ-4* down near the town of Echterdingen. That night a storm pulled the craft loose and destroyed it.

Yet Zeppelin's story continued, as envelopes of cash began arriving from all over Germany. The so-called Miracle of Echterdingen supplied his company with more money than the German government had offered. The count continued to build, and by 1910, Zeppelin dirigibles had begun carrying sightseeing passengers and mail. By 1914, a number of Zeppelin dirigibles were in regular service.

That year, World War I began. At first, the dirigibles dominated the skies, and the competing airplanes posed no threat to them. In 1915, German rigid dirigibles conducted the first long-range bombing attacks against targets in Great Britain, with little effective resistance from airplanes. However, faster and larger airplanes were soon able to catch the dirigibles, which proved to be large, slow targets. A single incendiary round of fire passing through a hydrogen gas cell could transform an airship into a fireball. In order to escape the airplanes, the Germans piloted their dirigibles to higher altitudes, where at 20,000 feet, water froze in the crews' canteens. The airplanes, however, were improved enough reach the dirigibles. By the end of the war, large airplanes had replaced rigids for long-distance bombing. The only dirigibles successful throughout the war were two hundred nonrigids the British used to guard convoys against submarines.

The long flights made by rigid dirigibles during the war suggested that dirigibles might be used for intercontinental passenger service, or even as flying warships. Continued research was conducted by four countries: France, Great Britain, the United States, and Germany.

France had a number of smaller nonrigids, as well as one large rigid taken from Germany as part of its war reparations. The airship was renamed the *Dixmude* and flew for several years, making a record-breaking flight over the North African desert. After the airship exploded in flight during a storm in 1923, France abandoned large dirigibles.

During World War I, the British had built an R (for rigid) series of dirigibles, which the British continued to develop after the war by reverse engineering from a captured German dirigible. On July 2, 1919, the *R-34* left England, and, four days later, it had completed the first east-to-west aerial crossing of the Atlantic Ocean.

In 1924, the British government started two competing programs to build dirigible airliners. The *R-100*, built with private funding, was known as the capitalist ship, and it flew well on a demonstration flight to Canada and back.

The *R-101*, built by the government, was known as the socialist ship and was heavy with safety features. To increase lift, the builders cut the ship in half and inserted an additional gas bag. They also loosened wire netting around the gas cells, so they could be expanded. Unfortunately, this adjustment allowed the cells to rub against the framework, causing many small leaks. Because officials wanted to use the airship for a prescheduled demonstration flight to India, the major changes were not flight-tested. The *R-101* launched from England on October 4, 1930, and early the following morning, it crashed into a hillside and exploded 40 miles northwest of Paris; forty-eight of the fifty-four people aboard died. As a result of this accident, Great Britain abandoned passenger airships and even scrapped the successful *R-100*.

In the 1920's and 1930's, the U.S. government operated four rigids as military ships intended for long-range reconnaissance. Two of the airships, the USS *Akron* and the USS *Macon*, actually carried their own fighter planes for defense. Because the United States held most of the world's helium supply and used helium for its LTA gas, none of these craft exploded. However, three were lost in storms, and the United States abandoned the giant rigids after the last, the *Macon*, broke up in a storm and went into the sea off Point Sur, California, on February 12, 1935.

The Luftschiffbau Zeppelin company of Germany, with its experience in building more than one hundred rigids and its thorough design details, had the best safety record of any dirigible manufacturing company. For several years after World War I, Germany was forbidden by the Treaty of Versailles from possessing dirigibles larger than 1,000,000 cubic feet. However, in 1922, the U.S. Navy placed an order for a dirigible, which was named the *Los Angeles*. Zeppelin's brilliant manager, Hugo Eckener, flew the craft to the United States. After the size limit on German dirigibles was lifted in 1925, Eckener organized construction of the *Graf Zeppelin*. Beginning in 1928, the *Graf Zeppelin* circled the world, flew regularly to Brazil and North America, made an Arctic expedition, and traversed one million miles before being retired.

The last and greatest rigid was the *Hindenburg*, launched in 1936. The *Hindenburg* was 803 feet long and 135 feet in diameter. Its 7,000,000 cubic feet of gas allowed it to carry fifty passengers and sixty crew in absolute luxury at a speed of 84 miles per hour for a range of 11,000 miles. The *Hindenburg* and the older *Graf Zeppelin*, represented great profits for Luftschiffbau Zeppelin and good propaganda for Germany's Nazi regime.

Then disaster struck. Although Luftschiffbau Zeppelin was negotiating with the U.S. government for helium, it still employed hydrogen in its airships. As the *Hindenburg* was docking at Lakehurst, New Jersey, on May 6, 1937, several crew members noticed a small fire in one gas cell. Within one minute, the craft had exploded into a ball of fire and lay on the ground, a smoldering wreckage. Although many theories proposed causes such as lightening, leaking gas, and anti-Nazi sabotage, filmed footage of the event convinced the public that large dirigibles were unsafe.

After the *Hindenburg* disaster, only nonrigids remained, and they played a major role in the antisubmarine warfare of World War II. However, they were retired in the 1950's, after it became clear that helicopters provided the same hovering capability with greater dash capability and easier storage. In the last third of the twentieth century, the few working nonrigid dirigibles were limited to use as advertising billboards and as vehicles for television cameras providing overhead views of sporting events.

Economics and Prospects

Although dirigibles at the beginning of the twenty-first century enjoyed a small resurgence in several niche markets, they will probably never recover their primacy in aviation for five major reasons.

The first reason is the massive investment cost of building and developing dirigibles. Several factors make dirigibles more efficient as their size increases. However, the increase in size increases the cost of design and building. Large size also reduces the number of units made, so dirigibles have less chance for lower costs and improved designs than do HTA craft, which are typically made by the hundreds or thousands.

Second, hangar costs are high. Dirigibles are kept inflated because their helium lifting gas is expensive and would require too much time and effort to pump back into tanks. However, inflated dirigibles can easily be swept off their parking areas by winds. Consequently, dirigibles must be housed in their own special hangars instead of being parked on runways as airplanes are.

Third, dirigibles are vulnerable to bad weather, which limits their performance. The giant buoyant structures can be seized by gusts of wind on takeoffs and landings and are more vulnerable than airplanes to icing. Zeppelin passenger flights were not scheduled in winter. Dirigibles are so large that winds may pull them in different directions while they are in flight, destroying them. The USS *Shenandoah*, *Akron*, and *Macon* were all destroyed in this way. Moreover, unless they are specially designed for high altitude, dirigibles cannot readily climb above storms as jet-propelled airplanes can.

Fourth, because dirigibles' great size causes more drag per unit mass of cargo, dirigibles are significantly slower than their HTA competition. They can at best obtain one-half the speed of propeller-driven planes and one-fifth that of jets. Thus, a jet with one-fifth of the cargo capacity of a dirigible can deliver the same cumulative mass of cargo. For the passenger market, shorter flight times are crucial.

Still, dirigibles have potential for certain markets because they can run quietly and smoothly, linger for long periods, carry heavy and awkwardly large payloads, and land without runways. These advantages have been increased by lighter and more fireproof materials. The number of advertising dirigibles increased steadily beginning in the 1980's. At the start of the twenty-first century, the present-day Luftschifftechnik Zeppelin company marketed sightseeing semirigids one-third the size of the *Hindenburg*. A German-American company called CargoLifter designed a cargo-carrying rigid larger than the *Hindenburg*.

Meanwhile, an entirely new concept was being developed: the use of dirigibles in the lower stratosphere as high-altitude platforms. Such platforms could serve many functions of communications satellites and astronomical satellites at a fraction of the cost of spacecraft.

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See also: Balloons; Blimps; Buoyant aircraft; *Hindenburg*; Icing; Lighter-than-air craft; Military flight; Reconnaissance; Alberto Santos-Dumont; Weather conditions; Ferdinand von Zeppelin

Dogfights

Definition: Aerial battles between two or more aircraft.

Significance: Since World War I, air-to-air combat and the establishment of air superiority has been one of the most crucial components of success in modern warfare.

History

World War I. By the beginning of World War I in August, 1914, many military strategists had already predicted the possibility of combat between aircraft. At the time, military aviation on all sides was limited to a few hundred rudimentary aircraft that were expected to perform reconnaissance missions, artillery spotting, and courier duties. The low performance of available aircraft at the time made the carrying of effective weapons initially pointless, because their added weight made the aircraft incapable of climbing to altitude or of overtaking any opposing aircraft. Early in the war, there existed a camaraderie of the air. Pilots treated each other with a restrained civility, often saluting or waving at enemy pilots in passing. Piloting an aircraft was akin to membership in an elite gentlemen's club.

As the value of aerial observation became apparent to ground force commanders, it soon became necessary to disrupt the enemy's reconnaissance activity in order to wage successful land and sea campaigns. In short order, both pilots and observers began attacking enemy aircraft with rifles, revolvers, semiautomatic pistols, and steel-dart flechettes in attempts to down opposing fliers. As the possibility of being shot out of the sky while on a mission became a real threat, aggressive pilots and resourceful ground crews soon initiated rapid development in both aircraft and aircraft missions in World War I. The three technological developments most noteworthy in the early intensification of aerial combat include the design and production of more powerful engines and robust machines; the installation of lightweight machine guns, synchronized to fire through the propeller arc of single-engine aircraft; and long production runs of mass-produced, standardized aircraft that made possible the institution of formation tactics. As soon as more powerful machines were available, flexible machine-gun mounts were fitted to either the sides or the upper wing surface of the aircraft. This positioning was necessary because the sides, rear, or above the propeller arc were the only safe directions in which to shoot without possibly destroying the front-mounted tractor drive propeller. These early aircraft could not be pointed so both pilot and aircraft were in alignment with the targeted enemy, making for dangerous flying circumstances during an aerial battle. After several experimental attempts, the forward-firing synchronized machine gun was designed and fitted to the cowl of high-performance single-seat scout aircraft. The mission of these aircraft was primarily offensive, and they were employed to destroy enemy reconnaissance and bomber aircraft. These were the first true fighter aircraft. In an effort to protect airplanes on reconnaissance and bombing missions, groups of fighter planes began flying as escorts. Flying out to meet the enemy's reconnaissance, bombers, and escorts was called interception. When fighter escort aircraft encountered fighter interceptors, an aerial melee, which became known as the dogfight, resulted. The sole purpose of the dogfight was to destroy as many enemy aircraft as possible before they could return the favor.

World War II. World War II saw the most prolific application of interceptor and escort strategies. Air-to-air

Image Not Available

combat and superior dogfighting aircraft swung the balance of power and ultimate air supremacy toward the Allied forces. Aerial duels during the Battle of Britain (1940), the Allied daylight bombing raids on Germany (1942-1945), the Pacific Island campaign (1942-1945), and operations on the Russian front (1941-1944) established the doctrine of air supremacy as the key to victory in modern conventional warfare.

Fighter Planes. Some of the most recognizable and renowned aircraft in the history of aviation have been fighter planes. Many well-known aircraft were designed specifically for the air-to-air mission. World War I fighters included the Fokker Dr-I triplane, the Sopwith Camel, the Spad XIII, and the Albatros D-III. World War II fighters included the Spitfire, the Hurricane, the P-51 Mustang, the P-38 Lightning, the Corsair, the Mitsubishi Zero, the Messerschmitt Bf-109, and the Focke-Wulf Fw 190. MiG-15 and F-86 Sabre jet fighters were used in the Korean War. MiG-21 and F-4 fighters were used in the the Vietnam War. MiG-23, F-15, F-16, F-18, and Mirage fighters were used in wars in the Middle East during the last half of the twentieth century.

Tactics

The duel between fighter aircraft to gain control of the skies above a battle theater has become a necessary command strategy. Control of the skies means unfettered access for one's own reconnaissance and bombers to the exclusion of the enemy's. The basic rules of air-to-air combat established during World War I have not changed since. Air-to-air combat, from its very inception, remains exclusively individualist. Early air warfare tactics were essentially individual in nature, evolved by pilots to reflect their own experiences and personalities and altered to suit the circumstances and the aircraft and its armament. Despite advances in technology, this warrior tradition remains in place.

During World War I, pilots learned that the key to success and survival in a dogfight was to gain surprise and get off the first shot. A protracted aerial dogfight, in which the advantage hinges on pilot skill, higher maneuverability, tighter turning radius, munitions, and greater speed, is not the optimum scenario. Drawn-out dogfights typically end in stalemate or random losses due to some unforeseen circumstance. The primary rule of all air-to-air combat is to take the enemy by surprise. Nearly all aerial kills are the result of the surprise attack, in which the attacking pilot obtains a favorable position, usually high and to the rear, and fires the initial attack. The victim usually never sees the attacker. The average aircraft-to-aircraft aerial duel takes less than ninety seconds.

An effective fighter pilot must not only be skilled but also must be able to apply those skills quickly under the intensity and pressure of a life-and-death struggle that takes place on a three-dimensional battlefield at incredible speeds. A dogfight is not a planned mission. Once the duel begins, all operational order is gone. One of the most common tactics in dogfighting is to force the enemy into elaborate maneuvers that deplete the enemy craft's fuel supply and force the enemy to break off the engagement, at which point the enemy becomes exposed and vulnerable to follow-up attacks. Interceptor pilots defending air space have an advantage in that they require less fuel. Defending interceptors can linger in their air space longer, and, because they are closer to their bases, they can land, refuel, rearm, and return to battle if necessary.

In modern warfare, weaponry and personnel are likely to be somewhat evenly matched. It has been known since World War I that excellence in fighter aircraft design is more important than greater speed and that maneuverability and weapons technology are the keys to successful fighter design. Often, however, the outcome of air-to-air combat is influenced by factors other than aircraft performance and firepower, such as the pilot's skill and morale, the tactical situation or mission, the weather, the balance of forces in the air, and intelligence data. Yet, to win a dogfight, the pilot must be equipped with an aircraft capable of keeping up with the enemy and must be trained to use the aircraft to its maximum potential. Superior aircraft coupled with inferior pilots is no match for skilled pilots in similar aircraft. Historically, about 5 percent of combat pilots account for more than 50 percent of all downed enemy aircraft during a conflict. Putting as many skilled pilots as possible into a battle theater is the most efficient way to gain air superiority.

From the beginning of air-to-air combat, spotting the enemy first, acquiring position, and firing the first shot have been the keys to success and survival. Although pilot skill remains an important factor, modern dogfighting is a matter of teamwork and applied technology. With the advent and application of long-range detection systems, weapons, and communications, pilots can detect, coordinate, and attack opposing aircraft from greater distances. In modern air warfare, the side with the superior detection systems usually gets the superior position and manages to fire the first shot. Early detection also allows for quicker adaptation to fluid battlefield conditions. Modern improvements in aircraft armament and sighting allow pilots to reach out and touch the enemy at greater distances and with a greater measure of success. A modern 30-millimeter cannon is highly accurate to 800 meters, compared with the 100 meters of an 8-millimeter machine gun of World War I. Modern air-to-air missiles have kill ranges of up to 200 kilometers and are highly reliable at ranges of 10 to 50 kilometers. Because of these long-range munitions, most modern dogfights often take place beyond the visual range of the combatants.

Randall L. Milstein

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See also: Battle of Britain; Black Sheep Squadron; Bombers; Fighter pilots; Fokker aircraft; Korean War; Luftwaffe; Messerschmitt aircraft; Military flight; Reconnaissance; Manfred von Richthofen; Eddie Rickenbacker; Sopwith Camels; Spitfire; Triplanes; Vietnam War; World War I; World War II

Jimmy Doolittle

Date: Born on December 14, 1896, in Alameda, California; died on September 27, 1993, in Pebble Beach, California

Definition: A pilot and pioneer of military aviation and instrument flying.

Significance: As a member of the U.S. Army Air Service in 1922, Doolittle made the first transcontinental flight in less than twenty-four hours. He was most noted for leading the first air raid over Japan during World War II.

James Harold "Jimmy" Doolittle was born in California but spent much of his youth in Alaska. He left the University of California in 1917 to enlist in the U.S. Army Reserve and was assigned to the Signal Corps. During World War I (1914-1918), he served as an aviator and flight instructor. Commissioned as a first lieutenant in 1920, he spent much of the following decade in the development of military aviation.

During this period, Doolittle combined his interest in aviation with the sport of flying. He took part in numerous races, winning a number of trophies. In September, 1922, he carried out the first transcontinental flight from Florida to California, a distance of more than 2,100 miles, in fewer than twenty-four hours. The purpose of the flight was to support the growing role of the U.S. Army Air Service in the nation's defenses. At the same time, the flight brought Doolittle to national prominence.

In 1930, Doolittle resigned from the Army to work for the Shell Petroleum Company. He continued to race, setting a world speed record in 1932. In 1940, Doolittle rejoined the Army Air Corps with a rank of major. On April 18, 1942, as a lieutenant colonel, he led a force of sixteen B-25 bombers from the USS *Hornet*, hitting targets in Japan more than 800 miles across the Pacific. Although the targeted cities, Tokyo, Yokohama, Kobe, and Nagoya, received negligible damage, the raid shattered the impenetrable image of the Japanese islands. Most of the planes and their seventy-five fliers crash-landed in China. Doolittle was awarded the Congressional Medal of Honor for his action.

During the war, Doolittle rose to the rank of lieutenant general, commanding the Twelfth Air Force in North Africa and the Fifteenth Air Force elsewhere in the region. In 1944, Doolittle assumed command of the Eighth Air Force, directing bombing of Germany until the end of the war. From 1948 to 1958, Doolittle served on both the National Advisory Committee for Aeronautics and and the President's Science Advisory Committee. He became director of Space Technology Laboratoriesfollowing his retirement from the Air Force in 1959.

Richard Adler

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See also: Air Force, U.S.; Bombers; National Advisory Committee for Aeronautics; Transcontinental flight; World War I; World War II

Doppler radar

Definition: A device for determining the radial velocity of an object by measuring the frequency change in the echo of a radio wave reflected from the object.

Significance: Doppler radar may be used to determine the speed of a distant object along the line of sight, or when installed in a moving aircraft, used to determine the true speed relative to the ground. Doppler radar is also used to map the internal structures of severe storm systems posing a potential hazard to nearby aircraft.

Radar, an acronym derived from "radio detection and ranging," uses radio waves of constant frequency reflected from a target to determine its position, distance, direction, and speed. When radio waves emitted from a transmitting antenna are interrupted by a solid object, a portion of the energy, called an echo, is reflected back toward the transmitter, which can also function as a receiver. The distance to the object is determined by the time required for the radio wave to travel from the transmitter to the object and back to the receiver. Since radio waves, like light, travel at the constant speed of 186,000 miles per second, the measured time delay is proportional to the distance. If the transmitter were operating continuously, however, reflected signals would also be continuous, making it impossible to disassociate the emitted signal from the returning signals of different objects. The emitted signal is therefore labeled by emitting the signal in short, high-powered pulses rather than continuously. During the short interval between pulses, the transmitter is operated as a receiver. If the transmitter is not emitting when the return signal arrives, the received signal can be associated with a specific transmitted pulse.

Doppler Effect

The Doppler effect, discovered by Austrian physicist Christian Johann Doppler in 1842, is the change in the observed frequency of a wave due to relative motion between the observer and the wave source. When observer and source approach one another, the emitted frequency of the waves is measured to be higher due to the velocity of approach; the greater the relative speed, the greater the frequency shift. When the source and observer are receding from each other, the emitted frequency is measured to be lower, in direct proportion to the velocity of recession. The effect is particularly noticeable for sound waves; when an ambulance speeds past, the pitch (frequency) of its siren drops noticeably.

Although the Doppler effect has been well-known for sound and light since the mid-nineteenth century, radar systems utilizing this effect were not developed until after World War II. By detecting the frequency shift in the reflected signal caused by an object having a component of velocity toward or away from the observer, the object's speed along the line of sight can be calculated from the Doppler equation. Unlike the pulsed systems, Doppler radar is a continuous wave system. A single antenna can be utilized because the reflected signal from a moving object returns at a different frequency, hence the outgoing and incoming signals are not confused.

Applications

Radar was developed by the military for its own use and still finds its major applications in the military arena. It is used to detect aircraft, missiles, artillery projectiles, ships, land vehicles, and satellites. Civilian applications include the surveillance of aircraft and weather in the vicinity of airports. Air route surveillance tracks aircraft between airports up to 200 miles away. Radar is also used as a surface detector at airports to give the controller the location and movement of ground-based vehicles within the airport.

A Doppler navigator is a simple continuous-wave system used to determine a plane's ground speed. The plane's radar has an antenna that directs a beam forward and down toward the ground at a 45-degree angle to the direction of flight. The plane's velocity can then be determined from the relative radial motion. A radar altimeter gives the height of an airplane above the ground by reflecting signals straight down.

The National Weather Service (NWS) and the Federal Aviation Administration (FAA) now deploy a network of Doppler radar systems to monitor potential weather hazards to aircraft. By measuring the radial velocity of precipitation in conjunction with the strength of reflected signals, the severity of storms up to 250 miles away can be accurately gauged. The intensity of the echoes from raindrops and ice particles reveals the type of approaching storm and enables forecasters to predict when violent storms will reach specific regions. Doppler radar can also be used to pinpoint hazardous wind conditions such as downbursts, strong blasts of air associated with storm systems and a major cause of aircraft accidents.

Since Doppler radar is the only remote sensing instrument that can detect and measure the radial velocity of wind inside areas veiled by clouds, it is also used to probe the internal motions and structure of tornadoes or other potentially hazardous weather systems. In addition to aiding researchers better to comprehend the dynamics and life cycles of severe storms, this unique capability provides improved early warnings of impending weather hazardous to human communities.

George R. Plitnik

Hearing the Doppler Effect

It is very easy to hear the Doppler effect at the auto races. Race cars are noisy and emit a jumble of sounds dominated by the roar of their engines. When a race car approaches a listener (or a microphone), the pitch of the sounds it emits is higher. As the car passes, the pitch drops noticeably lower. When a car, or an airplane, approaches a radar set, the reflected radar waves will be Doppler-shifted. This means that when the echo reaches the receiving antenna, the wavelength will be shorter, and the frequency will be higher than the radar waves originally sent out by the transmitter. Because the amount of the Doppler shift depends on the target's speed, this speed can be calculated. If the target is moving away from the radar set, or even if the set itself is on a moving aircraft, the target's speed can still be found from the Doppler effect.

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See also: Air traffic control; Airports; Federal Aviation Administration; Instrumentation; Military flight; Radar; Weather conditions; World War II

Dresden, Germany, bombing

Date: February 13-14, 1945

Definition: A series of British and American air raids during World War II that nearly destroyed the scenic and historic German city of Dresden.

Significance: The controversial Allied bombing of Dresden raised the issues of whether the mass bombing of an urban area was a legitimate military strategy and whether the bombing of Dresden, in particular, was more of a political than a military action.

Air Campaign

With the World War II nearing an end, the British air ministry in January, 1945, devised a plan called Thunderclap, an air offensive that was to be directed at Berlin and population centers in eastern Germany. The Allies' major justification of this campaign was that it would add to the growing chaos in Germany created by the rapid westward advance of Russian troops and thus make it more difficult for the German army to summon reinforcements and armaments to meet the Russian advance. The attack also was intended to crush German morale. The Russians had been pressuring the British and Americans to conduct such an offensive in order to paralyze German communications. It was an outgrowth of a grand Allied strategy initiated in 1943, which called for combined operations to crush the German war machine. Specifically, the plan called for bombardment by the Allies from the air, by Allied ground operations from the west, and by Russian ground operations from the east.

Dresden was officially designated a military target for several reasons. First, it was considered a primary communications center in the Berlin-Leipzig-Dresden railway complex. Second, it was an important industrial and manufacturing center directly associated with the production of aircraft components and other military items, including poison gas, antiaircraft guns, and small arms. Third, it was believed that a raid would devastate the area, curtailing communications within the city and disrupting the normal civilian life upon which the city's larger communications activities and manufacturing enterprises depended. In addition, it was theorized a widespread assault that included bombing strikes against the city's industrial plants, which were interspersed throughout the region, would be construed as part of the overall pattern of the raid. However, many historians have argued that Dresden had, from a military perspective, virtually no great strategic importance. The city had little heavy industry and for this reason had been spared earlier bombings, except for a small raid by the Eighth U.S. Army Air Force in October, 1944.

Noted for its magnificent architecture and its manufacture of fine china, Dresden long had been considered one of the most beautiful cities in Europe. Its streets were adorned with statuary and other art, much of which dated from the seventeenth century. Among the city's residents, there was a mistaken notion that the city's grandeur protected it from an all-out attack. Until February, 1945, Dresden suffered from only those problems confronting most other German cities of the time: the loss of men in action and the economic hardships resulting from the war. Residents further believed that a nonstrategic city with a large number of military hospitals, POW compounds, and refugees would not face the same attacks that other cities had. Consequently, most of the German air defense and flak batteries that would otherwise have been stationed in Dresden had been relocated to areas where it was assumed they were more needed.

Raids

On February 13, the British Royal Air Force (RAF) Bomber Command dispatched 796 Lancaster bombers and 9 Mosquitoes from the United Kingdom. The planes attacked Dresden in two waves, three hours apart, dropping first high-explosive bombs and then tons of incendiaries that precipitated a mammoth firestorm. The high-explosive bombs were intended to demolish roofs and windows, leaving the interiors of buildings vulnerable to the second wave of bombers that followed with the incendiaries. Soon, rising columns of intense heat merged into a single conflagration that sucked up oxygen and burned it, creating hurricane-force winds and temperatures of up to 1,000 degrees Fahrenheit. On the following day, U.S. B-17 bombers, in a third-wave strike against the city, contributed to the damage. Target sector markings on RAF photographs confirmed that the attack on the heart of the city was carried out as planned. Military areas situated north of the city, including factories and freight stations, received minimal damage, though part of an American P-51 Mustang fighter escort was ordered to strafe traffic on the roads around Dresden to heighten the chaos. Only eight Allied planes were shot down during the assault.

At the time of the attacks, Dresden was virtually defenseless, because all remaining German fighter planes assigned to the area had been grounded for lack of fuel. In addition, the inhabitants of the city were mostly women and children who recently had fled the Russian offensive in the east. Indicative of the town's feeling of relative security was the fact that it had never put into operation the civil defense precautions for lessening the effects of potential firestorms that had been taken in other cities.

The total devastation wrought on the city in the twenty-four-hour period was unprecedented in its suddenness and totality. The city was nearly extinguished in a single blow. For a long period of time, residents remained in a state of collective shock so intense that the shock itself nearly numbed their grief. However, their daily struggle for survival amid the ruins instinctively became their immediate concern. Helplessness and despair set in only later.

The firestorm created by the bombardment was impossible to extinguish, because the incessant assault made it extremely difficult for the fire service to utilize either the river or canals. The fires burned for seven days. Although a final death toll in the bombardment has never been established, estimates have run between 25,000 and 135,000. The hospitals that survived the raids were overwhelmed. Corpses were loaded onto farm carts for burial in mass graves or stacked in huge pyres, as distraught men and women roamed the desolate streets seeking any traces of relatives or friends. Survivors later related macabre scenes, such as a bus filled with dead soldiers, all sitting perfectly in their seats. In another area, some corpses were discovered dressed in costumes for a February 13 pre-Lenten carnival that some residents had been celebrating. The raid completely leveled the center of the city, including the cathedral, known as the Frauenkirche, or Church of Our Lady. Overall, almost 12,000 buildings were turned into a wasteland of rubble and smoldering corpses. Most of the deaths on the ground were caused by suffocation and carbon monoxide poisoning, as residents huddled in their cellars waiting for the fires from the first attack to be extinguished. The area of destruction was approximately three times that of the area damaged in London during the more than two months of sustained German bombing in the Battle of Britain (1940). The firebombing inflicted on Dresden left almost nothing standing and most of what did remain was bulldozed for safety reasons.

Aftermath

From its inception, the Allies' strategic bombing campaign in Europe had generated controversy. Despite its general horrors, the air offensive failed to break German morale and, until the last months of the war, did not decisively impact German industrial production. Although the bombing contributed to the ultimate Allied victory over the German forces, it clearly did not in itself bring about victory.

Much of the speculation on the motive for the attacks has centered on Air Vice Marshal Sir Arthur "Bomber" Harris, commander of the RAF Bomber Command. Harris was the principal proponent of nighttime area strategic bombing carried out by formations of heavy bombers attacking large targets, such as cities, which were nearly impossible to miss at night. He believed that long-term bombing was the most effective way of destroying an enemy's industrial centers and demoralizing its population. He also made it clear that he opposed the redeployment of bombers to other theaters of aerial operations. In the spring of 1944, he strongly objected to the temporary interruption of the strategic bombing campaign by Allied leaders who planned to relocate the bombers to France to help in the assault on rail lines and bridges in preparation for the Normandy invasion.

The Harris strategy was an outgrowth of the original doctrine of strategic heavy bombing that had emerged in Europe at the end of World War I and was adopted in part as a justification for separating air operations from the British Army. Prior to the bombing of Dresden, the cities of Lübeck, Rostock, Pforzheim, Hamburg, Hildesheim, Cologne, Magdeburg, Mainz, and Würzburg had been subjected to tactical bombardments, where the maximum number of bombs had been dropped within as large a target area as possible. Theoretically, strategic bombing would accomplish several goals, including the crippling of German industry and the undermining of the Nazi war effort. It was also felt that because the RAF was poorly trained in night bombing, a practice it was not expected to perform, it lacked efficient bombs and navigational aids to conduct precision bombing. However, even the daylight attacks proved wildly inaccurate and achieved little of strategic value. Photographic evidence revealed that only a small percentage of bombs was being dropped anywhere near designated targets. Consequently, the RAF adopted the policy of "area bombing," the less-discriminate bombing of entire cities and towns. During the course of the European air campaign, more than 500,000 German citizens and more than 55,000 RAF airmen fell victim to the strategic bombing campaign.

Image Not Available

Despite the criticism that followed the Dresden raid, Harris remained unrepentant, citing in his defense British prime minister Winston Churchill's approval of the raid. In the opinion of many military historians, Churchill only agreed to the bombardment because the RAF demonstrated such a great lack of accuracy during air operations. Although they were subjected to searchlights, heavy flak, and night fighter attacks, the RAF bombers and their crews were spared the vengeance of marauding Luftwaffe day fighters, who took a heavy toll on the Americans.

Following the war, Dresden became a part of East Germany, whose authorities continued the city's ruin by bulldozing vast areas of burned-out buildings and replacing them with Soviet-style, high-rise apartment buildings. With the fall of Communism, efforts to reconstruct the city received a fresh boost, as programs were developed to construct new housing and restore old landmarks.

Although some have viewed the Dresden bombing as cruel and senseless because it targeted civilians while German capitulation was so near, others have justified the raids by arguing that Germany started the war and carried out terror bombings on British cities. In the latter view, the real responsibility for the Dresden bombing rests with Nazi leaders. Although debate continues over the ultimate responsibility for the terror, there is little doubt that the bombing of Dresden represented a milestone in the annals of modern warfare.

William H. Hoffman

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See also: Air Force, U.S.; Bombers; Flying Fortress; Luftwaffe; Royal Air Force; World War II

Hugh L. Dryden

Date: Born on July 2, 1898, in Pocomoke City, Maryland; died on December 2, 1965, in Washington, D.C.

Definition: American aerodynamicist who conducted pioneering research in high-speed aerodynamics and coined the word "transonic" to mean "at or near the speed of sound."

Significance: Dryden studied the phenomenon of compressibility associated with fluid motion near the speed of sound and designed wind tunnels to test the aerodynamic problems of transonic flight. His innovative use of a hot-wire anemometer to measure accurately the levels of turbulence in wind tunnels enhanced scientific understanding of turbulence and the boundary layer as they affect flight.

Born in 1898, Hugh Latimer Dryden finished high school at the age of fourteen and received a scholarship to Johns Hopkins University in Baltimore, Maryland. There he studied physics and mathematics and completed his undergraduate work in three years. In 1919, at the age of twenty, Dryden completed his doctorate in applied physics, with a dissertation entitled "Air Forces on Circular Cylinders."

Dryden then accepted a full-time leadership position in the aerodynamic division of the National Bureau of Standards (NBS). In 1934, he was named chief of the mechanics and sound division. In 1940, he was asked to develop a radar-guided aerodynamic missile head at the Office of Scientific Research and Development (OSRD). He received the Medal of Freedom in 1946 for his work for the U.S. Army Air Force.

After World War II (1939-1945), Dryden was appointed assistant director and then associate director at NBS. He was named the director of aeronautical research of the National Advisory Committee for Aeronautics (NACA) in 1947 and the director in 1949. When the National Aeronautics and Space Administration (NASA) was created after the Soviet Union's launch of Sputnik 1 in 1957, Dryden became deputy administrator of the new organization, remaining in that position until his death.

The bulk of Dryden's scientific research was performed prior to his post at OSRD. His ground-breaking research in wind-tunnel design allowed scientists to predict the effects of turbulence on aircraft performance. Using a hot-wire anemometer to measure rapid air fluctuations, he and a colleague found that turbulence could indeed account for the drag on aircraft. Dryden's wind-tunnel experiments enabled engineers to gain a clearer understanding of laminar and turbulent flows in the boundary layer. Dryden's work also led him to redesign wind tunnels in order to reduce the effects of turbulence and drag. More efficient wind tunnels led to the design of more effective aircraft. Dryden's experimental work on the boundary layer and laminar flow validated the earlier theoretical work of Ludwig Prandtl.

In 1938, Dryden became the first American to deliver the Wilbur Wright Lecture sponsored by the Institute of Aeronautical Sciences in England, with an address entitled, "Turbulence and the Boundary Layer." Dryden received the Daniel Guggenheim Medal in 1950 for his contributions to aeronautics. In 1976, the NASA Flight Research Center in California was renamed the NASA Hugh L. Dryden Flight Research Center. Although Dryden was diagnosed with cancer in 1960, he continued working and lecturing for the next five years before finally succumbing to the disease on December 2, 1965.

Said Elghobashi

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See also: Aerodynamics; Forces of flight; High-speed flight; National Advisory Committee for Aeronautics; National Aeronautics and Space Administration; Ludwig Prandtl; Wind tunnels; World War II

E

Eagle

Also known as: F-15, F-15A, F-15B, F-15C, F-15D, F-15DJ, F-15E, F-15J

Date: First flight on July 27, 1972

Definition: The dominant U.S. tactical fighter jet since 1972.

Significance: The F-15 Eagle has served since the mid-1970's as the primary jet fighter in the U.S. arsenal, and it remains superior to any other operational fighter in the world. Several countries allied with the United States also utilize the F-15, which enjoys an outstanding combat record and has evolved into several air-superiority and ground-attack variants.

Development

Conceived during the Vietnam War (1961-1975) by engineers at McDonnell Douglas, the F-15 Eagle was designed as an air-superiority fighter capable of defeating all types of enemy aircraft at close or long range under any weather conditions. The first F-15A flew in 1972, with a two-seat training version, the F-15B, following one year later. After extensive flight testing, the U.S. Air Force in 1976 took delivery of the first Eagle slated for a combat squadron.

From its beginnings, the F-15 demonstrated its superiority over contemporary fighters, combining high speed with spectacular maneuverability via a high thrust-to-weight ratio and a low wing loading, or ratio of weight to wing area. The F-15 had more power and wing area in relation to its weight than any other fighter in the world, and it performed accordingly.

Equipped with two Pratt & Whitney F100-100 engines capable of 23,930 pounds of thrust each, the F-15 could reach an altitude of 50,000 feet from a stationary start in just 2.5 minutes and could attain a maximum speed of 1,650 miles per hour.

Power and maneuverability were, however, only two of the F-15's advantages. The F-15 also included a revolutionary heads-up display (HUD), which allowed pilots to monitor critical flight data, such as speed, course, and altitude, without taking their eyes off the sky. It boasted an inertial navigation system that allowed pilots to fly anywhere in the world with unerring accuracy, an advanced computer, and extensive electronic countermeasures for defense against enemy radar and missiles. With its Hughes APG-63 pulse-Doppler radar and a service ceiling of 65,000 feet, the Eagle could fly well above most potential enemies, could detect enemies from a long range at either high or low altitude, and, if necessary, could destroy enemies at minimum risk. Early F-15 models carried four AIM-7 Sparrow and four AIM-9 Sidewinder missiles as well as a 20-millimeter cannon. Later versions were equipped with up to eight AIM-120A advanced-medium-range air-to-air missiles (AMRAAMs) in place of the Sparrows.

In response to an increasing threat from the Soviet Union, the U.S. Air Force decided to improve upon the F-15's capabilities and field the F-15C and F-15D training models in 1979. These new Eagles carried more internal fuel, as well as exterior conformal fuel tanks, for a greater range of more than 3,400 miles without refueling. An increased maximum takeoff weight of 68,000 pounds allowed F-15 pilots to carry more weapons than ever before.

The seemingly elastic ability of the F-15 to adopt more capabilities led the Air Force to stretch the design even further when, in 1982, it fielded the two-seat F-15E dual-role fighter. Designed for air-to-air and ground-attack missions, the E model featured a larger HUD, a more powerful central computer, a forward-looking infrared (FLIR) camera, and Maverick missiles for use against ground targets at long range. It boasted the Hughes APG-70 radar for use in either ground-attack or air-superiority mode, and automatic terrain-following avionics and could perform long-range missions at night or in bad weather.

These improvements were showcased in 1990 and 1991, when the Air Force deployed F-15C, F-15D, and F-15E models to Saudi Arabia during Operations Desert Shield and Desert Storm. In combat against Iraq, Eagle pilots destroyed thirty-six enemy aircraft in air-to-air engagements without losing a single plane, and F-15E models were used in night attacks on Scud missile sites and against artillery positions with great effect. Since 1991, F-15's have patrolled the no-fly zone over northern and southern Iraq, escorted cargo planes during Operation Provide Comfort

F-15 Eagle and F-15E Strike Eagle Characteristics

	F-15C/D Eagle	*F-15E Strike Eagle*
Primary Function	Tactical fighter	Air-to-ground attack aircraft
Builder	McDonnell Douglas Corporation	McDonnell Douglas Corporation
Unit Cost	$34.3 million	$31.1 million
Power Plant	Two Pratt & Whitney F100-PW-220 or 229 turbofan engines with afterburners	Two Pratt & Whitney F100-PW-220 or 229 turbofan engines with afterburners
Thrust per engine (pounds)	23,450	25,000-29,000
Length (feet)	63.8	63.8
Height (feet)	18.5	18.5
Maximum Takeoff Weight (pounds)	68,000	81,000
Wingspan (feet)	42.8	42.8
Ceiling (feet)	65,000	50,000 (service), 35,000 (combat)
Speed	1,875 miles per hour (Mach 2.5 plus)	1,875 miles per hour (Mach 2.5 plus)
Crew	F-15C, 1; F-15D, 2	2
Armament	One internally mounted M61A1 20-millimeter six-barrel cannon with 940 rounds of ammunition; four each AIM-9L/M Sidewinder and AIM-7F/M Sparrow air-to-air missiles, or eight AIM-120 AMRAAMs, carried externally	One 20-millimeter multibarrel gun mounted internally with 500 rounds of ammunition, four each AIM-9L/M Sidewinder and AIM-7F/M Sparrow air-to-air missiles, or eight AIM-120 AMRAAMs, any air-to-surface nuclear or conventional weapon in the U.S. Air Force inventory
Inventory	Active force, 396; Reserve, 0; ANG, 126	Active force, 217; Reserve, 0; ANG, 0
Date Deployed	July, 1972	April, 1988

Source: Data taken from (www.af.mil/news/factsheets/F_15_Eagle.html) and (www.af.mil/news/factsheets/F_15E_Strike_Eagle.html), June 6, 2001.

in Turkey, flown combat missions in support of NATO operations in Bosnia and Kosovo, and performed many other assignments around the world.

F-15's form an important part of the air forces of several countries allied to the United States, including Japan (which uses specially designed F-15DJ and F-15J models), Saudi Arabia, and Israel. They have been flown with distinction in Israeli combat operations against both Syria and Iraq, and will remain an integral component of fighter squadrons around the world until at least the mid-twenty-first century. By then, the 396 Eagles in active service with the U.S. Air Force will have been transferred to Reserve or Air National Guard squadrons, having been replaced by the F-22 Raptor. Raptor pilots will count themselves fortunate if they find themselves in aircraft that prove to be as dominant over the next thirty years as the F-15 has been since 1972.

Lance Janda

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See also: Air Force, U.S.; Fighter pilots; Gulf War; Instrumentation; Military flight; Raptor; Vietnam War

Amelia Earhart

Date: Born on July 24, 1897, in Atchison, Kansas; died on July 2, 1937, near Howland Island in the Pacific Ocean

Definition: The most famous female aviator in the United States, known for her record-setting nonstop flights in the 1920's and 1930's.

Significance: Earhart demonstrated that a woman could withstand the rigors of long-distance solo flights just as well as a man. As the first woman to fly across the Atlantic Ocean, she gave popular lectures on her aviation adventures. While attempting to fly around the world in 1937, she and her navigator, Fred Noonan, disappeared; their bodies were never found.

Early Life

Amelia Mary Earhart and her sister Muriel never stayed long in one place as they grew up, because their father continually moved around the United States to find work. The girls spent some time living with their grandparents. Nevertheless, they had a good education and grew up to love books and music. While living in Toronto, Earhart befriended a Royal Flying Corps officer who took her to see his planes and airfield. This experience sparked her lifelong love of aviation.

In Los Angeles, Earhart began to take flying lessons and bought her first plane, financed partly by her parents and partly by money she had earned driving a truck. After returning to the Boston area in 1925, she went to work teaching English, first at the University of Massachusetts and later at Denison House, a social settlement. She continued her hobby of flying and became known among the local aviators.

Setting Records

In April, 1928, Earhart was selected by the publisher George Palmer Putnam to be a passenger on a flight that would make her the first woman to cross the Atlantic by air. The flight was sponsored by Amy Phipps Guest, an American flying enthusiast living in London who had bought the explorer Admiral Richard Byrd's Fokker Trimotor plane the *Friendship*. Unable to make the trip herself, Guest had asked Putnam to find a young woman to represent her in the promotion of women in aviation. Putnam saw qualities in Earhart that he hoped would make her an appealing icon of American womanhood.

Amelia Earhart was famous for her record-setting nonstop flights throughout the 1920's and 1930's. (Library of Congress)

Delayed by bad weather for several days, the *Friendship*'s transatlantic flight began on June 17, 1928, at Trepassy Bay, Newfoundland, when pilot Wilmer Stutz lifted off with Earhart and navigator Lou Gordon. Hampered by fog and a dead radio, they flew for twenty hours and forty minutes before landing their pontoon plane on a river near Burry Port, Wales.

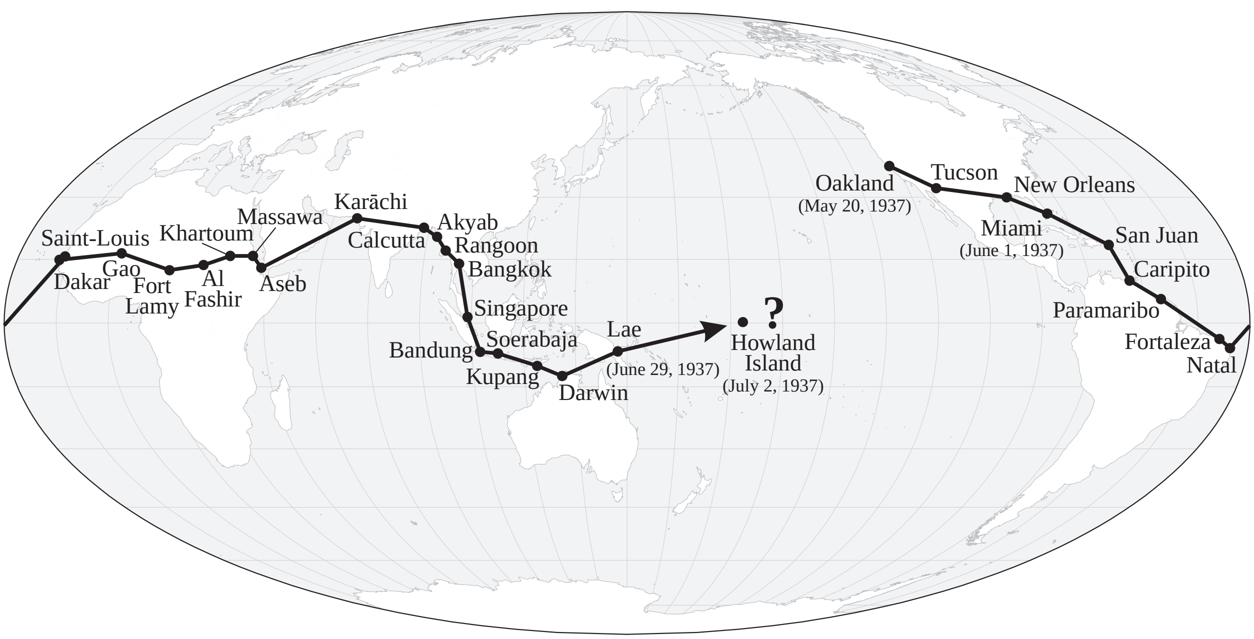
Earhart became an overnight celebrity, even though she had not done the actual flying. She attracted crowds of admirers in Southampton and London and was the guest of honor at parties, where she spoke with Winston Churchill and danced with Edward, prince of Wales. After sailing back to the United States on an ocean liner, she found more fame and opportunity. She received product endorsement offers and writing assignments for *McCall's* and *Cosmopolitan*. Putnam immediately organized a lecture tour for her and rushed her account of the flight, *Twenty Hours Forty Minutes* (1928), into print.

In 1932, Earhart, now married to Putnam, made a solo flight from Harbor Grace, Newfoundland, to Culmore, Ireland, landing in a pasture on May 22 after fourteen hours and forty-five minutes in the air. As the first woman to make a solo flight across the Atlantic, she was showered with honors such as the Distinguished Flying Cross from the Congress of the United States, an award from the French Legion of Honor, and a medal from the National Geographic Society. Although Earhart made other solo flights from Hawaii to California, from Los Angeles to Mexico City, and from Mexico City to Newark, New Jersey, and also set various speed records, none of these achievements attracted as much attention as her 1932 flight. She remained active on the lecture circuit but yearned for one more spectacular flight. In 1935, the trustees of Purdue University purchased a twin-engine Lockheed Electra for her, and she began planning an around-the-world flight.

The Last Flight

After much fund-raising and organizational effort, the flight began on June 1, 1937, when Earhart and her navigator, Fred Noonan, left Miami and headed south, where they would follow the equator eastward to Africa and Asia. A month of flying brought them to Lae, New Guinea, on June 29. Departing on July 1 for tiny Howland Island, in the middle of the Pacific. Despite assistance from the U.S. Coast Guard cutter *Itasca*, Earhart became lost in the clouds and was unable to make sufficient use of radio signals to find her way. She was last heard from at 8:45 A.M., July 2, 1937, when she radioed that she was lost and running low on fuel. An extensive search mounted

Amelia Earhart's Final Flight, 1937



by the U.S. Navy failed to find any trace of her plane or its occupants.

Earhart's fate became one of the century's greatest mysteries, resulting in many unusual claims and theories, mostly unsubstantiated by physical evidence. The most compelling of these is that she turned back from Howland Island, crashed in the Marshall Islands, then under unfriendly Japanese control, and perished of her injuries, either immediately or after languishing in a Japanese prison.

John R. Phillips

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See also: Ninety-nines; Record flights; Transatlantic flight; Transglobal flight; Women and flight

EgyptAir

Also known as: Air Egypt

Definition: The national airline and flag carrier of Egypt, as well as its largest airline.

Significance: EgyptAir is one of the oldest and largest airlines of the Middle East, running comprehensive domestic air service and international services throughout the region, as well as to Europe, North America, Africa, Australia, and the Far East.

History and Fleet

EgyptAir is a major airline, established in 1932 and headquartered in Cairo, Egypt. EgyptAir has owned and operated many different kinds of civil aircraft and was the first airline in the Middle East to operate jetliners. Beginning in 1980, EgyptAir embarked on a modernization and growth plan, developing it from an airline using only seven Boeing 707's and seven 737's to a large, market-oriented, self-financing airline. EgyptAir is a fully state-owned company but is duly vested with its own legislation as a deregulated autonomous organization.

Starting in the 1980's, Egypt Air carried out several dedicated marketing surveys of international and local markets to evaluate its total domestic and international traffic volume. Accordingly, EgyptAir planned its network to maximize its traffic and scope, reaching main cities in all five continents. To carry out its marketing plan, EgyptAir purchased a mix of modern aircraft and then developed an autonomous infrastructure to support and serve its fleet in order to operate in a safe and efficient manner.

As a result of its market research, EgyptAir was reinvented in a stepped-pyramid form. The base of the pyramid was EgyptAir's most profitable markets. In September, 1980, EgyptAir purchased eight Airbus A300-B4 wide-body, medium-range aircraft to cover international markets in Europe and the Middle East, at a total cost of $382.8 million. This became the basis of EgyptAir's process of gradual development. The economic operation of these aircraft enabled EgyptAir to fulfill its financial obligations to the European banks that had financed the purchase of the aircraft. This was a significant step toward establishing the airline's financial credibility, which can be very challenging for an airline from an underdeveloped region of the world such as Egypt.

To cover the domestic market, especially in Sinai, EgyptAir purchased three Dutch Fokker F-27 aircraft. In order to develop long-haul markets, EgyptAir purchased three Boeing 767-200 ER's. To increase its capabilities to serve its long-haul markets and to cope with the needs of the fast-growing passenger and cargo markets, EgyptAir purchased two Boeing 747-300 combis (mixed passenger and cargo planes) followed by two 767-300 ER aircraft. Following that, EgyptAir sought to renew its medium-range, wide-body fleet and purchased nine Airbus A300-600's. At the same time, EgyptAir replaced its medium-range, medium-capacity aircraft with seven Airbus A320-200's, making the airline one of the world's first operators of this high-technology, fly-by-wire (completely computer-controlled) aircraft. In order to link its local tourist market directly with international

The EgyptAir Fleet

Type of Aircraft	Number of Aircraft	Seats (Three-Class Congfiguration)	Delivery Date
Boeing 747-300	2	450	1988
Boeing 777-200	3	319	1997
Boeing 767-300	2	217	1989
Boeing 737-500	5	104	1991-1992
Boeing 737-200	2	130	Scheduled for replacement
Boeing 737-300	1	121	in 2002 by 3 Airbus 318's
Airbus 340-200	3	260	1996-1997
Airbus 300-600	7	253	1990-1991
Airbus 320-200	7	144	1991-1993
Airbus 321-200	4	185	1997

Total Available Seats: 7,997 seats

Source: Data taken from (www.egyptair.com.eg/docs/inside/fleet.htm), June 5, 2001.

destinations, EgyptAir purchased five Boeing 737-500's to replace its aging 737-200's, which had served the airline for more than twenty years. To fulfill the needs of its markets in Japan and North America, EgyptAir purchased three Airbus A340-200's and three Boeing 777-200 ultra-long-range aircraft for nonstop flights. EgyptAir was one of the first operators in the region using these two types of aircraft. It then purchased four Airbus A321-200's to serve charter operations in the development of tourism. EgyptAir financed a contract to purchase three Airbus A318-200's to be delivered early 2002. The process of fleet renewal resulted in a young fleet whose average age is similar to that of most major international airlines.

Corporate Infrastructure and Plans

EgyptAir has invested heavily in constructing an engineering complex to be outfitted with the most modern technical support for its fleet. Its in-flight services complex has a production capacity of twenty-five thousand meals per day. EgyptAir has also established a ground services complex to carry out its loading and off-loading services, as well as the transportation of crew members and employees. It has also established an in-house computer center to control all EgyptAir activities, linking with international reservations systems such as Galileo, Amadeus, SABRE, and World Span.

EgyptAir embarked on a plan of renewing and modernizing its sales offices in Egypt and internationally, as well as modernizing its training center to provide EgyptAir with highly qualified crew members, technicians, and personnel in all other business-related fields. EgyptAir's corporate headquarters were designed, constructed, and equipped with the latest technology and can accommodate 4,500 staff. Finally, as part of its comprehensive modernization plan, EgyptAir established duty-free shops at all Egyptian international airports.

Integrating its activities in the model used by most major world carriers, EgyptAir owns shares in many tourism companies and hotel chains, such as Cairo Airport Mövenpick, Tut Amon, and Nefertari in Aswan and Abu Simbel, and Taba Hilton resorts in Sinai. EgyptAir also owns shares in many charter companies, such as Shorouk Air and Air Cairo. Such investments have increased EgyptAir's assets tenfold since the implementation of the airline's modernization and expansion plan in 1980. EgyptAir's network has also expanded to reach major cities and capitals in all five continents.

The Crash of Flight 990

On the whole, EgyptAir's safety record is good, with a few exceptions. Its most notorious accident was the crash of EgyptAir Flight 990 on October 31, 1999. The New York-to-Cairo flight crashed into the ocean between Long Island, New York, and Martha's Vineyard, Massachusetts, with the loss of all 217 people aboard. The official investigation concluded that the copilot had committed suicide by deliberately diving the plane into the water, although EgyptAir vehemently denied that the copilot had ever shown any signs of mental instability. The presence of a number of Egyptian military officers on the flight suggested the possibility of a terrorist attack. The incident was the focus of much conspiratorial theorizing due to the fact that it occurred in the same general area as the July 19, 1996, crash of TWA Flight 800 and the July 16, 1999, crash of John F. Kennedy, Jr.'s Piper Saratoga.

Triantafyllos G. Flouris

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See also: Air carriers; Airports; Accident investigation

El Al

Also known as: El Al Israel Airlines

Definition: The national airline and flagship air carrier of Israel and a major international carrier.

Significance: Since its establishment in 1949 as the national airline of Israel, El Al has grown into an international carrier with a reputation for safety and customer service. The International Air Transport Association (IATA) has ranked El Al on several occasions as one of the world's most efficient carriers.

History

El Al Israel Airlines, in Hebrew *El Al Netive Awir Leyisra'el*, is the Israel national airline and flagship carrier. It was founded in November, 1948, by the government of Israel, shortly after the establishment of the new state. El Al is headquartered in Tel Aviv, which is also the airline's hub. It was El Al's inaugural flight that brought the country's first president, Chaim Weizman, to Israel from Geneva, Switzerland. El Al flew its first commercial scheduled flights to Rome and Paris in July, 1949. By the 1980's, the airline was flying routes from Tel Aviv to many of the major cities of Europe, as well as to Asia, Africa, and North and South America.

In 1981 and 1982, the Israeli government considered liquidation of the airline due to financial difficulties exacerbated by a government ban on Sabbath flights, but ultimately decided against it. The airline has had a history of setting aviation records: In June, 1961, El Al set a new world record for longest nonstop commercial flight on its first nonstop flight from New York to Tel Aviv using a Boeing 707, covering 5,760 statute miles in 9 hours and 33 minutes. In May, 1988, El Al set yet a new first, operating its longest nonstop flight in history: from Los Angeles to Tel Aviv, a 7,000 statute mile trip, covered in thirteen hours and forty-one minutes. On May 24, 1991, an El Al Boeing 747 airlifted a record-breaking 1,087 passengers, Ethio-

The El Al Fleet

Type of Craft	*Total in Service*	*Range (miles)*	*Engines*	*Cruising Speed (miles per hour)*	*Length*	*Wingspan*
Boeing 737-700	2	2,500	C.F.M.	524	110 feet	112 feet
Boeing 747-400	4	6,400	4 Pratt & Whitney	575	231 feet, 11 inches	213 feet
Boeing 747-200	6	4,500	4 Pratt & Whitney	570	231 feet, 11 inches	195 feet, 9 inches
Boeing 767	6	5,400	2 Pratt & Whitney	542	159 feet, 2 inches	156 feet
Boeing 737-800	3	2,500	C.F.M.	542	129 feet, 3 inches	112 feet
Boeing 757	7	3,300	2 Rolls Royce	542	155 feet, 3 inches	124 feet, 10 inches

Source: Data taken from (www.elal.com/glance/fleet/index.htm), June 5, 2001.

pian Jews flying from Addis Ababa to Israel as part of Operation Solomon.

El Al operates a fleet of Boeing 747's, Boeing 767's, Boeing 757's, and Airbus A320's. In 2001, El Al introduced three new, technologically advanced, long-range Boeing 777-200ER models into its fleet. The new aircraft, powered by twin Rolls Royce Trent 895 engines capable of developing 95,000 pounds of thrust, can fly 5,561 miles nonstop with a full payload of passengers and cargo. Among the new features and amenities these aircraft offer to El Al passengers (6 in first-class, 47 in business, and 245 in tourist class) are the most comfortable seats available and fully digital electronic entertainment, with provisions for personal computers and interactive features. Their acquisition was part of the company's overall strategy to expand service to business-class customers, toward which goal El-Al also invested $15 million in upgrading its other long-range airliners to match the standards of the 777.

Organization

El Al has described itself as "a unique combination of amenities and advantages earning international appeal and making El Al a preferred global gateway to every corner of the world." Teshet, a subsidiary company wholly owned by El Al, operates travel agencies, catering facilities, and hotels in Israel, as well as airports in the United States. Teshet operates two kosher catering companies: Tamam, based in Israel, and Borenstein in New York. Teshet holds interests in Maman, handles cargo at Ben Gurion International Airport in Tel Aviv, manages the Laromme Hotel Chain, and is the Israel representative of the Howard Johnson Hotel Group, Alamo Rent-A-Car, Air Nevada, British Midland, and international technical aviation companies such as Pratt & Whitney and United Technologies. Another subsidiary, Arkia Inland Airlines, founded in 1950 and owned 50 percent by El Al, provides scheduled domestic air services within Israel and serves as El Al's feeder carrier. El Al is the sole owner of yet another subsidiary airline, Sun D'or International Airlines. Sun D'or, operating charter flights between Israel and Europe, helps develop new routes and tourist markets for El Al.

Triantafyllos G. Flouris

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See also: Air carriers; Airports

Emergency procedures

Definition: Established steps in memorized, paper, or electronic format used in critical situations to aid the memory of those involved in a crisis.

Significance: Emergency situations place human beings under greater than normal amounts of stress, making them less able to solve problems appropriately. Clearly understood procedures enable people to act appropriately under such circumstances.

Introduction and Overview

For as long as there have been aircraft, there have been unexpected events that have necessitated methodical procedures in order to help ensure the safest possible outcome for both aircraft and crew. In aviation, emergencies are defined as situations in which immediate action by those involved is required in order to ensure the safety of a flight. In general, humans are ill equipped to deal consistently and effectively with emergencies.

A detailed set of guidelines or procedures for people to follow in the event of an emergency often helps to positively impact the emergency situation. These procedures have evolved from the relatively simple memorized procedures used by pilots of early aircraft to the relatively complex procedures used by a flight crew to deal with anomalies aboard large aircraft, such as the Boeing 777 and 747 heavy-transport aircraft.

Emergency procedures range from small-aircraft checklists for dealing the accidental opening of a cabin door during flight to large commercial airports' detailed emergency plans for dealing with an incoming aircraft that has been rendered virtually uncontrollable. In the first case, the procedure may involve only the pilot of the aircraft, whereas, in the second scenario, emergency procedures would typically involve many people in several different organizations all engaging in a highly coordinated and rehearsed plan of action in order to effectively deal with the situation.

Procedures in the Aircraft

In the case of a small aircraft, it is recommended that pilots carry a set of emergency procedures checklists readily available to them in the event of an emergency. These checklists may be in paper or electronic format. Emergency procedures cover a variety of topics dealing with engine failures, in-flight fires, electrical failures, flight control malfunctions and others.

Emergency procedures checklists will often be color coded with red and white or red and black in order to command attention. These are then readily distinguishable from other procedures checklists. Often, certain emergency procedures are considered to be time-critical in order to effect a safe outcome. Such procedures, generally limited to three to five items, are called immediate-action items and are usually committed to memory. An instance in which such a procedure would be necessary is the failure of one engine of a twin- or single-engine aircraft immediately after takeoff. An event such as this leaves little time for a pilot to pull out a checklist and go over it line by line. Once the immediate-action items are attended to, the pilot can then methodically go through the remaining items.

Generally, the more complex the aircraft is, the more involved are the emergency procedures. In larger transport aircraft, more than one pilot is available to assist during crisis situations, and the delegation of responsibility at such times rests upon the pilot in command. In an emergency situation involving a multicrew aircraft, generally one pilot continues to fly and maintain control of the aircraft while the other pilot (or two) are freed up to focus on the emergency procedures.

Electronic Aids

In modern aircraft with electronic flight instrumentation there are often systems on board the aircraft that will assist the flight crew in diagnosing a problem and will provide the appropriate checklist on what is called a multifunction display (MFD) on the flight deck. This display highlights the appropriate checklist items and forces the crew to acknowledge each checklist item before proceeding to the next item. The MFD is a helpful feature during periods of high stress on the flight deck, because it makes it more difficult to forget or omit critical items, as can happen with paper checklists.

Larger aircraft, such as the Boeing 757 and 767, are equipped with an engine information and crew alerting system (EICAS), which immediately brings a fault diagnosis to the attention of the flight crew. The crew must then execute the pertinent emergency checklist in its entirety in a challenge-response format, in which the pilot who is not flying issues a challenge such as “throttle closed,” to which the appropriate crew member response is “throttle closed.” In this manner, each crew member is made aware of the checklist item and its completion status.

Cabin Safety

Emergency procedures also exist for the cabin crew, or flight attendants, and for passengers. All passengers are required by the Federal Aviation Regulations (FARs) to be briefed on these procedures by the cabin crew prior to flight. Research has shown that those passengers who listen to the preflight emergency briefing information are much more likely to survive an air accident than those who do not.

Airline cabin crew members are required to attend annual recurrent emergency procedures training. This training consists of a review of basic emergency and evacuation procedures for the particular aircraft the crew members fly. Most major airlines have or have access to aircraft cabin simulators, which can simulate an aircraft accident. In these scenarios, the cabin fills with a harmless smoke agent and the lights go down, as they would in an accident. The crew members are then evaluated on the accuracy and timeliness of their actions in getting people to safety.

Survival

In order to survive an air accident, the crew and passengers must be able to do three things successfully. First, they must survive the impact of the crash, if applicable. Second, they must evacuate the aircraft safely in a timely manner, especially in the event of a fire. Third, if the accident occurs away from an airport, they must survive the post-accident environmental conditions until they are rescued or until safety is reached. The first two items are often largely dependent upon how much attention was paid to the preflight safety briefing, whereas the third item depends upon previous training. Many organizations around the country specialize in postcrash survival training. A survival course varies from one day to one week or more and will cover a variety of subjects, including land navigation, rescue-signaling techniques, shelter construction, and food- and water-gathering techniques. Flights over remote areas are likely to carry emergency survival kits on board, which contain a variety of survival gear including signaling devices, drinking water, high-energy food, and first aid kits. Flights over water are required to carry flotation devices and life rafts, and training in their proper use is imperative. Most life rafts have an on-board emergency radio-locator transmitter and a visual strobe light to aid in aerial location, as well as sun shelters, sunscreen, water, and other survival gear.

Airport Emergencies

The majority of aircraft accidents happen on the premises of an airport. If an aircraft accident occurs on or in the immediate vicinity of an airport, the occupants have a much greater chance of surviving the post-incident conditions, because all publicly certified airports have emergency action plans. There are approximately 5,400 public-use airports in the United States. Of these, approximately 670 are certified under Part 139 of Title 14 of the Code of Federal Regulations as certificated airports. The remaining airports, classified as non-certificated or general aviation airports, handle a relatively low volume of mostly light aircraft. If an airport has scheduled passenger or cargo airline service, it is required to be a certificated airport.

Certificated airports are rated according to classes A, B, C, D, or E, in accordance with the types of aircraft they serve. These classes, among other things, determine the amount and type of airport firefighting and rescue services (ARFF) the airports have. In the event of an aircraft accident, the emergency operations plan for the airport will go into effect. This plan is contained in, and is a preapproved part of, an airport's certification manual. The plan is generally put into effect by an airport's control tower, which will immediately notify the ARFF unit in the event of an accident. Other calls will be made in accordance with the emergency plan to such outside agencies as local law enforcement, ambulance services, hospitals, and coordinating fire and rescue departments in order to put them either on alert or into action, in accordance with the preapproved plan.

Every three years, certificated airports are required to conduct a live-fire training exercise under simulated accident conditions. In this exercise, the emergency action plan is put into effect, and all agencies react just as they would in an actual emergency. In this rehearsal, usually an aircraft is towed into a simulated crash position on the airport and costumed victims are situated in and around the aircraft, as they might be in an accident. Simulated crash victims are then extracted and treated, and fires are extinguished, allowing everyone involved a chance to identify areas of needed improvement in the plan. Each year, these same airports are required to go through the motions of the emergency plan in a "table-top" scenario, in which phone numbers are verified, calls are made according to the plan, and treating-unit capabilities are updated to ensure the currency of the plan.

Emergency Procedures in Action

On July 19, 1989, a series of events occurred in which well-rehearsed emergency procedures helped save many lives in an aviation event that might have been considered unsurvivable. On that day, United Air Lines Flight 232, a DC-10 wide-body transport aircraft, was flying passengers from Denver to Chicago when the airplane's center engine disintegrated, causing the aircraft to lose all available hydraulic fluid. Because the flight controls on this type of aircraft are hydraulically operated, the aircraft was rendered virtually uncontrollable. Because the crew members had been trained in cockpit leadership resources (CLR), which taught them to utilize all available resources in order to save an aircraft under adverse circumstances, they were able to regain some control of the aircraft using differential thrust from the two remaining engines on each wing, even though there was no specific procedure for such an occurrence. This solution was made possible with the help of a passenger who happened to be a DC-10 pilot for United Air Lines. The cabin crew alerted the flight crew of this passenger's availability, an event which might not have occurred had the crew not been trained in CLR. The aircraft subsequently crashed under limited control, broke apart, and then erupted in flames at the Sioux City, Iowa, airport. More than one-half of the occupants survived the ordeal, due, in large part, to the extraordinary efforts of the crew and to the fact that, very recently prior to the accident, the Sioux City airport had conducted its emergency action live-fire drill. This practice drill had enabled a much faster accident reaction time for rescuers.

A common theme throughout all aviation emergency procedures, whether they are on board an aircraft in flight or on the ground at an airport, is the importance of having structured, well-rehearsed and well-coordinated plans of action to follow. With these in place, human beings are much better able to perform under adverse circumstances, ensuring the minimum loss of life and damage to property.

R. Kurt Barnhart

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See also: Accident investigation; Air carriers; Airline industry, U.S.; Airport security; Flight attendants; Hijacking; Landing procedures; Maintenance; Runway collisions; Safety issues; Takeoff procedures; Taxiing procedures; Training and education

Enola Gay

Definition: The B-29 bomber that dropped the first atomic bomb to be used against a civilian population, on the Japanese city of Hiroshima.

Significance: The *Enola Gay* dropped the first of the two atomic bombs ever used in combat, on the Japanese city of Hiroshima, effectively ending World War II.

The B-29 Superfortress

Lieutenant Colonel Paul Warfield Tibbets, Jr., was twenty-nine years old when he first heard of the atomic bomb. At the time, he was one of the U.S. Air Force's best bomber pilots, having flown twenty-five B-17 missions, including the first raid against occupied Europe and the first mission in support of the North African invasion. As a test pilot, he helped bring the B-29 Superfortress into service. In September, 1944, he was briefed on the Manhattan Project, the code name of the project to build the atomic bomb. He was given the assignment to organize, equip, and train a unit to drop atomic bombs on Germany and Japan. Tibbets was told that if the bombs worked well, they might end the war.

The B-29 Superfortress was the first intercontinental bomber. Powered by four 2,200-horsepower engines, it stood three stories tall. With a 141-foot wingspan and a 99-foot fuselage, it filled half of a football field. It was armed with up to twelve 0.50-inch machine guns mounted in four turrets and the tail, and a 20-millimeter cannon mounted in the tail. To save weight, Tibbets requisitioned fifteen B-29's without protective armor, turrets, or guns, except for the 20-millimeter tail cannon. The B-29 had a pressurized cabin and could cruise above 30,000 feet, beyond the reach of antiaircraft fire and most enemy fighters.

Tibbets took command of the 393d B-29 bombardment squadron at the Wendover Army Air Base on the Utah-Nevada border. He had the squadron pilots train to drop a single large bomb from 30,000 feet and to perform a strange evasive maneuver in which they turned the planes 150 degrees while diving to gain speed. The squadron was told its mission would have an important effect on the war, but were given no other details. On December 17, 1944, orders were issued activating the 509th Composite Group, which eventually included more than 1,500 enlisted men and 200 officers. In the spring of 1945, the group began to move quietly to Tinian Island in the Marianas Islands.

The Hiroshima Bombing

On August 5, 1945, President Harry S. Truman gave his approval to use the atomic bomb on Japan. The bomber crews were briefed by William S. "Deke" Parsons of the Los Alamos National Laboratories. Honoring his mother, who had encouraged him to join the Air Force, Tibbets had the name *Enola Gay* painted on the nose of his selected B-29. With Tibbets as commander and pilot, the *Enola Gay* took off from Tinian at 2:30 A.M. on August 6, en route to Hiroshima. At first Tibbets flew at less than 5,000 feet, so that Parsons and his assistant could enter the unpressurized and unheated bomb bay to insert the cordite explosive that would propel the uranium-235 slug into awaiting rings of uranium-235 to form a supercritical mass. At 7:30 A.M. Parsons returned to the bomb bay and armed "Little Boy," the nickname for the 9,700-pound bomb.

During the 45-minute climb to the 31,000-foot bombing altitude, the weather plane flying ahead of the *Enola Gay* reported favorable conditions over Hiroshima. The plane was flying at a speed of 328 miles per hour as the bombardier, Major Thomas W. Ferebee, took control of the plane for the bombing run. Finding his aiming point, he let Little Boy fall away from the *Enola Gay*. Tibbets threw the bomber into its 150-degree escape maneuver, so that they were 11.5 miles away 43 seconds later, when Little Boy exploded 1,900 feet above the ground. After a blinding flash of light, Hiroshima was hidden beneath a huge, boiling cloud, that was simultaneously incredible and terrible. The bomb's estimated yield was 12,500 tons of TNT, a common high explosive. Captain Theodore J. Van Kirk, the *Enola Gay*'s navigator, later admitted to thinking as he watched the destruction, "Thank God the war is over and I don't have to get shot at any more. I can go home." The *Enola Gay* then returned to Tinian and landed at 2:58 P.M.

The Smithsonian Exhibition

As part of a fifty-year commemoration, the forward section of the *Enola Gay*'s fuselage was placed on display in the National Air and Space Museum of the Smithsonian Institution from June, 1995, to May, 1998. Initial plans for the display produced a hurricane of controversy. Objecting to a bare display of military hardware as a glorification of war, museum directors sought a larger context for the *Enola Gay* exhibit. One suggested theme was the dark side of air power and the inhumanity of nuclear weapons. An early script said that for most Americans, the war against Japan was a war of vengeance, but for most Japanese it was a war to defend their unique culture against the imposition of Western imperialism. Veterans' groups, along with many others, were outraged at what they considered to be a very biased treatment that glossed over the aggression and atrocities of Japanese warfare, focusing instead on the victims of the two atomic bombs. After Congress stepped in and threatened to cut off funds, the exhibit was restricted to the forward section of the *Enola Gay*, a plaque explaining its mission, and a video of the flight crew's training and experiences.

Charles W. Rogers

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Image Not Available

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See also: Air Force, U.S.; Bombers; Kamikaze missions; Military flight; Pearl Harbor, Hawaii, bombing; Superfortress; World War II

Evolution of animal flight

Definition: The process by which certain animals have biologically adapted to engage in three modes of flight: active gliding, passive gliding, and true or powered flight.

Significance: The air has provided a valuable ecological niche for many living things. The advantages conferred by flight are great: escape from predators, migration to suitable climates, and a means to search for food and mates.

Animal Adaptation to Flight

Insect flight evolved in the mid to late Carboniferous period, about 325 million years ago. The flight of certain reptiles, the first vertebrates to fly, dates from the Triassic period, between 230 and 195 million years ago. The first primitive birds evolved during the Jurassic period, 195 to 135 million years ago.

Throughout evolutionary history, flight has been a crucial characteristic of many insects, reptiles, birds, and bats, and more than one-half of the animal species now living can fly. Most of these contemporary species are insects, but about nine thousand species of birds and nine hundred bat species are at home in the air. The largest animal capable of flight was an extinct reptile, *Quetzalcoatlus northropi*, which weighed over 140 pounds (63 kilograms). The smallest flying creature, the chalcid wasp (*Encarsia formosa*), weighs about 0.0001 ounces (0.025 milligrams). Within the range of these extremes, the variety of flying animals is immense.

Flying animals that succeeded in surviving for long periods of time had to solve basic problems. Their survival in a particular ecological niche depended on achieving an optimum size, bone structure, wingspan, and cardiovascular system. Through trial-and-error methods, some flying animals survived and prospered while many others became extinct. Over the long years of animal evolution, animals have chanced upon a wide spectrum of solutions to the problems of flight. Some fliers developed long wings, others stubby ones. Some flapped their wings vigorously, others used gliding and soaring techniques. Gliding utilizes gravity by either launching toward a target (directed or active gliding) or relying on wind for motion (passive gliding or parachuting). Soaring is sustained gliding, taking advantage of rising columns of air. True or powered flight consists of using muscles to take off, fly, and land. The details of the evolution of animal flight are poorly understood, because most flying animals left no trace in the fossil record. How did primitive insects, reptiles, and birds solve the problems of flight? Did flying vertebrates evolve from running, jumping, or perching animals? Did early fliers have rigid or flexible wings? Some of these questions have been answered, others have been only partially answered, but many others remain to be satisfactorily answered.

Devices Developed for Flight

To enhance their ability to spend a significant part of their lives in the air, flying animals developed some devices that were similar to those now used by humans in constructing aircraft, but others were unlike the mechanisms found in flying machines. For example, the Wright brothers were helped in devising a wing-warping mechanism to control their *Flyer* by observing the flight of birds. When a jetliner is landing, the pilot lowers the landing gear and wing flaps to reduce speed in preparation for touchdown, just as birds extend their legs and lower their tails to increase drag when they are landing. On the other hand, aircraft designers have been unable to successfully copy the complex structures of feathers and the intricate ways that birds twist and flap their feathered wings.

Animal flight involves lift, thrust, and control, and such animals as insects, reptiles, birds, and bats have used a variety of methods in achieving flight, some of which are specific to a species, while others are shared across classes. For example, the largest insects have wings similar to those of the smallest hummingbirds, but animals such as flying squirrels lack the ability to flap their "wings" and so are confined to gliding. Scientists have studied the theoretical limits for such variables as size, wingspan, bone mass, and muscular strength in trying to understand flying animals.

Theories of the Evolution of Animal Flight

To explain how animals developed the devices that allowed them to fly, scientists have proposed various theories. Two classical models, dating from the nineteenth century, are the arboreal and cursorial theories. These theories try to explain how limbs developed into wings, how bones became lightened, and how feathers evolved from scales. Some scientists speculate that elemental wings first sprouted as lengthwise ridges along the sides of vertebrates. These ridges were constructed from available materials such as fur, skin, or scales. According to the arboreal theory, these protowings adapted the animals for life in the trees, especially for leaping from limb to limb. Selective pressures from predators subsequently changed these winglets into wings. The cursorial theory, whose name derives from the Latin *cursor,* "a runner," explains the origin of flight differently. To evade enemies, bipedal vertebrates habitually combined running jumps with short glides. Their increasingly winglike forelimbs helped them to generate the lift and thrust to spend time in the air instead of in the jaws of predators.

Both these theories have been criticized, but because of the deficiency of relevant fossils, it has been impossible to eliminate either one. Even when relevant fossils exist, they fail to resolve all problems. For example, *Archaeopteryx lithographica*, a fossil that had a reptilian skeleton and feathered wings, created a sensation when it was discovered in Germany just two years after Charles Darwin had published *On the Origin of Species by Means of Natural Selection* (1859).

This 150-million-year-old protobird was acclaimed as the "missing link" between reptiles and birds. As more *Archaeopteryx* fossils were found, a debate ensued over whether it was a birdlike reptile or a reptilelike bird. It resembled birds because it had feathers and a wishbone, but it resembled dinosaurian reptiles because it had teeth in its jaws, three clawed fingers on its wings, and a lizardlike tail. Some argued that *Archaeopteryx* was cold-blooded and flightless; others that it was warm-blooded and a flier.

Theories of the origin of animal flight have encountered what evolutionist Stephen Jay Gould has called the "5-percent-of-a-wing problem." Aerodynamic analysis revealed that flying animals needed to have wings that were long, light, flexible, and strong, but critics of Darwin's theory pointed out that protowings, which were short, dense, rigid, and weak, would have been a hindrance rather than a help. However, Darwinists responded that this all-or-nothing argument that wings are worthless until well developed ignores the possibility that winglets could confer such benefits as aiding animals in escaping from their enemies. Furthermore, rudimentary feathers could have served as heat insulators. Some scientists have called these winglets and protofeathers "preadaptations," and some writers have called these primordial creatures "hopeful monsters."

The Evolution of Insect Flight

Flying creatures developed independently several times during the course of evolution, but the fossil record reveals that the first to fly were insects. Because of their small size, insects need little energy to launch themselves into the air, but due to an inadequate fossil record, scientists have been unable to develop incontestable interpretations of the evolution of insect flight. Fossils of flying insects in amber have not yet been discovered from the Paleozoic era (600 to 230 million years ago), and the sparse evidence scientists possess of the number, variety, structures, and ecological niches of flying insects provides only meager clues for constructing explanations of how insect flight originated. Paleontological evidence does exist for giant dragonflies (*Protodonata*) during the Carboniferous and Permian periods (between 300 and 225 million years ago). Some scientists think that these insects were aerial predators. *Meganeura*, the largest known flying insect, dates from this period, and it had a wingspan of 2.4 feet (73 centimeters) and weighed just under 8 ounces (200 grams). Evolution certainly played a role in the creation of these giant insects, and the mechanism may have been an escalating competition between predator and prey.

Some paleontologists have used later fossils and aerodynamic studies of contemporary insects to theorize about early flying-insect evolution. Many scientists believe that insect wings evolved only once and that all fliers derive from a wingless ancestor, but how these wings evolved has been passionately debated. Some scientists hold that winged insects originated on land, where jumping due to a startle reflex in response to predatory attacks may have been the selective force that promoted crude flying. Other scientists argue that insect flight began in an aquatic environment, where winglets allowed insects to walk on water since flapping their winglets kept them from breaking through the surface tension of the water.

Explanations of the history of insect flight are complicated by the great structural and functional diversity of insects. Flying insects now range from large butterflies who oscillate their wings about five times per second to tiny midges who beat their wings a thousand times per second. As impressive as contemporary insect diversity is, even more remarkable are the varieties found in Mesozoic fossils (245 to 65 million years ago). Paleontologists have estimated that about twenty-eight insect orders existed prior to the great Permian extinctions that occurred about 245 million years ago. These insects had many kinds of wings, and they differed in their ability to use them. Enhanced maneuverability in the air also facilitated sexual selection. For example, in some species, males hovered, explored, and then engaged in high-speed chases to capture females. In short, flight has been a key element in the survival and proliferation of an increasing variety of insect species.

Pterosaur Flight Evolution

The evolution of flying vertebrates presents paleontologists with different problems from those of flying-insect evolution. For example, adult vertebrates generally lack exoskeletons and weigh much more than insects. Because of these differences, scientists have had to modify their theories of insect evolution to explain how vertebrate fliers such as pterosaurs, birds, and bats evolved. A commonly held theory has pterosaurs (flying reptiles) and birds evolving from thecodonts, the direct ancestors of the dinosaurs. Most thecodonts were small reptiles that walked on their two hind legs, as do many birds.

Flying reptiles have been found fully developed in the Lower Jurassic (195 to 135 million years ago), but they had a much longer history, even though paleontologists have failed to find any intermediate forms between thecodonts and pterosaurs. The most distinctive trait of a flying saurian was its membranous wings buttressed by greatly elongated fourth fingers. Their three other fingers bore claws that may have allowed them to cling to rocks or tree limbs, from which they either hung head down (like bats) or perched head up (like birds). Some paleontologists believe that pterosaurs descended from a small arboreal reptile that spent its life in trees where, like modern flying squirrels, it used flaps of skin attached to its limbs to facilitate its glides and brake its falls. Others believe that pterosaurs evolved from bipedal reptiles that ran along the ground, perhaps spreading their upper limbs for balance. Through gradual growth, these forelimbs evolved into wings.

All these ideas are highly speculative, and most paleontologists agree that the question of pterosaur origins remains open. However, sufficient pterosaur fossils have been found for scientists to conclude that these “dragons of the air” were one of evolution’s early success stories. Unhampered by enemies in the air, pterosaurs diversified into over 120 known species. The sparrow-sized *Pterodactylus elegans,* the smallest pterosaur, had a ten-inch wingspan, whereas the largest, *Quetzalcoatlus*, known from a fossil in the Big Bend region of Texas, had a wingspan of nearly 40 feet (12.2 meters). The small pterosaurs fed chiefly on insects, while the large pteranodons preyed primarily on fish. Though often described as flying reptiles, the pterosaurs were unlike modern reptiles in several respects. They were most likely warm-blooded and had a hairlike surface and highly developed brains. Pterosaurs lived and thrived for 150 million years, but all of them became extinct in a very short period of time 65 million years ago, at the end of the Cretaceous. Just as the origin of pterosaurs is disputed, so too is their extinction. Some paleontologists claim that pterosaurs, with their fragile bodies, had become so specialized that they were unable to adapt to changes in the Cretaceous climate. Others blame a large asteroid that slammed into Earth, making the demise of the pterosaurs part of the calamity that wiped out the dinosaurs. However, critics of the catastrophic theory point out that pterosaur species had been dwindling for millions of years prior to the cataclysm, suggesting that other factors may have contributed to their fate.

From Pterosaurs to Birds

Paleontologists have found no transitional forms between pterosaurs and the first birds, and most believe that birds and pterosaurs evolved separately from thecodonts rather than that birds evolved directly from pterosaurs. All modern theories of bird evolution have been influenced by a crow-sized creature that perished in a shallow lagoon 150 million years ago and whose bones and feather imprints were preserved in lithographic limestone found in 1861. Scientists naturally focused on this *Archaeopteryx lithographica* in their studies on the descent of birds. Strangely, during the nineteenth century, *Archaeopteryx* was not accepted as the missing link between reptiles and birds by most scientists nor by the public. Influenced by religious views of the fixity of species, the public viewed reptiles and birds as unchanging and unchangeable forms. In contrast, scientists had multiple interpretations of *Archaeopteryx*. For Richard Owen, the scientist who coined the name “dinosaur,” *Archaeopteryx* was the earliest bird, which was a transmuted form of a long-tailed pterosaur. On the other hand, Thomas Henry Huxley, traditionally described as “Darwin’s bulldog” because he eloquently defended natural selection, saw this fossil as proof that birds had evolved from dinosaurs.

The first and most influential book on avian evolution, *The Origin of Birds*, was written by a Dane, Gerhard Heilmann, in 1926. He argued for a thecondontian ancestry of birds, and his theory was supported by most textbooks and scholarly works on avian origins for the next fifty years. However, toward the end of the twentieth century, this classic theory came under attack. Some researchers interpreted thecodonts as a heterogeneous assemblage rather than a well-defined group. Others emphasized that birds were descendants of dinosaurs who were warm-blooded land-dwellers, and the first fliers, with their feathered wings, originated “from the ground up.” This cursorial theory of avian flight denied dinosaurs any life in the trees, and thus directly contradicted the arboreal theory championed by Heilmann, who had reconstructed in detail the evolution of birds from tree-dwelling to flying animals.

Besides questions of whether birds evolved "from the ground up" or "from the trees down," problems arose over the origin of feathers, the most beautiful and well-known adaptation in evolutionary history. The central difficulty with the explanation of feathers' evolution from reptilian scales is that a feathered airfoil had to meet stringent aerodynamic criteria to function as a manipulable wing for controlled flight. Some have proposed that feathers arose as netlike devices to catch insects, but nets must be pervious to air whereas airfoils need to be impervious to air. Furthermore, feathers are present in bird tails, where they could scarcely serve fly-catching functions. Other scientists speculate that feathers initially developed for temperature regulation, a preadaptation later used for flight. The difficulty with this thermoregulatory theory is that the microarchitecture of feathers, with their numerous filaments (barbs) and interlocking fringes (barbules), is so well adapted to flight that some scientists proposed that avian feathers evolved directly for flight. However birds originated, they rapidly diversified and colonized a variety of environments. The cataclysm that annihilated the pterosaurs at the end of the Cretaceous created ecological voids that birds increasingly occupied in an extraordinarily explosive evolutionary diversification.

Mammalian Flight

The final flying vertebrate to evolve was the bat. The only mammals to have developed true flight, bats have existed since the start of the Cenozoic era, 65 million years ago. As with pterosaurs and birds, transitional forms of bats have not been found in the fossil record. The wings of the earliest fossilized bat, from about 50 million years ago, were as completely developed as those in modern species. This absence of incipient-winged ancestors has not prevented scientists from speculating about bat evolution. Some paleontologists interpret bat evolution as a succession of small mammals whose fingers gradually lengthened as wings and the specialized muscles necessary to power them developed, but this theory encountered the criticism that these protowings, which restricted normal hand movements, would be disadvantageous. It was argued that a creature would not sacrifice usable hands for half-developed wings. Other paleontologists use bats as an example of quantum evolution, believing that wings and other biomachinery needed to support flight developed in an evolutionary spurt. In this theory, bats arose from arboreal insectivores who developed a membrane that stretched between their fore- and hind-appendages. These protowings were initially used for gliding from tree to tree. Gliding evolved into flying, because wings allowed bats to occupy the niche of flying insect eaters. However, at that time the niche of daylight insect feeding was occupied by birds, forcing primitive bats into becoming nocturnal insect eaters. Like birds, bats quickly diversified and are now represented by over 850 species. They have been particularly successful in tropical regions, where more bat species exist than all other mammals combined.

Paleontological Conclusions

Paleontologists have been able to sketch an outline for the evolution of animal flight, but the details of this picture have yet to be worked out in any completely satisfactory way. New fossil discoveries continue to expand and deepen scientific knowledge of flying-animal evolution, and computers have come to the aid of paleontologists, who are able to model prehistoric flying creatures by making use of detailed aerodynamic and physiological data. Thus scientists have new evidence to determine whether certain vanished creatures really flew. These studies have enhanced the appreciation of scientists and their students for the great diversity of flying insects, pterosaurs, birds, and bats that have flourished through evolutionary time. Once these animals conquered the air, new worlds were opened up to them, from deserts to mountains, from arctic tundra to tropical forests. The impressive distances covered by migratory birds and butterflies show the great energies these flying animals are willing to expend to traverse vast distances in their search for suitable environments in which to feed and reproduce. It took 300 million years to create the variety of flying creatures that live in the modern world, but it took *Homo sapiens* a much shorter time to achieve heavier-than-air powered flight. However, humans, who profited from their observations of birds in solving the problems of flight, have yet to solve the myriad of puzzles posed by the evolution of animal flight.

Robert J. Paradowski

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See also: Aerodynamics; Animal flight; Bats; Birds; Forces of flight; Insects

Experimental aircraft

Definition: Aircraft that is still in the experimental testing phase of development, or craft built by amateurs from kits or plans.

Significance: Experimental aircraft are important for the progress of the aviation industry. Flight test of an experimental aircraft validates expected performance criteria, tests structures, evaluates handling characteristics, and more. Scientific research is dependent on flight test results from experimental aircraft. A new airplane as such is experimental, but a proven and certified aircraft is experimental when mounted with new, untried applications requiring testing.

Types of Experimental Aircraft

A distinction must be made between true experimental aircraft and amateur-built airplanes constructed from kits or plans. The former category contains aircraft involved in research and design at costs reaching into the millions, while the latter group contains aircraft constructed by individuals for fun, at a substantially smaller cost. An experimental military project or airline endeavor may reach hundreds of millions of dollars before the production run gains approval. The homebuilt or kit plane project, on the other hand, is notably less expensive. Single airplanes built for personal use have flown at a cost well below $10,000. Another difference between the two groups of experimental aircraft includes the time spent in flight test. The large company projects may spend more than a year in flight test while a homebuilt or kit plane undergoes a basic forty-hour testing period.

The Design Process

Regardless of the group to which the airplane belongs, every aircraft flying today began in the much the same manner. Industry discovers a need for a particular design or a mission requirement. After the creation of a new concept, pilots, engineers, and mechanics discuss and research ideas for the production of the new craft.

The next step is sketching the design idea. More than a few new ideas begin as pencil drawings on napkins in restaurants over lunchtime discussions. From the first idea sketches, aeronautical engineers further refine the drawing by use of computer-aided design software. During the initial design period, engineers exchange ideas and make concessions and compromises that are eventually lofted into the drawing process. Modelers next construct a model of the new aircraft.

Models of the new airplane are necessary for many reasons. Wind-tunnel testing requires models of different sizes. Models enable designers to visualize proportional sizing. Problems not visible on a drawing board may vividly stand out in three dimensions.

After studying the models in depth, technicians and engineers develop mock-ups of various sections and components of the new aircraft. These mock-ups allow others to test the airplane and offer their opinions to the designers regarding positive and negative aspects of the new craft. Mock-ups also allow pilots, engineers, and mechanics to spot problems before production of the aircraft. The earlier design changes can be made, the more economically they can be incorporated into the production schedule.

The Prototype and First Flight

At the completion of the design process, construction of the prototype begins. Construction of one or two copies of the new craft is required for testing. This is an expensive proposition; until the craft goes into mass production, per unit cost of the craft can be phenomenal. The purpose of the prototype is further research and development. Changes follow in quick succession as shortcomings become evident and better construction methods become available. As the first prototypes are readied for flight, flight profiles are developed for the initial flight and the flight test program to follow. The most exciting event at an aircraft plant is the first flight of a new design, an event anticipated by everyone in the company.

Typically, first flights do not last more than about three-quarters of an hour. The only concern the company and the pilots have with the aircraft is whether it will fly. Initial flight testing does not try to test the edge of the flight envelope. Pilots, engineers, and managers are not interested in how fast or high the airplane is capable of flying on the first flight; they only want to see it fly and see it handle the way it is expected. Test crews will address other questions regarding the performance envelope later.

As test pilots put the aircraft through its paces, they keep meticulous data on every aspect of each flight. The company uses the data to refine the flying qualities of the prototype and suggest changes in the production run.

After completion of the flight test program, the new airplane will finally reach acceptance. If it is an airliner, company officials from the airline will either accept or reject the new craft. Military acceptance is somewhat different, in that the airplane flies through a more intense flight test program. Additionally, flight tests of military aircraft involve weapons systems compatibility.

Homebuilt Experimental Aircraft

The other type of experimental airplane is the burgeoning kit plane and homebuilt industry. In 2001, approximately twenty-two thousand homebuilt aircraft constructed by amateur builder-pilots were flying in the United States.

One organization dedicated to homebuilt enthusiasts is the Experimental Aircraft Association (EAA). The national headquarters of the EAA is located in Oshkosh, Wisconsin. There are local chapters of the EAA throughout the United States that allow homebuilding proponents to exchange technical information and discuss problems or other building concerns. Members also enjoy the camaraderie of other members, along with the encouragement offered at monthly or biweekly meetings.

Advantages and Disadvantages of the Homebuilt

There are many reasons pilots choose to build their own aircraft. One reason is performance. Since the 1950's, aircraft manufacturers have done relatively little in the way of increasing or improving aircraft performance. For example, a popular older model production aircraft flies at 100 knots, burns 7.5 gallons of fuel per hour, and can travel up to about 500 nautical miles before refueling. The latest model of the same aircraft today can fly about 106 knots, burns approximately 8 gallons of fuel per hour, and has a range of about 500 nautical miles. There has been virtually no change over the years in its performance.

However, ingenious amateur aeronautical engineers and pilots have produced airplanes using the same engines in newly designed airframes. These homebuilts are capable of 175 knots, with ranges beyond 1,000 nautical miles, using the same power plant, producing the same power at the same fuel flow. The backyard engineers have managed to attain much greater speeds over longer distances for the same amount of fuel.

While an increase in performance is advantageous, there are limitations to the use of a homebuilt airplane. For instance, homebuilts or kit planes are restricted from use in commercial operations. They also require a large amount of time for construction. Some pilots complain about the handling qualities of the smaller airframes. However, in many instances the advantages far outweigh the disadvantages.

One very important advantage is that of knowing the aircraft. As the owner-builder of the aircraft, the pilot is intimately familiar with all the systems of the airplane. Another benefit to constructing an airplane is that as the manufacturer of the craft, the builder is qualified to perform all maintenance and inspections on the airplane according to the Federal Aviation Regulations (FARs). In other words, each year, when it is time to inspect the airplane, the builder of the craft can save hundreds if not thousands of dollars in shop fees.

Another advantage homebuilt owners have over production aircraft owners is that they can build the airplane at their own pace, according to their own budget. A homebuilder can spend $600 one month, and if funds are lacking the next month, the building process can slow down while the builder spends only $50, or nothing at all. For the pilot who has purchased an aircraft with a loan, however, the bank will want payment each month.

Building Time

The time required to build a kit plane varies. With a fast-build option, a builder can have a plane airborne in less than a year. On the other hand, some builder-pilots have dragged out a project for twenty-five years. Average build times, depending on the make and model of the airplane, is about 2,000 to 3,000 hours of work. Working part time, this equates to two to four years.

After the airplane is finished, it is time for the first test flight. For this important first flight, many homebuilders opt to hire a professional test pilot familiar with their design. This is a smart choice for pilots who have allowed their flying skills to degrade during the construction process. Many would like to fly their homebuilt on the first flight, but this is a case where vanity must defer to common sense.

Following the initial flight, the homebuilder is free to fly the airplane through a test program. During this time, the airplane will be restricted to one geographical area for forty flight hours. After the airplane is proven through this test period, the restrictions are lifted. Now the owner-builder-pilot is free to use the airplane for personal use as any other airplane.

Some experimental aircraft begin as homebuilt inventions to test new designs, such as Fred Weick's homebuilt 1934 W-1A, which experimented with the use of tricycle landing gear. (NASA)

Types of Homebuilts

While the production market is limited, homebuilts offer a wide selection of airplanes to the potential builder, running the gamut from very simple single-seat ultralights to highly sophisticated, six-place family airplanes. A pilot desiring a production four-place family airplane that can cruise faster than 145 knots will spend more than $400,000, plus ongoing maintenance and upkeep. On the homebuilt market, however, one can choose from among many relatively inexpensive four-seat, high-speed, long-range airplanes. Similar savings can be made in home-building seaplanes and amphibious aircraft.

After choosing the group of airplanes from which to select, a pilot might research the safety aspects of particular designs. The next decision is the airplane's appearance, which is a matter of personal preference. Not only are there a wide variety of kits available for homebuilt plane types, but builders who want more than what is available on the market also can design a new craft incorporating all the desired attributes.

Most homebuilts and kit planes are smaller in size and weigh less than manufactured planes. Coupled with proportionally larger engines, this tends to increase the performance of the design. Many builders opt for two-place designs that provide opportunities for a great deal of compromise. Most pilots find themselves flying alone or with only one other person. When they have a need to carry more, they rent larger airplanes.

Construction Techniques and Materials

An exciting aspect of homebuilding is the selection of construction materials. Construction techniques vary with different airplanes. A popular airplane that uses construction techniques of the 1930's and 1940's is the Pitts Special. The fuselage of the Pitts is constructed of steel tube and wood formers covered with doped fabric. The wings are constructed of wood spars and ribs and covered in fabric. Other homebuilts constructed completely of wood are beautiful examples of artistic creation. Some use wood-working techniques that date back to World War I.

Conventional construction of modern light airplanes is sheet aluminum riveted on formed aluminum structures. In the early 1970's, homebuilders began experimenting with foam, epoxy, and other composite materials. Many of the new materials, such as Kevlar fabric and carbon graphite, are lighter than steel and provide greater tensile strength. In addition to being stronger and lighter, some of the new composite materials are easier to work with and enable the builder to form the compound curves of aeronautical structures more easily than when working with conventional materials.

Engines

With the use of Stirling engines or engines that use other alternative fuels, pilots may be able to fly farther and faster than ever imagined. Modern engines are one reason homebuilts are capable of such great speeds. The fact that the aircraft is experimental allows owner-pilot-builders to select the engine of their choice. Selection of the engine can be just as varied as selection of the aircraft itself.

The modern certified aircraft engine is a costly item. A new Lycoming or Continental aircraft engine can easily exceed costs of $20,000. Propellers and other accessories on the engine can drive that cost up another $5,000 or $6,000. Although such high prices may be discouraging, the homebuilder has many engine options.

The engine on a homebuilt does not have to be a certified aircraft engine. Because the airplane does not adhere to the specifications defined by the Federal Aviation Administration, builders can use any power plant they find suitable for their design. Indeed, many homebuilts are flying using engines from Volkswagen cars, chainsaws, snowmobiles, or outboard motorboats.

An automotive V-8 engine powers one of the most popular homebuilts, the Lancair IVP. The IVP can carry four passengers in pressurized comfort at altitudes above 25,000 feet, at speeds greater than 330 knots. Another example for those who doubt the use of automotive engines is that of the Volkswagen engine. Properly adapted for aerial use, this little engine has powered airplanes as fast as 230 miles per hour while getting more than 80 miles to the gallon.

While some doubt the validity of homebuilt and kitplane flying, this class of airplane is here to stay. For individuals with some technical background and the ability to work with their hands, homebuilding is a way to acquire an airplane inexpensively. The rewards they reap flying their own creations are many; chief among them the cost savings the homebuilder will realize over the years of flying the airplane. Saving money, however, is only a part of the compensation. The greatest reward is watching people admire the airplane. Most homebuilders are very pleased to hear the comments others make regarding the craftsmanship and work invested in the airplane.

Joseph F. Clark III

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See also: Airplanes; Manufacturers; Military flight; Model airplanes; Test pilots; Testing; X planes

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Federal Aviation Administration

Date: Formed on October 15, 1966, with the creation of the Department of Transportation

Definition: The U.S. government organization primarily responsible for overseeing aviation safety, air traffic control and navigation, federal funding for airport and airway facilities, and civil aviation security.

Significance: The Federal Aviation Administration is responsible for issues of aviation safety regulation, inspection, examination, certification, and issuance of licenses. The FAA oversees pilots, aircraft, airports, airlines, air traffic control and navigation, aircraft and parts manufacturing, repair, civil aviation security, and even commercial space transportation—blasting private satellites into space.

Functions and Structure

The Federal Aviation Administration (FAA) has three main areas of responsibility: air traffic control and navigation; civil aviation safety regulation, certification of airlines and aircraft, and licensing of pilots, mechanics, and other aviation personnel; and civil (as opposed to criminal) aviation security regulation and enforcement to safeguard airports, airplanes, and personnel and passengers from terrorism and other criminal threats to aviation. To accomplish these functions, the FAA maintains a headquarters in Washington, D.C., nine regional offices, and hundreds of other offices in the United States and worldwide. The FAA has two major research centers in Oklahoma and New Jersey.

The FAA employs almost 50,000 employees, approximately 35,500 of whom perform air traffic services. The job of regulating, inspecting, and licensing airlines, aircraft, pilots, and mechanics is performed by a regulation and certification workforce numbering approximately 6,000. More than 1,000 personnel work in the area of civil aviation security, and the remaining personnel work predominantly in administration, in research, or even in the overseeing the safety of commercial space launches to put satellites into orbit for telecommunications companies or other businesses.

The FAA is headed by an administrator who serves a five-year term under the U.S. secretary of transportation. A deputy administrator and several associate and assistant administrators oversee the different areas of FAA responsibility.

Although the size of the FAA workforce may seem extraordinary, it is appropriate to the role of aviation in the United States. Each year, air traffic controllers must handle approximately forty-five million flights, and FAA airport towers log fifty million operations. As of 2000, there were 19,281 airports in the United States, 3,953 of which were public-use airports with paved runways. There were 651 FAA-certificated airports in the United States, serving air carrier operations with aircraft seating more than thirty passengers. As of December 31, 2000, there were 635,472 active U.S. pilot certificates: Whether they were students in small propeller planes or airline captains commanding jetliners carrying hundreds of passengers, more than one-half million people held licenses permitting them to fly.

The FAA expends eleven billion dollars yearly in the performance of its functions. Much of that total is paid by the traveling public through excise taxes added to the price of airline tickets. These taxes, totaling almost twelve billion dollars annually, go into a national aviation trust fund to pay for improvements to airports and airways.

Origins

Soon after Jean-François Pilâtre de Rozier and the marquis François d'Arlandes completed the first untethered balloon flight on November 21, 1783, the first effort at aviation regulation was made. In April, 1784, a French police ordinance required permits for balloon flights over Paris.

Early laws were hardly conducive to aviation. Roman law proclaimed that whoever owned land also owned the sky above that land. Early property law provided that if one owned the land on the surface, then one owned it to the center of the earth and to the heights of the sky. This legal concept did not prove especially troubling until air travel became possible.

At the time of Wilbur and Orville Wright's success on December 17, 1903, the prevailing legal concepts made the dominion of the skies somewhat like that of the ocean: Both were considered to belong to all people but not to any one person. By the end of the World War I, that theory had been replaced by the realization that a nation's skies were the key not only to its defense but also to its prosperity. Thus, each nation's skies became protected airspace. Treaties were drafted to keep nations' aircraft from entering other nations' airspace and to regulate the economics and safety of international aviation.

Regulatory Framework

In 1919, the world powers met in Paris to devise a plan for the implementation of an international regulatory framework to carry out civil aviation in a peaceful, safe, and efficient manner. The sovereignty of each nation's airspace was recognized, and the group proposed minimum standards for certification and safety regulation as well as general rules for air traffic control. Each nation would be required to adopt regulations to certify its airlines, aircraft, and pilots and to oversee the safety of its operations. Although the United States sent representatives to attend the Paris conference, it did not adopt the convention's agreements.

The United States would become a signatory to later air commerce and navigation treaties, and eventually the international oversight of aviation would be governed by the International Civil Aviation Organization, a part of the United Nations. To this day, the international regulatory plan depends on each nation having aviation safety laws and a government agency to enforce them. Although the FAA would eventually fulfill that role for the United States, it was still decades in the making.

The U.S. Air Mail Service

The U.S. Post Office was the beneficiary of the first U.S. aviation regulation. In 1920, after numerous airmail accidents, the head of the U.S. Air Mail Service set about to improve the situation. Pilots were required to complete 500 hours of flight training, pass an examination, and undergo a physical to establish medical fitness. Orville Wright assisted the effort to qualify and license the nation's pilots, personally signing some of the earliest U.S. pilot's licenses.

Air mail was privatized with the Air Mail Act of 1925, known as the Kelly Act. The routes were put up for bid, and wealthy American industrialists, such as Henry Ford, William Rockefeller, Cornelius Vanderbilt, and Marshall Field, garnered the first contracts.

On May 20, 1926, the Air Commerce Act was passed at the urging of the aviation industry, after the aviation industrialists realized aviation could not reach its significant commercial potential without the federal government providing safety regulation. It is unsurprising, then, that the job of aviation safety was given to the U.S. Department of Commerce. The secretary of commerce was charged with promoting air commerce, enforcing air traffic rules, licensing pilots and planes, certificating aircraft, establishing airways, maintaining aids to air navigation, and generally working to improve aviation's dismal safety record. With that, the seeds of the future FAA were planted, and there was much to be done. There were only 6,000 passengers willing to brave the airlines in 1926.

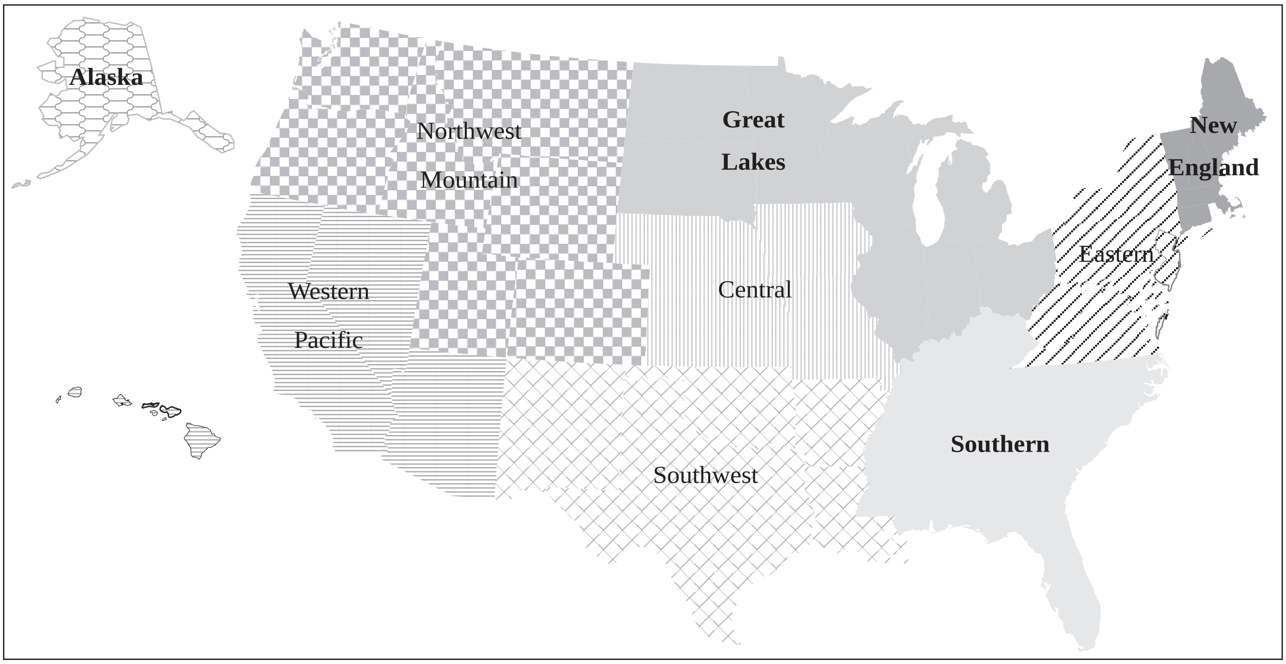
Forerunners of the FAA

By 1933, the nation's system of 18,000 miles of airways with 1,500 beacon towers and 263 landing fields was finished. Aerial navigation was very much a ground-based enterprise, with a cross-country system of ground beacons, small towers with a flashing rotating light and two course lights. In addition, ninety radio navigation stations had been built to provide aural and visual guidance to pilots. In 1930, the first radio-equipped air traffic control tower was built in Cleveland, Ohio, with twenty more to follow by 1935. In 1935, the cities of Chicago and Newark set up air traffic control systems to control their flights. The Bureau of Air Commerce was formed in 1934 within the Department of Commerce, and, two years later, it took over the responsibility of air traffic control.

By the 1930's, the airlines, in the throes of destructive price-cutting competition spurred by mail-contract bidding, were themselves clamoring for federal regulation. The airlines wanted to upgrade their fleets with the new, sleek, metal marvels of the aviation world: the Douglas DC-3 aircraft. To afford these airplanes, the airlines needed to be spared from cutthroat price wars. The airlines' solution was federal economic regulation. By having the federal government regulate not only air traffic control, safety, and certification, but also airline profits, they would be protected from huge losses caused by destructive competition, and they could afford to buy the marvelous new DC-3's.

Thus, in 1938, the Civil Aeronautics Act created the Civil Aeronautics Authority to regulate safety and economics. In 1940, the authority was split into the Civil Aeronautics Board (CAB), which had the powers of safety regulation, accident investigation, and economic regulation and also established airline fares and routes, and the Civil Aeronautics Administration, which was responsible for air traffic control, pilot and aircraft certification, safety enforcement, and airway development. The airline plan worked. Americans loved the DC-3, which remains the most successful transport plane ever. Almost 11,000 were built in the United States and at least as many were manufactured overseas. By 1941, there were three million U.S. airline passengers, who looked to the U.S. government to protect their safety.

FAA Regions



Source: Federal Aviation Administration.

During World War II, both military and civil aviation changed dramatically. Newly developed radar technology was applied to air traffic control. In 1944 alone, the United States produced 96,318 airplanes. Aviation was credited by many historians with winning the war.

During the Cold War, the federal government provided money for airports and instrument landing systems. Equipment, such as pressurized airplanes, airborne weather radar, and autopilots, were dramatically improved, and passenger comforts were increased. By 1956, U.S. airline passengers outnumbered rail passengers, a trend that was never reversed.

However, during this time, several tragedies shook the confidence of the flying public. The world's first jet commercial airliner, the British De Havilland Comet commenced passenger jet service in May, 1952, but its success was short lived. Of the nine Comets in commercial passenger service, three seemingly came apart in midflight. In 1956, a United Air Lines flight collided in midair above the Grand Canyon with a Trans World Airlines (TWA) flight, killing 128. After it was discovered that an air traffic controller had seen the planes' collision course on his radar and had failed to warn the pilots, the reputation of the CAA was tarnished. After two more U.S. midair collisions, between U.S. Air Force planes and civilian airliners, it was recognized that changes were required.

Federal Aviation Agency

In 1958, the new, independent Federal Aviation Agency was created and took over the CAA's functions. It also took from the CAB the job of promulgating safety regulation and coordinating military and civilian air traffic control. The CAB retained the responsibilities of economic regulation and accident investigation, but not for long. A midair collision on December 18, 1960, between a United Air Lines and a TWA flight in the skies above New York killed 135 people, including 8 on the ground, and intensified the public demand for improvements.

The 1960's brought the radar-based air traffic control (ATC) system, with its banks of green screens that enabled controllers to monitor the nation's airports and airways. In 1966, the Department of Transportation (DOT) was formed to coordinate the regulation of all modes of transportation within one department. The Federal Aviation Agency, now operating under the DOT, became the Federal Aviation Administration. The accident investigation function was removed from the CAB's jurisdiction, and an independent accident investigation organization, called the National Transportation Safety Board (NTSB), was established. Although the FAA may assist in aircraft accident investigation, the NTSB remains primarily responsible.

Reacting to Tragedies

Unfortunately, in the coming decades, air tragedies continued to direct the course of the FAA. Aircraft hijackings in the 1960's caused the FAA to institute security regulations and requirements, followed years later with more-stringent requirements following more deadly and catastrophic aircraft crimes, such as the terrorist bombing of Pan American Flight 103 in 1988. Plastic explosives were hidden in a personal tape recorder, which was loaded in Frankfurt, Germany, into the baggage compartment of the doomed plane. There was no passenger on board the flight to accompany the baggage.

Major domestic security changes were ordered after a tragic episode in 1987, in which a fired Pacific Southwest Airlines (PSA) employee boarded the airliner with his old employee badge and, after takeoff, shot his former boss, a passenger. The killer then shot the aircraft's pilots, and the plane plunged to earth, killing all on board.

The most shocking tragedy occurred on September 11, 2001, when teams of terrorists hijacked four commercial jets. Two 767's out of Boston's Logan Airport, American Airlines Flight 11 and United Air Lines Flight 175, were intentionally crashed into the Twin Towers of the World Trade Center in New York City, causing both buildings to collapse. The third plane, American Flight 77, a 757 out of Washington's Dulles Airport, was crashed into the Pentagon in Washington, D.C. The fourth plane, United Flight 93 out of Newark, New Jersey, crashed in a field near Pittsburgh, Pennsylvania, when passengers stormed the cockpit of the 757. In total, more than 5,500 people, from the planes and on the ground, were killed. The hijackers smuggled box cutters on board the aircraft, gained access to the cockpits, either killed or incapacitated the flight crews, switched off the transponders, and took over the controls. Two of the terrorists, Islamic fundamentalists associated with Osama bin Laden's al-Qaeda network, were on a Federal Bureau of Investigation (FBI) watchlist but were allowed to purchase tickets.

Eventually, the NTSB would discover the trend that the most frequent among many causes of accidents was the failure of the FAA to act to avert catastrophe.

Airline Deregulation

In 1978, the FAA faced another problem, when the airline economic deregulation unwittingly dealt airline safety an insidious blow. Bowing to intense political pressure, the federal government hastily freed airlines from almost all economic regulation. The debate over the wisdom of deregulation has continued ever since. The CAB was abolished, and with the elimination of economic regulation, a substantial part of airline regulation disappeared. The government no longer regulated the routes that airlines could fly or how frequently they could fly them. The airlines could set fares and invent combinations of arbitrary fare restrictions. The airlines could price their tickets below the cost of buying, flying, and maintaining the planes. As the U.S. airline fleet aged, cash-strapped carriers delayed maintenance, cut corners on safety, and, in some cases, even falsified maintenance records.

The FAA, however, did not change the way it policed the airlines. In the years following deregulation, dozens of upstart carriers entered the airline business. Many of these companies operated with meager financing, old planes, little experience, and low-paid employees. They planned to meet vital functions, such as maintenance and safety, by contracting with the lowest bidders. Such airlines came to be called virtual airlines, and almost all of them went bankrupt or otherwise ceased to exist within a few years.

One such carrier, ValuJet, caused the biggest FAA crisis in history, but also caused the FAA to increase by 267 percent its remedial action. On May 11, 1996, a ValuJet flight crashed into the Florida Everglades, killing all 110 on board. The American public's faith in the FAA was shaken when both the FAA administrator and the DOT secretary of transportation stood at the crash site and, before any investigation, on national television pronounced the airline safe. The airline was not safe, however, and days later, ValuJet was grounded for safety violations. A document produced from within the FAA showed that FAA inspectors had recommended grounding ValuJet months before the crash.

Congressional and Senate hearings probed the problems within the FAA, and the FAA admitted to Congress that with the advent of virtual airlines, its ability to inspect and oversee the airlines had been significantly hampered. The dual mission of the FAA, both to promote aviation and to regulate safety, inherited decades before from its predecessors within the Commerce Department, was an obvious inherent conflict. The FAA was tasked by Congress to set about improving its own safety record, as well as that of the U.S. airlines.

Air Traffic Control and Crowded Skies

By the 1980's, the nationwide air traffic control system of banks of blinking green screens and paper strips tracking thousands of planes across the skies had become antiquated. Congressional hearings examined the problem of demand for air travel exceeding the ability of the old air traffic control system to handle the traffic. The FAA's initial efforts to replace the system had failed by the mid-1990's. The first replacement program was woefully behind schedule and well over budget. The FAA, ordered by Congress to start over, began phasing in over many years parts of the new air traffic control replacement system. The overall completion date was targeted for 2015, with most of the system projected to be finished by 2008. The completed system allows for completely computerized and automated air traffic control aided by global positioning system (GPS) satellites. The aircraft itself will be able to communicate with the air traffic control system. Should something happen to the pilots, a verbal or electronic command from the aircraft's home base or air traffic control can tell it to return to its home airport or to another designated airport.

Under the new system, pilots will finally be able to legally and safely choose paths across the sky, without bonfires or beacons, without cumbersome air routes dictated by green blinking radar screens and strips of paper, and without needless tragedy that imperils pilots, passengers, and even pedestrians on the ground below.

Mary Fackler Schiavo

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See also: Accident investigation; Air carriers; Air traffic control; Airline Deregulation Act; Airline industry, U.S.; Airports; Commercial flight; Manufacturers; National Transportation Safety Board; Pilots and copilots; Safety issues; Training and education

Fighter pilots

Definition: The pilots of tactical jet aircraft used for defensive posturing and offensive attacks. The men and women who fly tactical aircraft are usually the best pilots available in terms of both talent and training.

Significance: Since World War I, fighter pilots have been a major component of modern warfare. They usually fly the most technologically advanced aircraft of their day, and are trained to exceptionally high standards. The fighters may be land based or deployed aboard aircraft carriers.

The Beginning of Aerial Combat

At the beginning of World War I, airplanes were very scarce and primarily used for surveillance. Both the English and the Germans had aircraft designed to be observation platforms, and that was the extent of their use. Few people seriously regarded airplanes as practical war machines; early military officers, like much of the public, thought of airplanes as expensive toys, frivolous and of little practical use. They were noisy, breezy, hard to communicate within, and dangerous. Typically, their engines would quit at any time without notice, and flight crews would be lucky to survive.

In the early days of the war, it was very rare for a pilot to come across another aircraft in flight. It was even more unusual to come across an enemy aircraft. Eventually, however, that is exactly what happened. When the two pilots realized that they were flying alongside one another, after the cursory waves to each other, they proceeded to fly along a little further. Then one of them realized that the other truly was the enemy and decided that action was required. Reaching into his tunic, he pulled out his revolver, carefully aimed it at the other aircraft, and squeezed the trigger. The other pilot decided to turn and run. Thus, aerial warfare was born.

From those very humble beginnings in World War I, the job and title of fighter pilot has become synonymous with heroism. From airplanes that flew no faster than 80 miles per hour to jets capable of more than 1,800 miles per hour, the duty and challenge of guiding these machines has been one sought after by many.

Training

The fighter pilot must be capable of multitasking, maintaining extreme situational awareness, and working in a very demanding and hostile environment, all the while being capable of using his airplane and its weapon systems to their limits. Fighter pilots are typically young men or women in their late twenties or early thirties. They are college graduates, and some possess graduate degrees.

Typically, they have wanted to be fighter pilots all their lives. They maintain a driving desire to attain any goal they set their minds to achieving. They have probably the most refined single-minded focus of any group of modern professionals.

Fighter pilots begin their careers with maintaining good grades throughout high school and college. The choice of the major course of study in college is not as important as aptitude and attitude. Of course, a technical degree will serve an aspiring career military aviator better than a nontechnical degree.

Fighter pilots must be commissioned as officers in the military services. To obtain a commission, a candidate will take part in the Reserve Officers' Training Corps (ROTC) while in college or Officer Candidate School (OCS) after graduating from school. Another route to a commission is through appointment and graduation from one of the nation's military academies.

After graduation and commissioning, the newly appointed second lieutenant or naval ensign passes through flight training, a process that takes from two to three years. During the time spent in flight training, new pilots learn all the basics of flying, including formation flying, instrument flying, and finally, aerial warfare.

Fighter Aircraft of the U.S. Navy and Air Force

In 2001, U.S. Air Force pilots could expect to fly the F-16 Fighting Falcon or the F-15 Strike Eagle. Another attack airplane in the Air Force inventory is the A-10 Warthog, the tank killer of the Gulf War. The F-16 and F-15 are true fighters, while the A-10 is an attack aircraft.

The pilots flying the F-15 and F-16 can reach speeds well in excess of 1,000 miles per hour, while the mission of the A-10 does not require such speeds. The A-10's strength is in "tank-busting" and ordnance delivery. The A-10's straight-wing design gives it the advantage of more wing area, so it can carry a bigger bomb load than the F-15 or F-16. The integrated gun is also larger, with 30 millimeters on the A-10 versus 20 millimeters on the other aircraft.

While the mission of the A-10 is ground attack, the F-15 and F-16 can perform both missions of ground attack and aerial warfare. They have the capability of attacking ground targets, but they excel in the air-to-air arena.

Navy fighter pilots fly the F-14 Tomcat and the F/A-18 Hornet. Each airplane, carrier-based and used for air-to-air fighting and ground attack, can fly faster than 1,000 miles per hour. While the F-14 came off Grumman's design table as a fighter aircraft, the F/A-18 was a multimission aircraft from the start. The F/A-18 is intended eventually to take on all roles of fleet defense and ground attack, with the F-14 being phased out.

Unlike Air Force aircraft, there are special considerations for naval aircraft. They have to be able to take the abuse of being aboard ships and dealing with the very harsh saltwater environment. While all tactical jets are built to survive extreme wear, the navy aircraft are constructed a little more sturdily to survive the catapult shots for takeoff and the hard landings required to land aboard a floating runway.

From their floating airfields, F-14 pilots and their counterparts in the backseat, the radio intercept officers, defend the fleet against aerial assault. Depending on the location of the fleet, the threat environment, and the rules of engagement, the F-14's may or may not become involved in traditional dogfights. Once Navy fighter pilots complete their missions, they must return to the ship. While the Air Force pilots have the luxury of landing on long runways, the naval aviator is faced with the daunting task of landing a multiton fighter on a pitching carrier deck.

Air Combat Maneuvering

Dogfighting, the term applied to airplanes engaged in aerial combat against one another, has come a very long way from the time the first British and German pilots shot at each other from their observation aircraft. From World War I to World War II, aerial combat was refined into a lethal art. Pilots learned maneuvers that would best allow them to get behind their enemies and bring their weapons to bear. In World War I, a dogfight lasted minutes. By contrast, a modern dogfight may take less than one turn to complete and is over in seconds.

If the fight degenerates into a turning fight, fighter pilots put their aircraft through basic air combat maneuvering, which includes maneuvers such as the rolling scissors, flat scissors, the high yo-yo and low yo-yo, and the Lufberry circle, to name a few. These are the maneuvers a pilot would use to gain an advantage over an enemy for a close-in gun shot or an intermediate missile shot.

In contrast to the fighters of the earlier days, today's fighter pilots have the capability for what is known as beyond visual range (BVR) shots. Depending on the theater, the threat environment, and the rules of engagement, fighter pilots may have the option of shooting down enemy aircraft without ever seeing them. This is dependent on the certainty that any aircraft coming from a certain sector is the enemy.

It is a risky endeavor and has resulted at times in Allied losses due to friendly fire. Everyone operating in the particular area has to be operating by the same rules. If not, there is the possibility of mistakes with terrible results. As a result, fighter pilots tend to be absolutely sure of themselves. There is always a chance that the consequence of any mistake may be fatal to themselves or someone else. Consequently, fighter pilots tend to be on the cautious side, only acting when certain that their knowledge and their actions are positively, literally, and completely correct.

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See also: Air Force, U.S.; Aircraft carriers; Airplanes; Dogfights; Eagle; Gulf War; Hornet; Kamikaze missions; Korean War; Luftwaffe; Marine pilots, U.S.; Navy pilots, U.S.; Pilots and copilots; Manfred von Richthofen; Eddie Rickenbacker; Royal Air Force; Spitfire; Tomcat; Training and education; Vietnam War; World War I; World War II

F-16C/D Fighting Falcon Characteristics

Primary Function: Multirole fighter
Builder: Lockheed Martin Corporation
Power Plant: One Pratt & Whitney F100-PW-200/220/229 or General Electric F110-GE-100/129
Thrust: 27,000 pounds
Length: 49 feet, 5 inches
Height: 16 feet
Wingspan: 32 feet, 8 inches
Speed: 1,500 miles per hour (Mach 2 at altitude)
Ceiling: Above 50,000 feet
Maximum Takeoff Weight: 37,500 pounds
Range: 1,740 nautical miles
Armament: One M-61A1 20-millimeter multibarrel cannon with 500 rounds; external stations can carry up to 6 air-to-air missiles, conventional air-to-air and air-to-surface munitions, and electronic countermeasure pods
Unit Cost: $34.3 million
Crew: F-16C, 1; F-16D, 1-2
Date Deployed: January, 1979

Source: Data taken from (www.af.mil/news/factsheets/F_16-Fighting_Falcon.html), June 6, 2001.

Fighting Falcon

Also known as: F-16, single-seat F-16A and F-16C; two-seat F-16B and F-16D; F-16XL delta wing
Date: First flight on January 20, 1974
Definition: A highly maneuverable, lightweight, air-to-air and air-to-ground attack fighter first developed in the United States and adopted by many world nations.
Significance: Proven in combat and in numerous world aircraft competitions, the F-16 Fighting Falcon is considered by experts to be the best multirole, cost-effective fighter aircraft ever made. Its technical evolution from the 1980's through the beginning of the twenty-first century has kept it ahead of all other contemporary potential threat aircraft.

Specifications

The F-16 is a single-seat air superiority and multirole fighter. Its wingspan is 32 feet, 10 inches, and its length 49 feet, 6 inches. Its power plant is one 25,000-pound thrust Pratt & Whitney F100-PW-200 (3) turbofan. When empty, it weighs 15,580 pounds; it weighs 35,400 pounds at gross capacity. The F-16's range is 2,000 miles and its service ceiling is 50,000 feet. The plane can reach a top speed of Mach 2, twice the speed of sound. For armament, it carries one 20-millimeter multibarrel rotary cannon plus two wingtip mounted sidewinder missiles, as well as seven external pylons for fuel tanks and other selected air-to-air and air-to-ground weapons.

Development

The F-16 was first planned and designed in the late 1960's by Pierre Spray, a civilian working in the office of the assistant secretary of defense, and John Boyd, an Air Force major and flight instructor, along with Harry Hillaker of the General Dynamics Corporation. The project received further support from the 1972 Lightweight Fighter Prototype program sponsored by the U.S. Air Force. The plane was conceived to be smaller, lighter, faster, more maneuverable, and less expensive than the U.S. Navy's F-14 Tomcat and the F-15 Eagle of the U.S. Air Force. Another idea was to sell the plane to allied nations worldwide in order to increase production and lower the cost of the plane.

In August, 1972, the U.S. Air Force appointed General Dynamics Corporation and Northrop, another United States corporation, to build concept prototypes, one of which would be selected for production. On December 13, 1973, the first two General Dynamics prototypes, called YF-16, were ready to be tested and evaluated by government-appointed test pilots Phil Ostricher and Neal Anderson. On January 13, 1975, U.S. Air Force secretary John L. McLucas announced the YF-16 as the winner of the lightweight fighter competition and in February of that year, a North American Treaty Organization (NATO) consortium offered $5.16 million each for the production of two thousand F-16's for the United States and NATO allies. In December, 1976, the first test flight of the single-seat F-16A occurred and in January, 1979, the first military operational F-16's were delivered to the 388th Tactical Fighter Wing at Hill Air Force Base in Utah. The U.S. Air Force special demonstration team, the Thunderbirds, adopted the F-16 in November, 1982, and the U.S. Air Force increased its planned F-16 purchase total to 3,047 in February, 1986.

Technical Highlights

One technical innovation of the F-16 was the fly-by-wire electronic computer-assisted steering system, which was less vulnerable to damage from attack. This system had faster and more precise steering and maneuver capabilities compared to the old hydraulic systems.

The F-16 also had a new advanced radar system with look-down capability to track small high-speed objects below the airplane at treetop level, such as ground-to-air antiaircraft missiles.

Many experts consider the F-16 Fighting Falcon to be the best multirole, cost-effective fighter aircraft ever made. (U.S. Department of Defense)

Another innovation was the heads-up display (HUD), which projected data from the control panel onto the windshield, enabling pilots to keep their eyes on the sky and more quickly evaluate the data.

Combat

On Sunday, June 7, 1981, eight F-16's of the Israeli air force successfully bombed a nuclear reactor power plant located 11 miles southeast of Baghdad, Iraq, without suffering any losses of human life or airplanes. The mission is noteworthy in that the F-16's low-altitude flying eluded radar detection and the bombs dropped were precisely on target, thereby completely destroying the entire power plant facility.

During that same month, Israel launched a full-scale land and air campaign that removed the Palestine Liberation Organization (PLO) from occupied territories in Lebanon. On a single day, June 9, 1981, a total of ninety Israeli F-15 Eagles, F-16 Falcons, and Kfirs (Israeli-built versions of the French Mirage V) shot down about thirty of sixty Syrian MiG warplanes and bombed sixty SA-6 SAM ground-to-air missile sites. During air combat over the next two days, an additional fifty Syrian fighter planes were shot down, and by the end of the month, the Syrian total aircraft losses were numbered at eighty-five. During the entire month of June, 1981, not one single Israeli airplane was shot down.

In the Gulf War, 249 F-16's were deployed against Iraq during the forty-three-day air war in January and February, 1991. They flew the most missions or sorties of any coalition aircraft against ground targets, including parked Iraqi aircraft, airfields, Scud missile sites, and production facilities manufacturing weapons and chemicals.

Following the Gulf War, F-16's from several nations played a key role in enforcement of the United Nations sanctions and no-fly zones over Iraq and Bosnia. On December 27, 1992, the first United States Air Force F-16 to score an air-to-air victory occurred when an Iraqi MiG-25 was shot down by an F-16 over Iraq. In 1994, F-16's shot down three Serbian jets over Bosnia.

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See also: Air Force, U.S.; Eagle; Fighter pilots; Gulf War; Military flight; Testing; Tomcat

Firefighting aircraft

Also known as: Airtankers

Date: First aircraft used for firefighting in 1919; first airtankers produced in 1946

Definition: Aircraft, both planes and helicopters, modified to carry and release water or other flame-retardant liquids for the extinguishing of large fires, usually in remote areas.

Significance: The use of firefighting aircraft allows government agencies and civilian corporations to provide firefighting services primarily in large areas that are densely forested.

History

The first use of an airplane to combat a wildland fire occurred in California during 1919. Modifications to private aircraft continued for several decades but remained limited and experimental. In 1946, Glenn L. Martin, founder of the Martin Aircraft Company, designed an aircraft known as the Mars, which he initially envisioned as a long-range mission bomber with heavy lift capabilities. The four Mars planes, named the *Marianas*, *Phillippine*, *Hawaii*, and *Caroline*, transported troops and cargo between the islands of the South Pacific from 1946 to 1959. After setting world records for flight duration and airlift ability and logging more than eighty-seven thousand accident-free hours while in service with the U.S. Navy, the airplanes were retired. In 1959, after a series of catastrophic forest fires, a group of timber companies formed the Forest Industries Flying Tankers and purchased the four Mars planes, modifying them to serve as water bombers. In 1961, the *Marianas* crashed on a firefighting mission and in 1962 a hurricane destroyed the *Caroline* on land. The other two aircraft, the *Phillippine* and the *Hawaii*, were still in service at the beginning of the twenty-first century.

The Mars aircraft carries a crew of four, including the captain, first officer, and two flight engineers. Within ten minutes of receiving an emergency call, the planes are airborne and provide the initial attack on large fires, followed by repeated drops every fifteen minutes during sustained operations. Once the aircraft reaches the water source, the pilot begins the intake procedure by maintaining a constant speed of 60 to 70 knots while the scoops are turned to the down position. Water injected at the rate of 1 ton per second requires the flight engineer to continually advance the throttle to maintain the proper speed. When the tank is full the scoops are raised and the flight engineer takes off just as in a normal takeoff from land. Once the plane is back in flight, a foam concentrate is injected into the 7,200 gallons of water, where it remains inert until dropped. As the water falls, the tumbling action causes the foam to expand, transforming the water into a fire-retardant 4 percent solution. The aircraft, equipped with four Wright Cyclone R3350-24WA engines, measures 120 feet in length, has a 60,000-pound water/foam load limit, and can fly for over 5 hours before landing. When dropped from a height of 150 to 200 feet, the foam covers an area of 3 to 4 acres. Two additional aircraft assist the Mars planes in their firefighting efforts. The Grumman G21A Goose spots the fires and guides the Mars pilots into the bombing pattern. Responsible for coordinating efforts with the fire boss on the ground, the pilot of the Goose determines altitude and drop height and develops an exit plan. All of the pilots are trained on both the Mars and the Goose aircraft, enabling them to predict in-flight and drop requirements more accurately. Since 1974, Bell 206L-1 LongRange helicopters have also been used for smaller fires caused by lightning strikes. Each helicopter is equipped with a Bambi Bucket with a capacity of 140 gallons. The helicopters are also used to evacuate people and provide tactical support. While the Forest Industries Flying Tankers concentrate on large fires located on property owned by Weyerhaeuser Company Limited and TimberWest Forest Limited, the two lumber companies that own Forest Industries, they also contract out their services on occasion.

Private Aerial Firefighting Companies

Since the early 1960's, a number of other companies have offered similar services using a variety of aircraft developed for firefighting missions. Based primarily in heavily forested areas, the firefighting enterprises include several multiengine airtanker companies. Aero Flite, of Kingman, Arizona, was founded in 1963 and operates one C-54E, one C-54G, one M-18B Dromader, one Aztec, and one Piper Cherokee 6 within the continental United States and Alaska. Aero Union Corporation of Chico, California, the largest contractor of firefighting services in the United States, manufactures aerial firefighting aircraft and systems with a patented constant flow drop system used on Lockheed C-130's, Lockheed L-188's, and P3's, as well as on the Lockheed P-2V aircraft. The company also provides aircraft and personnel for firefighting missions in cooperation with the U.S. Department of Agriculture and numerous other federal agencies. Aero operates a fleet of six P3's, four SP-2H's, and two C-64's and contracts for services in California, Idaho, Oregon, Arizona, and Utah. The company manufactures retardant aerial delivery systems (RADS), helicopter-borne aerial firefighting systems, auxiliary fuel systems, aerial spray systems, aerial refueling tanks, modular airborne firefighting systems, bulk fuel transport tanks, 1080 refueling store systems, and automated cargo handling systems.

ARDCO of Tucson, Arizona, formed in 1976, has a fleet of three DC-4's and covers areas in Nevada, Oregon, and California, providing firefighting services for the U.S. Department of Agriculture and the Forest Service. Butler Aircraft Company of Redmond, Oregon, founded in 1946, introduced the B-17 into aerial firefighting and also uses two DC-7's, one DC-6, and one C-130 in its fleet providing services for the U.S. Department of Agriculture and Forest Service in Washington, Oregon, Arkansas, Tennessee, Alaska, Michigan, and Minnesota. Hawkins & Powers Aviation, out of Greybull, Wyoming, has specialized in aerial firefighting and agricultural spraying since 1958. Its fleet includes five PB-4Y-2's, fourteen P-2V's, seven C-130A's, six C-97's, and one P2-T, as well as a fleet of heli-tankers that includes two Bell UH-2B's, two Bell 206L3's, two Bell 206 BIII's, two Hughes 500D's, and two Hiller 12E's. The company provides services in Alaska, Australia, Washington, Oregon, Minnesota, Idaho, Nevada, Colorado, New Mexico, Arizona, Montana, Utah, Tennessee, North Carolina, Florida, Pennsylvania, New York, California, Oklahoma, Texas, and South Dakota.

Hirth Air Tankers of Buffalo, Wyoming, was formed in 1987 and operates two PV-2 airtankers, two PV-2 sprayers, and one Grumman American G164B-600 Ag-Cat single-engine airtanker. Neptune, of Missoula, Montana, was founded in 1993 and operates nine Lockheed P2-V Neptunes throughout the United States. International Air Response of Chandler, Arizona, founded in 1965, operates three C-130's, one DC-7 airtanker, and two DC-7 sprayers throughout the continental United States, Alaska, Spain, and France. T.B.M., of Tulare, California, founded in June, 1957, has provided aerial firefighting services since 1959.

Its fleet includes two C-130's, one C-54, one DC-6, one DC-7, and one SP-2H leased from Aero Union.

The two major companies that provide heli-tanker contract services are Erickson Air-Crane Company of Central Point, Oregon, and Heavy Lift Helicopters of Clovis, California. Single-engine airtanker companies such as Downstown Aero of Vineland, New Jersey, and Queen Bee Air Specialties of Rigby, Idaho, also provide services on a contractual basis.

Many of these companies use vintage World War II aircraft modified with retardant aerial delivery systems (RADS). One of the most common systems is used on the Lockheed P-3 Orion and L-188 Electra aircraft. Manufactured by Aero Union Corporation, the RADS II system is a constant-flow belly tank using a computer-controlled door system that allows the crew to select the appropriate flow rate. Equipped with a 3,000-gallon tank, the computerized system maintains a constant flow with a uniform drop rate with no overlapping or gaps. Used for initial attacks on grasslands or heavy timber fires, the advanced system prevents possible fire burn-through.

One of the more common heli-tankers is the S-70A/UH-60L Firehawk. The Firehawk has a one-thousand-gallon water tank, a 30-gallon foam tank, a 1,000-gallon-per-minute snorkel, and computer-controlled doors. The snorkel allows the heli-tanker to fill the water tank in one minute. The most recent addition to the fleet of heli-tankers is the S-64 Skycrane Fire Fighting Tank, with its 2,000-gallon water tank and 60-gallon foam tank. The Skycrane's snorkel is also capable of filling the water tank in one minute, even though its capacity is double that of the Firehawk.

Military Firefighting

Although several private companies across the country provide firefighting services, sometimes the U.S. military is called upon to assist when resources are limited and the extent of the fire warrants additional aircraft. Instead of building planes specifically for firefighting missions, the military transforms the Lockheed C-130 Hercules cargo planes into firefighting aircraft by adding systems such as the Modular Airborne Fire Fighting System (MAFFS).

Installation of the MAFFS system can be completed within one hour and contains a 3,000-gallon tank that can be filled in fifteen minutes and fully discharged in five seconds. Releasing the retardant alternately from a series of tanks, the MAFFS system allows pilots to maintain complete control over the aircraft during the drop, as opposed to other systems that require in-flight compensation as the nose of the aircraft pulls up and gravity pulls the retardant out of the rear of the plane. Installation of the MAFFS system is a two-step process. The initial installation of the lower tank is permanent and adds approximately 500 pounds to the aircraft. The upper tank attaches to the floor line and is removed after the firefighting mission is over, allowing the C-130 to be used once again for cargo and troop transport. The fire retardant released from the MAFFS system is a chemical called phos chek. In addition to reducing the combustion of plants and trees even after it loses its moisture, phos chek also contains a fertilizer that enhances regrowth of burned areas and helps prevent further soil erosion.

Mission and Operation

The mission of the firefighting aircraft is to extinguish forest and wildland fires in cooperation with federal, state, and local agencies. In the United States, the federal agencies responsible for wildfire firefighting are the Forest Service, the Bureau of Land Management, the National Park Service, the Bureau of Indian Affairs, and the Fish and Wildlife Service. Private airtanker companies work together with these agencies to control and manage fires. During the first six months of 1999, more than 1,097,400 acres of wildland had burned. Two of the worst fires occurred in Florida, where eight hundred firefighters fought the blaze for several weeks. When a wildland fire is reported, local crews respond first with an initial attack. This is usually provided by private companies, and 98 percent of fires are put out at this stage. If additional resources are required, one of the eleven nationwide coordinating centers are notified. Geographic area coordinating centers are located in Albuquerque, New Mexico; Riverside, California; Salt Lake City, Utah; Fairbanks, Alaska; Portland, Oregon; Broomfield, Colorado; Missoula, Montana; Milwaukee, Wisconsin; Reno, Nevada; Atlanta, Georgia; and Redding, California. The coordinating center then notifies the National Interagency Coordination Center in Boise, Idaho, where the National Wildfire Coordinating Group assumes control over the efforts. This group has extensive resources available nationwide, including 70 twenty-person Hotshot crews trained to handle complex firefighting situations; 409 individual smoke jumpers with 19 support aircraft for initial attacks in the western portion of the United States; 58 contract airtankers; a large transport for crew and equipment; 11 lead planes for tactical operations; 23 helicopters; 3 aircraft outfitted with infrared scanners capable of mapping the fires; 17 incident management teams trained specifically for handling complex situations; 447 twenty-person geographically located teams that can be called upon if necessary; 50 communication kits; 21 contractors that provide catering and shower facilities for the firefighting teams; and 11 warehouses full of firefighting equipment and supplies.

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See also: Airplanes; Bell Aircraft; Helicopters; Lockheed Martin; McDonnell Douglas; Manufacturers; Weather conditions

Flight attendants

Also known as: Stewards, stewardesses, cabin boys, sky girls or boys, air hostesses

Definition: Flight crewmembers who are responsible for aircraft passenger safety and comfort.

Significance: The training, duties, and employment requirements of flight attendants have changed greatly since the earliest passenger flights. Flight attendants are men and women of all ages, races, and family situations. According to the Bureau of Labor Statistics, there were 99,000 flight attendants in the United States in 1998. Flight attendants are highly trained, safety conscious, and skilled professionals serving masses of people traveling to all corners of the earth. A specific number of flight attendants are required by government regulations to be on all commercial airline flights, but they can also be found on private, corporate, and charter flights.

Background

Stewards provided the first in-flight service in the elegant dining rooms and private compartments of European airships between 1910 and 1937. In contrast to this luxurious and quiet mode of travel, the first paying airplane passengers in the United States traveled with the mail and fended for themselves.

In 1922, Daimler Airways of Britain hired the world's first airplane stewards, known as cabin boys. Selected on the basis of small stature and light weight, cabin boys provided general assistance and reassurance to passengers brave enough to fly the early flying machines but did not serve refreshments.

Stout Air Services of Detroit, which eventually became part of United Air Lines, hired male aerial couriers to serve aboard Ford trimotors between Detroit and Grand Rapids, Michigan, in 1926. Later, Transcontinental Air Transport, which eventually became Trans World Airlines (TWA), also hired male couriers on its trimotors. They were the sons of the airlines' investors and were promised that these jobs would launch their aviation careers.

Several airlines around the world introduced in-flight service in 1928. Western Air Express, forerunner of Western Airlines, began using stewards on its Los Angeles-to-San Francisco run to serve box lunches from a Los Angeles restaurant. Lufthansa of Germany hired a professional waiter to serve lunch on board its Junkers aircraft between Berlin and Vienna. Mexicana hired stewards on its Ford trimotors. Air Union, a forerunner of Air France, also employed stewards.

In 1929, Pan American Airways introduced the cabin boy type of attendant to serve on board Sikorsky flying boats and Fokker aircraft between Miami, the Caribbean, and South America. Food service was essential on flights to remote areas because there might not be food available for passengers along the way.

The crew often would bring several days' worth of food on the flight. The galley (kitchen) was in the tail of the flying boat. The cabin boys had to be small and nimble enough to crawl back to the galley, prepare the food, and serve it to the passengers. In May, 1930, New England and Western Airways was the first to employ African American attendants, Pullman railroad porters who had already been trained for on-board service.

On May 30, 1930, a more surprising and lasting innovation was brought into the airline cabin. Boeing Air Trans-

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port hired eight women to be the world's first airline stewardesses. Ellen Church, a registered nurse, is credited with convincing the company that would become United Air Lines to hire women cabin crewmembers. Pilots did not immediately welcome the women, and the pilots' wives were even less enthusiastic, but the flying public responded well.

Stewardesses went to work for Delta Air Lines in 1940, Continental Airlines in 1941, and Pan American Airways in 1944. The airlines had little choice but to hire women during World War II because all the able-bodied men were drafted into military service. By 1950, the stewardess was an integral part of air transportation. Her glamorous job was sought after by young women and idolized by little girls, but sometimes denigrated as being a glorified waitress.

In the mid-twentieth century, stewardessing was one of the few occupations open to women that provided adventure. Stewardesses personified the airlines for which they worked, were the main connection the public had with the airline, and were often used for promotional campaigns and advertising. On some airlines, stewardesses wore ethnic costumes as their uniforms. In the 1960's, miniskirts, hot pants, and sexist advertising overshadowed, but did not diminish, their safety responsibilities.

Qualifications

Body size and appearance dominated the hiring qualifications for the first in-flight personnel because of the constraints of the aircrafts themselves. Cabin ceilings were low and aisles were narrow in the early airplanes. Even though jet aircraft provided more space, stewardesses were still expected to be slim, have beautiful legs, and wear girdles. Weight checks were prevalent.

The original eight stewardesses were registered nurses. This was a requirement until nurses were needed in the military during World War II. Stewardesses could not be married, were age twenty-five or less, weighed no more than 115 pounds, and could be no taller than five feet four inches. Stewardesses had to retire at age thirty-two or when they got married.

The Civil Rights Act of 1964 promised equality for the cabin attendants, but it took a 1967 court case brought against Braniff Airlines by a stewardess to break down the marriage barrier. Until then, men who worked as stewards or pursers could be married and have children, but stewardesses had to remain single.

It took more litigation in the 1970's before women with children could work as flight attendants—the new nongender-specific job title. These changes, plus the removal of the maximum age cap, encouraged men and women to make cabin service a career. Flight attendants can work into their seventies or when they are pregnant, as long as they can perform their duties. Some stay on the job for fifty years.

Qualifications vary among the airlines and change as equipment, routes, job markets, and regulations change. Flight attendants must be in good health and pass a physical examination and drug test. They must have good eyesight, hearing, and communication skills and be able to handle stress, irregular working hours, and being away from home. Airlines generally require flight attendants to be at least five feet two inches tall in order to reach the overhead compartments. Weight should be proportionate to height.

The minimum starting age for flight attendants is between eighteen and twenty-one. Some new hires start much later, choosing cabin service as an exciting second career after working as doctors, lawyers, teachers, or in any other profession. A high school diploma is required, some college education and experience working with people is preferred. Speaking two or more languages is a plus, especially for international airlines. Flight attendants must be able to work well in teams. The ideal flight attendant is well groomed, friendly, resourceful, and confident.

Duties and Working Conditions

A flight attendant's most important responsibility is to provide for the passengers' safety. This begins with checking safety equipment, securing carry-on items, and making safety announcements about exits and emergency equipment such as oxygen masks and life vests. Flight attendants enforce Federal Aviation Administration (FAA) requirements such as fastening seat belts, use of electronic equipment, and no smoking.

Flight attendants help passengers stay safe when flying through turbulent air and take charge when dealing with an emergency landing or other problems. They handle medical situations, unruly passengers, and children flying alone. Flight attendants stand for long periods of time and must be able to push and pull carts that weigh from 150 to 250 pounds.

Food and beverage service on airlines has changed dramatically over the years. After elegant dining on airships came box lunches and coffee from thermoses served on airplanes. Fried chicken became a staple for most early airline meals. Food service improved as galleys were installed on larger aircraft. European airlines had always provided alcoholic beverages, but U.S. airlines did not begin to offer liquor or wine until 1950.

During the 1960's and 1970's, when the price of airline tickets was regulated by the Civil Aeronautics Board (CAB), airlines competed with each other through the in-flight service they provided. Jet aircraft made more elaborate meals possible and introduced two to three different classes of seating and service. The wide-body jets, especially the Boeing 747, dramatically changed in-flight service and flight attendant duties. Cocktails could be served in VIP lounges on an upper deck and meals could be cooked in a galley in the aircraft's belly and brought up to the main level by elevator.

The Airline Deregulation Act of 1978 gave the airlines greater economic freedom and drastically affected every aspect of air transportation, including in-flight service. As price became the major ticket selling point, the labor-intensive, service-oriented industry struggled to cope with the new rules. Job security was replaced with uncertainty and sometimes layoffs as established airlines filed for bankruptcy and new airlines came and went throughout the 1980's and 1990's.

Most airlines only provided the minimum number of flight attendants required by FAA regulations—one per fifty seats—and all the seats were usually filled. Food service was reduced and often eliminated for economy passengers. The snack bags which passengers grabbed before boarding were less ample than the box lunches of the 1920's.

Flight Attendants in the Twenty-first Century

Full-time flight attendants work 75 to 85 hours per month in the air and another 75 to 85 on the ground. Flight delays can extend these hours. The airlines provide hotel accommodations and allowances for meal expenses when attendants are away from their home base. If flight attendants do not live at their assigned base, they must commute to the base on their own time to start their work assignments.

Most airlines use computerized bidding systems for work assignments. The most senior employees get the first choice of assignments, which are made one month at a time. Flight attendants on reserve status must be ready to work when they are called. Starting salaries averaged $15,000 annually in 2001, with experienced flight attendants earning about $25,000 and some as much as $50,000. Experienced flight attendants may become pursers or supervisors or become involved in training and recruiting.

Flight attendants work in a confined, moving environment at high altitudes, breathing recycled air. Their work is strenuous and they are susceptible to back injuries. While doing mundane work with a smile, they must be ready to handle disruptive passengers, medical problems, aircraft emergencies, hijacking, and terrorist situations.

Flight attendants have worked to improve the environment for themselves and their passengers. Their efforts led to U.S. airlines banning smoking on domestic flights in 1990 and on international flights in 1997. Through their professional associations, they work for improved safety features and regulations. The Association of Flight Attendants is the world's largest flight attendant union, with about fifty thousand members at almost thirty airlines.

The benefits of this occupation are enormous for those who like to travel and work with people. Flight attendants travel while they are working and may be able to sightsee on their layovers. They receive free airline travel passes for themselves and family members and discounts on other travel accommodations. Flight attendants enjoy the satisfaction of helping people, and many have heroically saved lives.

Training

Only a small percentage of applicants are selected for training and not all of those pass the four to seven weeks of rigorous, intensive training and testing at the airline's training center. Trainees learn aviation terminology, company policy and operations, FAA regulations, and all about the airplanes on which they may fly.

Trainees must thoroughly understand safety procedures and equipment, demonstrate that they can perform such duties as putting out fires, evacuating aircraft, and helping passengers survive a ditching at sea. Trainees learn to give first aid and cardiopulmonary resuscitation (CPR) and to use a defibrillator (AED). As new equipment is developed, it is added to the training. Flight attendants are trained to be alert to potential medical and security problems.

Safety and emergency procedures are the most important aspects of flight attendant training, but attendants also learn how to project their airline's image through their appearance and the service they provide. They learn to prepare and serve elegant meals and beverages for first class, as well as fast service and clean-up on short hops. They are schooled in personal grooming, weight control, and how to wear their uniforms.

Upon successful completion of initial training, flight attendants are assigned a base. They spend a certain length of time on probation and on reserve status. They may have to relocate. Qualifications are maintained by participating in a minimum of twelve hours of recurrent training every year. Safety related topics are emphasized. Flight attendants sometimes train with the pilots and other personnel to improve teamwork and communication.

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See also: Air carriers; Airline industry, U.S.; Commercial flight; Emergency procedures; Food service; Training and eduction

Flight control systems

Definition: Electric, mechanical, and hydraulic systems that help to move an aircraft while flying.

Significance: Flight control systems allow pilots to adjust the speed, attitude, and direction of an aircraft.

Early History

The early experimenters and inventors who preceded Orville and Wilbur Wright, who made their first flight in 1903, did not fully appreciate the necessity for positive control of the machine. Prior to 1903, the prevailing ideas about aircraft control were that the airplane must have some kind of inherent stability and that the pilot's only function was to make small directional changes. Much of inventors' efforts prior to beginning of the nineteenth century were directed at obtaining a lightweight engine. The Wright brothers realized that a proper engine was a necessary ingredient in mechanical flight. However, they appreciated the importance of control and the fact that the pilot must be an active participant in the control of the airplane. By 1909, a control system had evolved consisting of ailerons, a rudder, and an elevator, which, in its essentials, remains in use today.

Types of Controls

Modern aerodynamic flight control systems, as opposed to engine controls, are essentially the same for all airplanes. Flight controls can be separated into two categories: primary and secondary controls. The primary controls change the angles that the airplane makes relative to the ground. The secondary controls are flaps that control the lift of the airplane, especially at low speeds, and tabs that reduce or eliminate the forces the pilot must exert on the controls in the cockpit.

All controls, whether primary or secondary, have three important subdivisions. The first are external moveable surfaces on the airplane, such as the rudder, aileron, and elevator. The second are the cockpit controls, which are moved by the pilot to change the direction of the airplane. The third are the links between the cockpit controls and the external surfaces of the airplane. These connections might be cables, electrical-conducting wires, electrical motors and computers, hydraulic lines, and hydroid motors.

Primary Controls

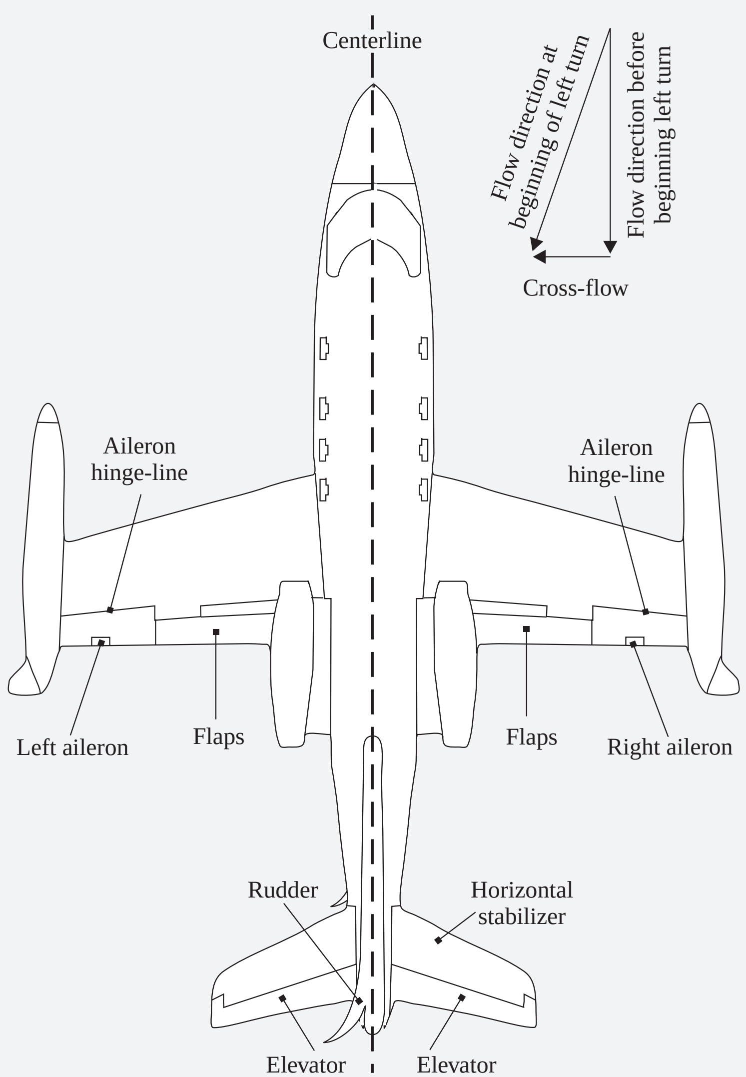
There are three categories of primary controls. Category A refers to the three hinged panels that are rotated about their hinge line to change the angular attitude of the airplane.

Category B controls are those which the pilot moves to change the direction of the aircraft and, to a limited extent, the speed of the aircraft, particularly the descent rate. These controls consist of the stick or wheel, which is moved to pitch and roll the airplane, and the rudder, which is moved to yaw the airplane. These controls have not changed significantly since 1915, during the second decade of mechanical flight.

Category C controls vary the most widely between different types of airplanes. These types of controls have also evolved most radically over the history of mechanical flight. A small, low-cost training plane connects the pilot's control to the aerodynamic controls with cables or push rods; hydraulic lines and associated motors perform the same function in high-speed commercial airliners. Electrical conducting wire or even fiber optic lines might be used to carry the control signal from the cockpit to an electrical motor at the surfaces in other commercial airplanes or high performance military airplanes.

The airplane responds to the movement of the primary category A cockpit controls in a number of ways. The ele-

Location of Airplane Controls



vator is deflected to change the pitch angle of the airplane: When the trailing edge of the elevator is moved upward, a down force is generated on the horizontal stabilizer. The result is that the nose of the airplane pitches upward. The airplane will pitch in the opposite direction if the trailing edge of the elevator is moved downward.

When the rudder is moved to the left side of the airplane, from the point of view of the pilot, a side force to the right is applied to the vertical stabilizer. This force swings, or yaws, the nose of the airplane to the left. Reversing the direction of the rudder movement will reverse the yaw direction.

Finally, movement of the ailerons causes the airplane to roll. The ailerons move differentially; when one aileron moves upward, the other moves downward. On the wing with the downward aileron, there is a slight increase in the lift. On the wing with the upward aileron, there is a slight decrease in lift. The unbalance in lift between the two wings causes the airplane to roll.

Cockpit controls are connected to the airplane's external controls. Moving the stick back brings up the elevator trailing edge, placing a down force on the horizontal stabilizer. The horizontal stabilizer and tail goes down while the nose goes up. Reversing the direction of the stick movement reverses the motion of the pitch of the airplane.

The rudder is moved by pushing on the rudder pedals located on the floor of the airplane. Pressing the left pedal causes the trailing edge of the elevator to move to the left, resulting in the application of a side force to the right on the vertical stabilizer. The tail of the airplane moves to the right, and the nose moves to the left. Moving the nose left or right is called yawing the airplane left or right.

Finally, the ailerons are moved by either sideways motion of the stick or rotation of the control wheel. To roll the airplane to the right, for example, the stick is moved to the right, lowering the left aileron and raising the right aileron.

Secondary Controls

The secondary aerodynamic controls are the tabs and the flaps, both of which can be operated by the pilot from the cockpit. The tab is a small elevator hinged to the trailing edge of the elevator. To hold the nose up for a prolonged period of time, the pilot must continually apply a backward force on the stick to keep the elevator in the up position. By moving the tab downward, in this case, a small force through leverage balances the much larger force on the elevator, with the result that there is no or little stick force required of the pilot to keep the elevator trailing edge upward. Tabs are found also on the rudder and aileron. On an airplane with two wing-mounted engines, a rudder tab is nearly essential in helping the pilot set and hold the extreme rudder deflection required for single-engine flight.

Flaps deflect in unison, unlike ailerons, which move differentially. Flaps help maintain lift, especially during low-speed flight. The pilot can control the deflection angle of the flap. Flaps are deflected at maximum deflection for landing and at a small angle for takeoff.

There are three basic flap designs. The split flap, the simplest but least effective, consists of a small plate that comes down from the lower surface of the wing. Because this flap does not change the contour of the wing, it primarily produces drag. The plain flap changes the shape of the wing and therefore produces lift as well as drag. The slotted flap is derived from the plain flap with special attention given to the junction of the flap and the wing. The design of this junction is crucial to the flap's effectiveness. The Fowler flap is the most effective and the most mechanically complicated flap. When deflected, it changes not only the shape but also the area of the wing.

There are two types of control used on airplanes: primary and secondary. Primary controls are the elevator, rudder and ailerons, and the primary cockpit controls are the stick and rudder, located in the cockpit. The secondary controls are tabs and flaps. The flaps allow the airplane to fly at lower speeds than would otherwise be possible. The tab allows the pilot to remove any forces required to hold control deflections. Tabs are usually located on the elevator and can also be found on the rudder and ailerons.

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See also: Ailerons and flaps; Airplanes; Cockpit; Landing procedures; Rudders; Stabilizers; Tail designs; Takeoff procedures; Wing designs

Flight plans

Definition: Documents used to track the progress of aircraft in flight.

Significance: The three types of flight plans, visual, instrument, and defense visual, enable air traffic controllers and flight service specialists on the ground to more accurately sequence aircraft into the nation's air traffic flow. Flight plans can also assist rescuers should an aircraft go down unexpectedly.

Flight Plan Information and Procedures

A flight plan contains information such as the aircraft's type, color, speed, special navigational equipment, and amount of fuel carried on board. It also contains information on the intended route of the flight, the expected cruising altitude, the destination airport and any potential alternate airports, the number of passengers aboard, and contact information for the pilot. It is important for the pilot to keep the various flight service stations informed about the progress of a flight should there be any unexpected delay during the flight. Flight service stations will begin to attempt to locate an aircraft if its flight plan is not expressly closed by the pilot within thirty minutes after the original expected time of arrival listed on the plan. It is precisely for this reason that many pilots are encouraged to file flight plans, as a source of insurance, especially if no one other than the pilot is aware of the pilot's intentions for a particular flight. Should something unexpected happen during the flight that forces it down away from the intended airport, the aircraft's whereabouts will be sought within a relatively short span of time. In the event of such an occurrence, the specialist in charge of the flight plan will begin attempting to locate the aircraft by telephone after the flight is thirty minutes overdue. Calls are initially made to the intended destination airport, to airports surrounding the intended destination, and even to the airport of departure in an attempt to locate the aircraft on the ground. Most such searches end with these telephone calls, because most often pilots merely forget to close their plans upon arrival at their destination. If such attempts are unsuccessful, however, more elaborate search procedures, involving local law enforcement, the Civil Air Patrol, and ultimately the United States Armed Services, are initiated.

There are three main types of flight plans: visual flight rules (VFR) flight plans, instrument flight rules (IFR) flight plans, and defense VFR (DVFR) flight plans.

Visual Flight Plans

VFR flight plans are most typically used by pilots of small, privately owned and operated aircraft, who operate aircraft by using outside visual references to the earth's surface. VFR flight plans are managed by a network of federal flight service stations across the United States. There is approximately one flight service station per state in the United States. These stations are primarily responsible for the gathering and dissemination of weather and other critical flight information to pilots for use in planning and flying a particular flight. The pilot places a VFR flight plan on file with a flight service station, either over the telephone or with an Internet-capable computer, shortly before departing on a flight. Most often, pilots place flight plans on file for cross-country flights to another destination, generally 50 nautical miles or more away. This flight plan is generally filled out in paper form and relayed over the telephone to a flight service specialist, who then copies the relevant data and keeps it on file for activation by the pilot. The specialist then enters the flight plan into an appropriate computer for dissemination to other flight service facilities as necessary.

Instrument Flight Plans

The second type of flight plan used in the United States is the instrument flight plan for pilots engaging in flight under IFR. These flight plans are reserved for civil aircraft using more complex forms of navigation than are used in small aircraft. All scheduled airlines and most other large aircraft operate under instrument flight rules. Although the routing and alternate airport requirements vary slightly on IFR flight plans, they are otherwise identical to VFR flight plans. IFR flight plans may be filed by the pilot, as are VFR flight plans, or they may be filed by a company dispatcher in the case of scheduled airline operations. Whereas VFR flight plans are optional at the discretion of the pilot, IFR flight plans are a requirement for flight under instrument flight rules, because they are used by air traffic controllers for the scheduling and coordination of air traffic. IFR flight plans are closed automatically by an air traffic controller upon the aircraft's landing at an airport, as long as that airport has an operating control tower. Otherwise, the pilot is responsible for closing the IFR flight plan, as with the VFR plan. Search-and-rescue procedures are the same for an IFR flight as for a VFR flight. However, an overdue aircraft operating under IFR will be missed sooner than an overdue aircraft operating under VFR, because IFR aircraft are either under radar surveillance or are required to make periodic position reports to air traffic control.

Defense VFR Flight Plans

The third type of flight plan is known as a DVFR flight plan. This type of a plan is filed when a VFR flight is entering the United States from another country or U.S. territory and will be penetrating the U.S. Air Defense Identification Zone (ADIZ). This is an area located just off shore that the U.S. Department of Defense uses for positively identifying all aircraft entering the United States. This type of flight plan is required of all VFR pilots entering the United States. It is otherwise the same as the previous two types of flight plans mentioned, except that a pilot must list the exact point of intended entry into the United States.

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See also: Air traffic control; Airports; Federal Aviation Administration; Landing procedures; Pilots and copilots; Takeoff procedures; Safety issues; Training and education

Flight recorder

Also known as: Black box

Definition: An instrument that records the performance and condition of an aircraft in flight.

Significance: The data retrieved from a flight data recorder can be used to generate a computer-animated video reconstruction of the flight of an aircraft, making possible the investigation and analysis of aircraft accidents or other unusual occurrences.

Flight Data Recorders

An aircraft flight recorder records many different operating conditions of a flight and provides information that may be difficult or impossible to obtain by any other means. By regulation in most countries in the world, newly manufactured aircraft must monitor at least twenty-eight important parameters. These include time, altitude, airspeed, heading, vertical acceleration, and aircraft pitch. Some recorders can record the status of more than three hundred additional in-flight characteristics that can aid in an accident investigation. Some of these include flap position, autopilot mode, and even smoke alarms. To ensure that a large amount of information is recorded, a flight recorder is able to record for at least twenty-five hours.

Computer programs have been written to take flight recorder data and reconstruct animated videos of aircraft flight. The animation allows the investigation team to view the last moments of a flight prior to an accident. In the event of an accident, investigators can visualize the instrument readings, power settings, airplane's attitude, and other important characteristics of a given flight.

Cockpit Voice Recorders

A cockpit voice recorder records the flight crew's voices, as well as other sounds within the cockpit. Communications with air traffic control, automated radio weather briefings, and conversation between the pilots and ground or cabin crew are recorded. Sounds of interest to an investigation board, including engine noise, stall warnings, landing gear extension and retraction, and any clicking or popping noises, are typically recorded. Based on these sounds, important flight parameters, such as speed, system failures, and the timing of certain events can often be determined.

In the event of an accident, an investigation committee creates a written transcript of the cockpit recorder tape. Local standard times associated with the accident sequence are determined for every event on the transcript.

Image Not Available

This transcript contains all the pertinent portions of the cockpit recording. Due to the highly sensitive nature of the verbal communications inside the cockpit, a high degree of security is provided for the cockpit recorder tape and its transcript. The timing of release and the content of the written transcript are strictly regulated.

History

The idea of a device to record both the voices and the instrument readings in the cockpit of an aircraft was originally conceived by Dr. David Warren at the Aeronautical Research Laboratory in Melbourne, Australia, in the 1950's. A demonstration unit was constructed in 1957. Although Australian aviation authorities did not initially approve the device, it was taken to Great Britain and the United States for further development.

On June 10, 1960, a Trans-Australian Airlines Fokker F-27 crashed while landing at an airport in Queensland, Australia, killing all twenty-nine people on board. The subsequent board of inquiry was unable to arrive at any definite conclusions as to the factors underlying the accident. The board recommended that all airliners be fitted with flight recorders. In 1961, Australia became one of the first countries to make flight recorders mandatory in aircraft. Any craft with a takeoff weight greater than 12,568 pounds must carry both a cockpit voice recorder and a flight data recorder.

Flight recorders and cockpit voice recorders, also known as black boxes, are actually painted bright orange to aid in their recovery following an accident. They have provided critical clues in solving the mysteries associated with many of the world's air disasters and have also been invaluable in helping to prevent future accidents.

Specifications

Flight recorders and cockpit voice recorders are housed in titanium boxes that are lined with many layers of insulating material. This design protects the recorders against impacts that produce accelerations up to 3,400 times the acceleration of gravity, against fires of up to 2,000 degrees

Fahrenheit (1,093 degrees Celsius), and against pressures at water depths of up to 20,000 feet. The recording devices are protected against contact with seawater and inadvertent erasure of recorded information. These specifications preserve the devices in the most serious accidents and in extreme climatic conditions. In addition, the boxes are fitted with battery-powered ultrasonic beacons that aid with underwater recovery. The beacons can transmit pulses from water depths of up to 14,000 feet for at least thirty days over a range of 2 miles.

Because they are more reliable and require minimal maintenance, computer memory chips have replaced most magnetic tapes as the recording media. Flight recorders are connected to a flight data acquisition unit that processes, digitizes, and formats the data for recording on the memory chips. Both the flight recorder and the cockpit voice recorder are carried in the tail of an aircraft. Flight data recorders reveal what happened in an accident, whereas cockpit data recorders reveal why it happened.

Even before a crash occurs, it is possible to monitor the safety of flights by using a quick access recorder. This device records even more parameters than a typical flight recorder and samples the data at higher rates for a longer duration of time. The data are stored on an optical disk and can be studied to identify problems before they become fatal. A ground-based computer analyzes the data and determines what is going wrong, rather than what went wrong.

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See also: Accident investigation; Airplanes; Cockpit; Communication; Emergency procedures; National Transportation Safety Board; Pilots and copilots; Safety issues

Flight schools

Definition: An institution that provides the education and training necessary for a student to learn to pilot an aircraft.

Significance: Flight schools educate pilots and prepare them for certification. Flight schools teach pilots who intend to fly for their personal enjoyment, who intend to pilot commercial aircraft, and who intend to pilot military aircraft.

History

In the early days of aviation, there were no government regulations to control the certification of pilots. Learning to fly was largely a matter of experimentation, observation of others who knew how to fly, and trial and error. As the field of aviation evolved, the need for more formal methods of training pilots became apparent. Flight schools first began to appear in the late 1920's. Parks College was the first flight school to be awarded a Transport and Limited Commercial Ground and Flying School Certificate, granted in 1929 by the U.S. government. During the Great Depression years of the 1930's, the few flight schools in existence were fortunate if they were able to stay in business, and significant growth in flight training did not occur until the early 1940's.

The outbreak of World War II generated a need for a number of pilots, each of whom needed to be trained to a certain standard in a relatively short amount of time. In 1939, the U.S. Congress appropriated four million dollars to create the Civilian Pilot Training Program. The flight training done under this program was conducted at more than 400 colleges nationwide. After World War II, there continued to be a strong interest in aviation, particularly by the returning veterans. The G.I. Bill (1944) provided funding for veterans to obtain flight training, and thousands of students took advantage of this program. This source of income provided a foundation for flight schools to continue to grow and prosper.

Pilot training today is regulated by the Federal Aviation Administration (FAA), an agency of the federal government. The FAA issues Federal Aviation Regulations (FARs), which are the rules that govern aviation in the

United States. These rules include the certification of pilots and aircraft and the governance of flight operations. Flight schools train prospective pilots to meet the certification requirements specified by the FARs for various levels of pilot certificates and ratings.

Types of Schools

There are a number of different types of institutions that provide flight training and education in the United States. These include fixed-base operators (FBOs), collegiate aviation programs, proprietary professional aviation academies, and military programs. The type of flight school best suited to a particular student depends on that student's goals and intentions in aviation.

FBOs are businesses that operate at airports. They often provide a variety of services to the aviation community, including aircraft rental, maintenance, refueling, and the sale of aviation equipment, in addition to pilot training. Pilot training at this type of facility is typically tailored to an individual's schedule and personal goals. This type of flight school is usually attended by students who are interested in flying for pleasure or for personal business transportation.

Collegiate aviation programs, available at both two-year and four-year institutions, are designed for those students who wish to pursue a career as a pilot. Both types of institutions typically provide flight training through at least the Commercial Pilot Certificate, and usually the Certified Flight Instructor Certificate. Graduates of two-year programs receive an associate of science degree, whereas graduates of four-year programs receive a bachelor of science degree. In addition to completing the required ground and flight training for a Commercial Pilot Certificate, students at these institutions complete course work in a variety of areas important to understanding aviation. These may include maintenance, weather, aerodynamics, and aviation management courses. There are more than one hundred colleges and universities, large and small, that offer flight training as part of the curriculum for a degree. The Council on Aviation Accreditation is the accrediting body for collegiate aviation programs, and most reputable college programs have received accreditation by this organization.

Proprietary professional aviation academies are also designed for those students who wish to enter the aviation profession as a pilot. These schools typically provide training through at least the Commercial Pilot Certificate, and often through the Certified Flight Instructor Certificate. Enrollment in this type of school is most often a full-time endeavor. Since the late 1980's, the educational requirement for career advancement to a position as a pilot for a major airline has been a four-year college degree, so a number of proprietary aviation academies are also associated with a collegiate institution.

Military flight schools are utilized to train those personnel accepted into a branch of the U.S. Armed Forces for a pilot position. These programs provide high-quality initial training in basic piloting skills, followed by training in the specific type of aircraft and operation to which the person is to be assigned. The training period for both the initial course and the advanced course is typically one year each. The U.S. Army, Air Force, Navy, Marine Corps, and Coast Guard each have personnel assigned to pilot positions. The training for these personnel are conducted at various military bases throughout the country.

Whatever the type of institution, a flight school will provide a fleet of aircraft in which to conduct training, and a staff of certified flight instructors (CFIs) to provide flight training. Both the size of the aircraft fleet and the size of the CFI staff may vary from one to more than one hundred.

Types of Training Offered

At any of the civilian institutions described above, flight training may be conducted under either FAR Part 61 or FAR Part 141. Part 141 specifically describes minimum requirements regarding training facilities, personnel, course syllabi, and student performance rates for FAA-approved flight schools. Programs conducted under Part 141 are subject to continuing oversight and approval by the FAA. Collegiate and proprietary aviation academies are typically certified under FAR Part 141, although a number of FBOs also have Part 141 certification. FAR Part 61 specifically governs the certification of aircraft and pilots, and flight training can also be conducted under this part. Often, training for students who are interested in flying for their personal benefit or enjoyment is conducted under Part 61 at a local airport FBO, whereas training for students who desire a career as a pilot is conducted at a Part 141 school. Part 141 schools tend to be more structured and formalized, and Part 61 schools tend to be tailored more toward the individual requirements of the person receiving training. For example, a businessperson who wants to obtain a pilot certificate for transportation purposes may desire to participate in flight training only twice a week and at a different time each week. This type of schedule is often best accommodated at a local airport FBO under Part 61. A person interested in a career as a pilot would most likely desire to pursue this goal in a full-time capacity, and many Part 141 schools can accommodate this arrangement.

Types of Certificates

There are a number of types of pilot certificates issued by the FAA. These include the Recreational Pilot Certificate, the Private Pilot Certificate, the Commercial Pilot Certificate, the Certified Flight Instructor Certificate and the Airline Transport Pilot (ATP) Certificate. Training to obtain any one of these certificates involves a specified minimum of both flight and ground training, often called ground school. Both the Recreational and Private Pilot Certificates are designed for individuals who wish to fly for their own personal enjoyment. The Recreational Pilot Certificate has a number of limitations, such as the requirement that recereational pilots remain within 50 nautical miles of the departure airport, carrying no more than one passenger, and that a recreational pilot not fly an aircraft with more than four seats. The Private Pilot Certificate allows more freedom, with no limit on passengers or distance from the departure airport.

The Commercial Pilot Certificate is required in order for a pilot to be paid for flying an aircraft. The CFI Certificate is required to be able to instruct others in flight training, and the ATP Certificate is required to be a captain (or pilot in command) of an aircraft operated by a commercial air carrier. In addition to these certificates, an important rating that can be added to the Private and Commercial Certificates is the instrument rating. The ATP Certificate essentially includes an instrument rating as part of its privileges and limitations. The instrument rating allows pilots to fly in bad weather, called instrument meteorological conditions, which include such things as clouds or low visibilities. Before obtaining an instrument rating, pilots are restricted to visual meteorological conditions, which means they must maintain certain minimum visibilities and distances from clouds. If a person intends to use aviation as a dependable and regular means of personal transportation, obtainment of an instrument rating is essential. If a pilot is to fly for hire, an instrument rating is likewise required.

One additional rating that must be obtained before flying an airplane that has more than one engine is a multiengine rating. Since most flight students first learn to fly in a single-engine aircraft, this rating is usually added to an existing Private or Commercial Single-Engine Certificate. CFI and ATP Certificates also specify whether the pilot has single-engine privileges, multiengine privileges, or both.

Ground Training

Training conducted at flight schools, while often termed flight training, in reality consists of both ground training and training in an actual aircraft. Ground training may be conducted in a formal classroom setting, with a number of students receiving instruction from a teacher, or it may be conducted informally by a student's flight instructor before or after a flight. Typically, Part 61 flight schools tend to use more informal methods, whereas larger Part 141 flight schools and college programs tend to use traditional classroom settings for ground school. Again, the best method depends on the interests and background of the flight student.

Ground school covers a variety of topics, including applicable FARs, aircraft systems and performance, aerodynamics, weather, flight planning, and navigation. Often, flight schools own one or more flight-training devices in addition to their fleet of aircraft. These flight-training devices are more simplified versions of what are commonly known as flight simulators. Most often, they have a cockpit mock-up and a rudimentary visual display. However, there is no movement of the device in response to aircraft control movements. These devices are used most heavily during training for the Instrument Rating. Students working on this rating receive training in these flight-training devices in addition to conventional ground school and flight training in an aircraft.

Obtaining a Pilot Certificate

To obtain any level of pilot certificate or rating, an applicant must do a number of things. First, the ground and flight instruction specified by the FARs must be obtained from and certified by a CFI. A knowledge test, administered in a computer-based testing format, must be taken and passed with a minimum score of 70 percent. An appropriate medical certificate must be obtained from an aviation medical examiner for the level of certificate desired. For example, for a Private Pilot Certificate, a third-class medical certificate is required. For a Commercial Pilot Certificate, a second-class medical certificate is required, and for an Airline Transport Pilot Certificate, a first-class medical certificate is required. Finally, a practical test is conducted by a pilot examiner. This test consists of both an oral exam and a flight exam. During the oral exam, the examiner will cover items such as aerodynamics, weather, aircraft systems, aircraft performance, and flight planning. During the flight, a series of maneuvers will be evaluated to determine whether the applicant meets the minimum standards specified for the certificate for which he or she is applying. If the check ride is satisfactory, the student will be issued the certificate for which he or she applied.

Selecting a Flight School

A flight school is best selected by considering the needs of an individual. Such items as the location of the school and the schedule of lessons are key issues, as are the types of training typically conducted and the structure of the school, for instance, whether it is geared toward those interested in aviation as a profession or toward those interested in learning to fly for fun. Other things to consider are the size and availability of the training aircraft fleet and the availability of instructional staff. The school's safety record, how long the school has been in operation, and its reputation are also important. In addition, maintenance of the training fleet should be examined. Many schools offer an introductory flight lesson, during which a CFI will allow a prospective student to manipulate the controls of the airplane in flight. This provides an opportunity for the prospective student to examine the flight environment firsthand, as well as a chance to experience a representative training aircraft and instructor.

One aspect of the decision regarding a flight school selection involves whether to select a FAR Part 141-approved flight school or a FAR Part 61 flight school. To obtain a Private Pilot Certificate, thirty-five hours of flight training are required under Part 141, whereas forty hours of flight training are required under Part 61. However, the national average of flight hours to obtain a Private Pilot Certificate ranges from sixty-five to seventy hours, so it would be an error to base a decision to use a Part 141 school instead of a Part 61 facility solely on the flight-time requirement for a Private Pilot Certificate. If a student is interested in pursuing a Commercial Pilot Certificate, there is a flight-time benefit in utilizing a Part 141 flight school. The flight time required for a Commercial Pilot Certificate is 250 hours under Part 61 and 190 hours under Part 141.

Cost of Flight Training

The cost of flight training varies widely depending on the area of the United States in which a student resides and the type of flight school attended. Many flight schools offer package deals for flight instruction, but it is important to understand what items are included in the package. During flight training in an aircraft, both an airplane rental fee and a flight instructor's hourly fee are charged. Aircraft used for instruction usually have a digital recording clock, called a Hobbs meter, which records the amount of flight time for a given flight by subtracting the Hobbs meter reading at the beginning of the flight from the Hobbs meter reading at the end of a flight. Preflight and postflight briefing time, which is conducted by a student's CFI and which is necessary for effective flight training, is also billed.

The most common type of package offer includes the cost of these items up to a certain number of hours, with excess hours becoming the student's responsibility if they are required. Other packages may guarantee obtainment of a certificate, with no maximum number of hours specified, although there are often many other stipulations in this kind of package. The minimum time required by the FARs to obtain a Private Pilot Certificate under FAR Part 61 is forty hours: twenty hours with an instructor, called dual instruction, and twenty hours of solo flight time. For flight-school package offer-comparison purposes, however, an average student usually requires from sixty-five to seventy hours to obtain a Private Pilot Certificate, with forty to forty-five flight hours of dual instruction and twenty-five hours of solo flight time.

The total cost of a university education, including the obtainment of Commercial Pilot and Certified Flight Instructor Certificates as well as a four-year degree at a private university, can equal more than $100,000. However, much of this cost would also be incurred in the course of obtaining a bachelor's degree from a private university in a field other than aviation. The cost is typically less at state-supported universities and less still at junior colleges or community colleges. Often, two-year program graduates can continue their studies at a four-year university to complete a bachelor of science degree.

The cost to attend a proprietary professional academy, usually resulting in the obtainment of Commercial Pilot and Certified Flight Instructor Certificates, can range from approximately $50,000 to $85,000. This type of program is often selected by individuals who have already obtained a four-year college degree and who are interested in changing careers. The sole focus on flight training allows such individuals to accelerate their training so they can begin to pursue their new career path. In addition, there are students who choose to enroll in this type of program right after high school, and then serve as certified flight instructors while earning their college degrees.

Other Types of Flight Schools

The preponderance of flight schools in existence in the United States are for airplane pilots. However, in addition to training for pilot certificates for airplanes, there are also flight schools that conduct specialized training in other types of aircraft or operations. For example, helicopter pilots, glider pilots, pilots involved in agricultural operations, and seaplane pilots are required to receive appropriate ground and flight training for the type of operation and aircraft they pilot. Some large flight schools conduct these types of training in addition to more traditional airplane pilot training, whereas other schools choose to specialize in a niche market.

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See also: Federal Aviation Administration; Military flight; Pilots and copilots; Training and education

Flight simulators

Definition: Devices which are used to enable a person to experience flight situations and/or movements without actually flying in an aircraft or spacecraft.

Significance: Flight simulators can save time and money in the training of pilots. They are also used in flight testing to investigate the stability, control characteristics, and behavior of aircraft and spacecraft, allowing detailed and realistic simulations of all aspects of flight with no risk to either vehicle or pilot.

Flight simulation involves the use of a ground-based device to enable a pilot, student pilot, or an aerospace engineer to experience or evaluate the behavior of an aircraft or spacecraft in flight. The inside of the simulator looks like the cockpit of an airplane or spacecraft.

In the course of the first century of human aviation, flight simulators have evolved from crude devices consisting of little more than a chair and a set of imitation controls mounted on a wood platform that can be pitched and rolled by training personnel, to multimillion-dollar computer-controlled aircraft or spacecraft cockpits that can duplicate every conceivable motion and reaction of the real vehicle.

Every child who has placed a chair in a large cardboard box and used anything from a broomstick to a baseball bat to pretend to control a make-believe airplane has experienced flight simulation at a very basic level. Flight simulators allow people to "pretend" to fly.

Teaching Tools

An important use of flight simulators is to help teach pilots how to fly an airplane with only their instruments to tell them the position, attitude, and direction of flight of their airplane. An important aspect of such training is teaching pilots that they cannot rely on the body's natural senses of sight and balance to fly under "instrument flight conditions"; they learn to fly using the information provided by the flight instruments alone. A simple desktop computer screen and a set of airplanelike controls can be used with any of many flight simulator computer codes to accomplish this task. Older pilots will recall training in simulators that were made to resemble little airplanes with small wings and tails and that were mounted on mechanically or hydraulically powered platforms designed to move the small cockpit like an airplane as the pilot "flew" the trainer, using an array of instruments identical to those on a real instrument panel.

Pilots of craft, from fighters to general aviation craft to space shuttles, train in sophisticated flight simulators in which the pilot can see realistic in-flight images of sky, terrain, and airports and learn to fly the vehicle using both its instruments and the simulated view from the cockpit. The simulator can, with the flick of a switch or the turning of a knob, subject pilots to the conditions they would face with the loss of an engine, severe turbulence and weather, loss of part of the control system, or almost any other emergency imaginable.

There is continued debate about whether training is more or less effective when the simulator moves to replicate the body forces which pilots might experience in training maneuvers. Both moving and nonmoving simulators are used in teaching pilots how to react to almost any situation that may be encountered, ranging from an ordinary flight to a severe emergency.

Research and Development Tools

These same simulators are used to study ways to improve the control systems of airplanes and spacecraft. Engineers can write "control law" equations that will alter the way the vehicle behaves in flight, simulating everything from a shift in payload weight, to the loss of a rudder in combat, to a complete redesign of the airplane wing or tail. Simulators are used to investigate such changes and events without risk of loss of life or vehicle in a flight test. If there is any question of control system failure or problems in an aircraft accident, simulators are used to determine the effect of that loss on the performance and handling of the plane and to compare the test results to the facts known about the accident. Using these control laws, every newly designed aircraft is "flown" for hundreds of hours in the simulator before a test airplane ever leaves the ground; it has become commonplace for the test pilot to report after the first flight that the plane flew just like it did in the simulator.

Some of the world's most sophisticated flight simulators are used in the design and development of military aircraft such as fighters. Several government facilities have twin simulators in which two fighter pilots can fly simulated dog-fights against each other with the "enemy" simulator programmed to handle like real enemy aircraft. The simulators are coupled in such a way that the two pilots can see the opponent aircraft projected onto huge screens surrounding their multimillion-dollar full-motion flight simulators. This type of simulation allows the military to determine the best maneuvers for use in aerial combat and to design or redesign their aircraft and control systems to give them the edge in a fight.

Dozens of very sophisticated flight simulator programs and games now on the market allow anyone with a home computer to experience flight simulation. Many of these programs provide excellent simulations of actual airplane motion and control effectiveness, rivaling that of real flight training simulators. Some of the best such programs have been developed using the control laws of real aircraft, both modern or historic, and can give users an outstanding feel for the thrill of flight in their airplane of choice.

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See also: Accident investigation; Airplanes; Cockpits; Fighter pilots; Flight control systems; Instrumentation; Pilots and copilots; Space shuttle; Spaceflight; Testing; Training and education

Flying Fortress

Also known as: B-17, Flying Fort, Fortress

Date: First prototype built in 1935; production ended in 1945

Definition: A four-engined heavy bomber of World War II; one of the most important bombers of any kind in that war, it was legendary for the amount of battle damage it could absorb and still fly back to its base.

Significance: Considered one of the greatest military aircraft of World War II, the Boeing B-17 was a mainstay of the U.S. daylight strategic bomber fleet that helped defeat Germany. The B-17 also confirmed belief in the efficacy of strategic bombing, which continued as U.S. military policy for the next three decades.

The B-17 was born in 1937. The Boeing company had privately designed and made the Model 299 prototype when the U.S. Air Corps needed a heavy bomber to replace the smaller, slower Martin B-10. The early B-17's, B through D models, had no tail turret, no forward armament, and no ball turret; they had .30-caliber machine guns, which proved too light for defense against German fighters. After some combat experience with the early B through D models, the B-17E was designed with increased armament, entering service in 1941. This became the general type on which all later models were based. Over twelve thousand B-17's of all types were built through 1945. Most B-17's saw service in Europe, although they were also used in the Pacific and other theaters.

Specifications

The B-17 was a midwing monoplane constructed of aluminum skin over a steel and aluminum framework. The wingspan was just over 103 feet; the plane was just over 74 feet long. The four engines, two in each wing of the aircraft, were turbocharged 1,000-horsepower Wright radial engines, powering the plane to a maximum speed of more than 300 miles per hour, with a service ceiling of between 34,000 and 38,000 feet. The aircraft was unpressurized; aircrew breathed from an oxygen system and were thickly dressed against the thin air and subzero temperatures of the high bombing altitudes. Armor in the plane shielded each position. The B-17 was capable of carrying up to 17,600

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pounds of bombs, depending on the length of the flight, the types of bombs carried, the target, and the amount of fuel needed. Without extra tanks in the bomb bay, the maximum amount of fuel that could be carried was 780 gallons.

The B-17 carried a crew of ten men in its fuselage: the pilot and copilot in the cockpit, bombardier and navigator in front of them in the nose of the plane; the flight engineer (who also was top turret gunner) standing in a motorized turret directly behind and slightly above them; and the radio operator (who also operated a machine gun) behind the flight engineer. Beyond the bomb bay were two waist gunners, each with a .50-caliber machine gun; at their feet was the revolving Sperry ball turret, which contained one gunner, curled up in the ball turret and operating two machine guns. The tail of the plane contained two more .50-caliber machine guns, operated by the tail gunner. There were various configurations—some standard, some individually rigged by crews after hard experience—of .50-caliber machine guns in the nose, operated by the navigator and bombardier, until the development of the G model, which had a chin turret containing two .50-caliber machine guns under the nose.

B-17's were modified in several different configurations. Some B-17's dropped lifeboats mounted under the belly of the plane; others were fitted with radar and used for search and antisubmarine warfare. The YB-40, conceived as a bomber escort, carried no bombs, but had extra machine guns and ammunition. It proved to be too slow and was not built in numbers.

Combat and After

One major reason for the fame of the Flying Fortress was the amount of battle damage it could absorb and still make it back to base after a bombing run. Flying Fortresses could return to base with only two of the four engines operating; with tail, wing, and nose surfaces sheared off; and with holes made by bullets and cannon shells peppering the fuselage. Many wounded airmen credited the B-17 with saving their lives. The aircraft was not invulnerable, however—four thousand B-17's were destroyed in combat during the war. Attrition was highest before Allied fighters with auxiliary fuel tanks began escorting the bombers on missions in 1943. B-17's usually flew in a combat formation that maximized the defensive firepower of the aircraft as well as the aircraft surrounding it. Missions could last up to eight hours from takeoff to the return of the planes to their bases.

B-17's were superseded in the Pacific by the larger, faster B-29's. Many B-17's were converted and used as aerial spraying planes, transports, water-bombing planes for fighting forest fires, and for other uses. Of the over twelve thousand Flying Fortresses built, most were scrapped after the war, but many B-17's remain intact, retained or reconverted to military status by collectors and historic aircraft foundations. Many serve as static displays or "gate guards" at military (especially Air Force) bases and museums throughout the United States and Europe. Many others are still flying in the United States and Great Britain as part of historic aircraft collections.

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See also: Air Force, U.S.; Bombers; Dresden, Germany, bombing; Firefighting aircraft; Military flight; World War II

Flying Tigers

Also known as: American Volunteer Group

Date: From April 15, 1941, to July 4, 1942

Definition: A group of American civilians flying fighter planes for the Chinese against the Japanese during World War II.

Significance: The Flying Tigers helped keep supply lines open to the Chinese Nationalist government in southern China during World War II.

Background

In 1941, war between the United States and Japan seemed imminent. The Japanese had been bombing Chinese cities since 1937 and had virtually destroyed China's Air Force. The idea for a group of American volunteer pilots to assist the Chinese in their struggle, similar to the Lafayette Escadrille of American volunteers who flew for France during World War I, had been brewing for some time.

Claire Lee Chennault and the Volunteers

Claire Lee Chennault, a retired Army Air Corps captain and air advisor to China, was authorized by Nationalist leader Chiang Kai-Shek to form a volunteer group consisting entirely of American airmen to protect China's skies and to help train Chinese aviators. The idea was sold to President Franklin D. Roosevelt, who, on April 15, 1941, signed an executive order authorizing the formation of the American Volunteer Group (AVG), as the Flying Tigers were officially known.

The order permitted members of the U.S. Navy, U.S. Marine Corps, and U.S. Army Air Corps to resign from their branches of service with the assurance that they would be reinstated to their former rank or grade upon completion of their contract. The Flying Tigers were to defend the Burma Road, China's lifeline to Burma and Indian Ocean ports. Because the United States technically remained at peace with Japan in April of 1941, the plan required some subterfuge. Central Aircraft Manufacturing Company (CAMCO) was chosen as a cover. CAMCO, owned by William Pawley, had an aircraft factory at Loiwing, China, supplying parts and planes to Chiang's air force. The volunteers signed one-year contracts with CAMCO to perform certain services not technically relating to combat.

Training and Combat

In September, 1941, Chennault and the volunteers gathered in Toungoo, Burma (now Myanmar), about 170 miles north of Rangoon. At Toungoo, Chennault taught and trained his pilots in the intricacies of the P-40 Tomahawk, the volunteers' fighter plane, and taught them how to use the P-40 against the Japanese fighter pilots. Chennault emphasized that although the Japanese fighter planes had superior maneuverability and rate of climb, the P-40 had superior armor, firepower, and diving speed.

The Flying Tigers first clearly demonstrated their abilities on December 20, 1941, when they attacked a formation of ten Japanese bombers on its way to Kunming (K'un-ming), the capital of Yunnan (Yün-nan) Province, China. Only one Japanese bomber returned safely to its base. During January and February, 1942, the Flying Tigers began compiling the extraordinary record of victories that placed them firmly in history.

Flying into History

Over the skies of Myanmar and China in January and February, 1942, the Flying Tigers destroyed at least 217 enemy aircraft in thirty-one encounters and lost only six pilots. It was during these two months that the Chinese dubbed the AVG the Flying Tigers. AVG personnel painted the sharp-toothed mouths of sharks on the noses of their P-40's.

The men of the AVG did not always fly P-40's. In March and April, 1942, the AVG obtained P-40E Kittyhawks as replacements for lost P-40's. The P-40E's had all the instrumentation that the original Tomahawks never had as well as six free-firing .50-caliber machine guns in the wings and bomb racks. When Japanese planes were hit by a P-40E's machine guns, the Japanese planes would often disintegrate in the face of a single well-aimed burst.

Disbandment

After the Flying Tigers disbanded, members who wished were absorbed on July 4, 1942, into the United States Tenth Air Force, which became the nucleus of the China Air Task Force and was reorganized in March, 1943, as the Fourteenth Air Force. This group remained under the command of Chennault, who was promoted to brigadier general. During their six and one-half months of aerial combat, the Flying Tigers destroyed 297 enemy planes, with another 153 probably destroyed. Twenty-two AVG personnel lost their lives. The Flying Tigers were so important to the war effort that Winston Churchill lauded them on the floor of Parliament in London. Starting with the Japanese attack on Pearl Harbor, the United States suffered a number of disasters. As a result, Americans saw the AVG in Myanmar as one early bright spot in the war against Japan.

A great many Flying Tigers later became airline captains. One even started his own airline, with the help of several members of the group. Some became test pi-

The Flying Tigers painted shark teeth on their P-40's to symbolize their ferocity in keeping Chinese supply lines open in the face of Japanese aggression in the early days of World War II. (Digital Stock) lots. Others went on to successful military and business careers.

Dana P. McDermott

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See also: Air Force, U.S.; Fighter pilots; Pearl Harbor, Hawaii, bombing; World War II

Flying wing

Also known as: All-wing and *nurflügel*

Definition: The American term given to airplanes that are predominantly the lifting component, the wing.

Significance: The all-wing design was among the earliest aerodynamic ideas for reducing drag and costs through high efficiency. Its simplicity has challenged generations of designers, teaching them many aerodynamic fine points.

Early Development

Before the invention of the airplane, English physicist Sir George Cayley, who in 1853 built the first manned glider, suggested that flying machines would be most efficient if they were only a wing. After the airplane became a reality in the early twentieth century, most successful airplane designs were linear. Their noses sported vertical or horizontal stabilizers, or perhaps an engine, and worked backward toward the cockpit, wings, rudimentary fuselage, and vertical or horizontal stabilizers, or both.

Airplanes are engineered to suit mathematical logic and economic reality. Pilots seek aerodynamic poise, while passengers seek comfort and amenities. Operators measure an aircraft's reliability, and accountants measure its economy. Most people also judge airplanes for their inspiring beauty. One design, the flying wing, exhibited grace, economy, and performance. Inspired by Cayley's belief in eliminating the drag and weight of fuselages and tails, the flying wing has long been aviation's Holy Grail. Because all-wing airplanes need fewer parts and construction steps than do conventional designs, they are more energy-efficient both to build and to operate. Still, flying wings are rare.

During and after World War I, the development of aircraft engines quickly overpowered the aerodynamic drag produced by early airplanes. This development spelled doom for the flying wing design. Because airplane designs were still new, people had little preconception of how airplanes should appear. By the 1940's, airplanes had proved viable, and society's view of airplanes included a fuselage and tail. The economic boom and low energy costs had made conventional designs inefficiencies tolerable.

The earliest flying wings, sporting vertical stabilizers, were not purely wing-only designs. In 1907, British airpline designer John William Dunne showed that conventional tails were unnecessary. His balanced aerodynamics have infused tailless and all-wing airplanes ever since. By 1930, Germany's Walter and Reimar Horten first flew their model all-wing airplane, called a *nurflügel* in Germany. In 1933, the Hortens flew a manned all-wing glider model called the HO-1. Knowledge gained from the HO-1 inspired the HO-5, a twin-engine machine potentially leading to an all-wing fighter. German general Ernst Udet, long appreciating the Hortens' *nurflügel* ideas, succumbed to political blame for other project failures and in November, 1941, took his own life. Germany's all-wing idea had lost a patron, and the proposed all-wing fighter languished until 1945, when advancing American soldiers discovered one nearly completed twin-jet HO-9 fighter. Other Horten all-wings flew as developmental projects. However, the most ambitious project, the HO-18 long-range heavy bomber, remained only an idea.

Northrop's All-Wing Designs

In the United States, John Knudsen Northrop dreamed of flying wings. His single-seat 1933 design, the Model 1, had thin, tubular twin booms supporting a conventional horizontal stabilizer with twin rudders. Northrop began testing a true *nurflügel* in July, 1940, when the N-1M first flew. It was a flying laboratory, designed to change configurations between flights. Changes in wingtip droop, sweepback (the taper of the wing's leading edge), and wing dihedral (angle of the wingtips) could provide a bank of information. The Americans considered building a medium bomber based on the N-1M. Encouraged, Northrop continued testing predominantly all-wing airplanes, including four N-9M engineering test airplanes. Although one N-9M crashed, the remaining crafts saw duty as trainers, giving pilots firsthand experience with the flight characteristics of all-wing airplanes.

Following World War II, Northrop built the prototype XB-35 all-wing bomber, a six-engine, propeller-driven pusher design that was a true wing-only machine. Jet engine technology was making propellers obsolete for combat airplanes, so Northrop soon rebuilt the XB-35 into the YB-49, an eight-engine all-jet bomber. Although the YB-49 project did suffer airplane loss, the design was sound, and officials who were influential in procurement favored the U.S. Air Force's adoption of the YB-49. However, the project was mired in political intrigue, dooming America's flying wing. So sour were the feelings of those involved that Air Force secretary Stuart Symington ordered not only the flying wing's cancellation in 1950 but also the destruction of all XB airframes. None remained even for museum display.

The Stealth Bomber

Four decades later, on November 22, 1988, the Air Force unveiled the B-2 stealth bomber, designed by the Northrop Corporation, to the American public. Several years earlier, Northrop company officials had secretly revealed the airplane to the eighty-five-year-old Northrop, who died the following year, knowing that his dream would finally fly. In 1996, the McDonnell Douglas Corporation revealed its idea of a BWB-1 (blended-wing body) airliner to seat 800 passengers. Efficient design would permit the three-engine jet to operate at about two-thirds the cost of a conventional airplane of the same capacity. In 2001, Northrop Grumman used company funds to construct an all-wing uncrewed combat air vehicle (UCAV) for aircraft carrier use. With leading edges swept back 55 degrees and trailing edges sweeping forward 30 degrees, the inherently stealthy design was a logical step in airplane development toward autonomous, or "smart" aircraft. To meet the military's need for extended endurance, the Northrop Grumman Corporation began to look at extensions on each wingtip, transforming the UCAV's aggressive arrowhead shape into the more elegant, traditional all-wing design.

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See also: Aerodynamics; Airplanes; Bombers; Sir George Cayley; Experimental aircraft; Heavier-than-air craft; Stabilizers; Stealth bomber; Ultralight aircraft; Uninhabited aerial vehicles; Wing designs

Fokker aircraft

Definition: Aircraft designed and produced by Anthony Fokker or by companies under his ownership or direction or that bear his name.

Significance: Fokker aircraft have played a significant role in the history of aviation. Innovative designs and construction techniques, combined with foresight into the needs of both military and civilian aviation, kept Fokker companies at the forefront of aircraft design and manufacture for nearly ninety years.

Anthony Fokker was born in Kediri, Java, in 1890. After his family returned to the Netherlands, Fokker began a lifelong commitment to aviation. When he was twenty-one, he started an aviation company in Wiesbaden, Germany. Fokker's first two attempts to build viable aircraft ended in crashes; the Spin I hit a tree in 1910, and the Spin II crashed in 1911. In 1913, however, Fokker's Spin III model tested successfully and was purchased by the German military. Prior to the outbreak of World War I, Fokker made overtures to both the British and Dutch governments concerning purchase of his aircraft for military purposes. He was rejected by both, and so turned his attentions to designing exclusively for the German military authority.

World War I

The first true fighter aircraft to appear in World War I were Fokkers. Fokker produced 7,600 aircraft for Germany during World War I. Of these, his most famous designs include the Fokker Eindecker series, the Fokker Dr-I triplane, the Fokker D-VII, and the Fokker E-V/D-VIII.

The Fokker Eindecker monoplanes caused a revolution in concepts of employing aircraft as weapons. Fokker produced about 450 Eindeckers in four versions, E-I to E-IV, with the E-III produced in the greatest numbers. The Eindecker was the first aircraft to effectively employ a fixed, forward-firing machine gun that was synchronized with the engine to fire bullets through the propeller arc, an innovation credited to Anthony Fokker. The machine gun was aimed by pointing the entire plane at the target. The results achieved with these machine-gun-equipped Fokkers were so spectacular that during 1915, when they reigned over the Western Front, the era is referred to as the "Fokker Scourge," and Allied aircraft referred to as "Fokker Fodder."

The Fokker Dr-I was the result of a triwing design concept first built by the British Sopwith Company in 1917. No less than thirty-four prototypes were tested by the German military to counter the Sopwith. Of the planes tested, only the Fokker Dr-I triplane was produced. The plane was small, light, and exceptionally agile. The Fokker design was unique in that it had no wire bracing between the wings, only a single strut connecting the lifting surfaces near the tips. It was the first aircraft to employ the Göttingen 298 airfoil with a 13 percent thickness ratio, a feature adopted on almost all subsequent Fokker designs. This airfoil gave the Dr-I one of the lowest zero-lift drag coefficients of all World War I fighter aircraft. The Dr-I was issued to elite fighter squadrons and used in combat for less than a year. The Dr-I is one of the most recognizable of all aircraft ever manufactured, inexorably linked to its most famous pilot, Manfred von Richthofen, the "Red Baron."

In 1917, Fokker and Reinhold Platz designed a new aircraft using input from Manfred von Richthofen. The result was the Fokker D-VII. The plane had a squarish airframe equipped with an in-line engine and an air-cooled radiator. The most advanced feature of the D-VII was its internally braced cantilever wings with thick airfoil sections and a wooden structure. The first of these planes reached the front in April, 1918, and by October, eight hundred were in active service. Popular with German pilots, the D-VII was strong and fast, and it performed superbly at high altitudes. Most aviation historians view the D-VII as the most advanced and outstanding fighter plane of World War I. The quality of the Fokker D-VII was acknowledged by the terms of the Treaty of Versailles. Article IV stated that all Fokker D-VII planes had to be handed over to the Allies, the only aircraft to be specifically targeted by the armi-

Events in Fokker History

1910: Aviation pioneer Anthony H. G. Fokker builds his first aircraft, named Spin (Dutch for "spider")

1912: Fokker establishes an airplane factory at Johanneshal, Germany, where he develops the Dr-I triplane flown by Manfred von Richthofen, the Red Baron, during World War I.

1914-1918: Fokker develops German pursuit planes during World War I and invents a timing mechanism for the shooting of forward-mounted machine guns through an airplane's propeller blades.

1919: Fokker builds a factory in Amsterdam, the Netherlands.

1920: Fokker designs the F.II, one of the first passenger transport planes.

1922: Fokker moves to the United States, where he eventually builds three more aircraft factories.

1939-1945: Fokker's company designs several successful military aircraft used during World War II, including the Fokker G-1.

1955: The Fokker F-27 Friendship turboprop aircraft makes its first flight.

1964: The Fokker F-28 Fellowship jet makes its first flight.

1983: Two new Fokker aircraft are launched to replace the F-27 and the F-28: the Fokker 50 and the Fokker 100.

1996: Fokker Aircraft declares bankruptcy and is reorganized as Fokker Aviation, which is acquired by Stork.

1999: Fokker Aviation is renamed Stork Aerospace Group.

stice. After the war ended, Fokker managed to smuggle two hundred dismantled aircraft, five hundred engines, and other machine parts to the Netherlands, where he started his own factory at Sciphol outside of Amsterdam. During the 1920's, the Fokker D-VII became the mainstay of the Dutch Air Force.

Fokker Between the Wars

In 1918, the German Air Force sponsored a fighter design competition. Twenty-five prototypes were submitted; five were Fokker-designed monoplanes. The Fokker D-VIII parasol monoplane was the winner. It entered production too late to affect the war's outcome, but its design concepts were a significant change in aircraft theory. Unlike earlier aircraft, the D-VIII had a wing that was tapered in both platform and thickness ratio, and it was covered entirely in plywood, giving it great strength and rigidity. The tapered wing reduced wing weight and stress, while increasing aerodynamic efficiency and strength, giving the plane a higher rate of roll.

In July, 1919, N.V. Nederlandsche Vliegtuigenfabriek was incorporated in Amsterdam. Although Anthony Fokker was its managing director, his name was not included in the company name because people had not forgotten that during the war, Fokker had designed some of the most effective German military aircraft at his Fokker Flugzeug-Werke GmbH factory in Germany. Often accused of choosing the wrong side during the war, Fokker always pointed to the fact that before the outbreak of hostilities, both Great Britain and Holland had turned down the aircraft he had offered them. Because of his notoriety, however, it was not until much later that the name Fokker was included in the corporate title. A number of well-known civilian and military aircraft were produced by Fokker between the World Wars.

In October, 1919, another aviation company was incorporated in the Netherlands, N.V. Koninklijke Maatschappij (KLM). Fokker became KLM's main supplier of aircraft and remained so for years. Due to contracts with KLM, orders for Fokker civilian aircraft increased worldwide. Fokker set up factories in the United States and by the late 1920's had become the largest aircraft manufacturer in the world. Numerous aircraft were built under license, and Fokker planes were used by airlines the world over.

The success of postwar Fokker aircraft was linked to a simple construction technique in which the fuselage and the tail section were made of welded steel pipe. In 1933, Douglas Aircraft Company began marketing a modern, streamlined, all-metal aircraft with a retractable undercarriage, and Fokker realized too late that he had stuck with his cheap and simplistic design theory for too long. The DC-2 and DC-3 forced Fokker from the airliner market, when KLM made Douglas their main supplier. It was not until 1958 that Fokker placed a new passenger airliner on the market.

World War II and After

During World War II, production of Fokker aircraft came almost to a standstill. Between 1940 and 1945, when the Netherlands was occupied by Nazi Germany, the Fokker factory was used for the repair and construction of German military aircraft. By the war's end, Allied bombing had reduced the Fokker factory to ruins, and salvageable tools and machines had been plundered by the retreating Germans. After the war, the Dutch government decided that aircraft production in the Netherlands should resume, and the government consolidated its aircraft industries into one company, Fokker. Reconstruction of the Fokker Company had to start from scratch, forcing the company to lag behind its competitors. In countries such as the United States, Great Britain, and Germany, the war had given the aviation industry a great boost, with the outcome being new designs, technologies, and engines, especially the jet engine. Initially, all Fokker was able to do was provide services to refit DC-3's and convert military aircraft into civilian passenger aircraft. Later, however, the postwar Fokker Company developed a number of successful small business aircraft and military trainers, including the S-11 and S-14 models. The company also began the assembly and licensed production of military aircraft designed by others, including the Sea Fury, the Gloster Meteor fighter jets, the Hawker Hunter, the F-104 Starfighter, and the F-5, and later participated in coproduction of the F-16 Fighting Falcon. Nonetheless, these contracts did not make Fokker an independent manufacturer of passenger aircraft. In 1949, on its thirtieth anniversary, the company changed its name to N.V. Koninklijke Nederlandse Vliegtuienfabriek Fokker.

In 1955, Fokker developed the F-27 Friendship, the successor to the popular DC-3, and later, the F-28 Fellowship. Market research indicated there was a demand for a replacement for the famous DC-3. The new aircraft needed a capacity of forty to fifty passengers. While they never became stars in the aircraft marketplace, both the F-27 and F-28 were dependable workhorses and continued to be used in the air fleets of many countries through the beginning of the twenty-first century. Between 1958 and 1986, 786 F-27's were sold, making it the most successful turboprop aircraft in the Western market. The F-28 was the first passenger jet developed by Fokker. It was less successful than the F-27 because of competition from the Boeing 737 and the DC-9. Fokker delivered 241 F-28's between 1968 and 1986. The successors to the F-27 and F-28 were the F-50 and F-100 airliners, introduced in the late 1980's. The largest export order in Dutch history was the sale of seventy-five F-100's to American Airlines. During this period of production, the Fokker Company employed more people than did the civil aircraft division of McDonnell Douglas. However, Fokker was deeply in debt from the cost of the simultaneous development of these two new aircraft, as well as from losses resulting from an all-time low in currency exchange rates and an unexpected drop in aircraft demand.

In an attempt to save the company, Fokker became one of the first major corporations to implement cross-border corporate integration by merging with the German VFW Company. When this merger ended in failure, Fokker attempted a second merger with DASA in the 1990's. Unfortunately, the Fokker Company went bankrupt despite the fact that its product line was well liked and respected, and orders for Fokker products were backlogged. In 1997, the last airliner to bear the Fokker name was assembled at Amsterdam Airport Schiphol, marking the end of a tradition whose origins traced to the earliest days of aviation. In the late 1990's, the Stork Company bought what remained of Fokker and converted it to the specialized manufacture of major components, electric and power distribution systems, and advanced aerospace materials and maintenance. The Fokker Aircraft Group still exists and is in partnership with several global aircraft projects. Following a 1997 decision by the Netherlands government, it participates in projects with Airbus.

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See also: Airbus; Fighter pilots; Luftwaffe; Manufacturers; Military flight; Manfred von Richthofen; Triplanes; World War I; World War II

Food service

Definition: Meals and beverages served by airlines on board an aircraft in flight.

Significance: Airline food quality among the biggest airlines in the United States has never been remarkable, but some regional carriers have made a point of serving tasty meals that regularly garner rave reviews from frequent fliers. Several international airlines, notably those in Asia and Europe, have made food service a priority, especially in first and business classes.

Airline Food

Although airline food quality has often been the butt of jokes, most airlines continue to strive for quality in the meals they provide to passengers. The prevailing view of U.S. domestic airline food is hardly complimentary, but two airlines, Hawaiian Airlines and Midwest Express, are noted for their cuisine. Singapore Airlines, Cathay Pacific, and Japan Air Lines are also known for quality food in all classes of service. First Nations Air, serving the Inuits' Nunavut territory in Canada, also has become recognized for its meal service, notably its salmon dinners.

On Midwest Express, a regional carrier with hubs in Milwaukee and Omaha, meals are served on china with linen napkins. Every meal ends with complimentary wine or champagne. On some flights, chocolate chip cookies are baked on board. Midwest Express spends more than twice the per-meal industry average on food services, and the extra effort is evident.

Between 1995 and 2000, the amount spent on food service by an average airline declined by 15 to 20 percent. An economy-class meal cost an average of $4.81 in the year 2000. Midwest Express spent an average of $10.05. Amounts spent on food service among other U.S. carriers ranged from $8.44 per passenger by American Airlines to $.26 per passenger on Southwest Airlines, which serves nothing but light snacks. Food service for business- and first-class passengers can be considerably more expensive, with a meal, including beverages, sometimes costing more than $30. Singapore Air spends up to $45 per passenger on its first-class food and beverage service.

Midwest Express

Midwest Express was ranked during 1998 and 1999 as the number-one U.S. passenger air carrier in the *Zagat Airline Survey*, which compiled the opinions of 31,500 frequent fliers. The *Zagat Airline Survey* rates seventy airlines for their comfort, service, and food on its signature thirty-point scale. In the 1999 *Zagat Airline Survey*, Midwest Express ranked first in all three categories. Midwest Express was given high marks for its food and service, with the only complaint being that the airline did not fly to enough destinations. Midwest Express not only offers excellent meal service but also provides first-class seat size to all passengers at coach-seat fares.

Midwest Express has been expanding, a fact illustrated by its announcement, in April of 2000, of a one-half-billion-dollar purchase order for new 717-series jets from Boeing. The deal represented twenty new aircraft, with options on twenty to thirty more. This single deal almost doubled the size of the Midwest Express fleet. By 2001, Midwest Express and its commuter partner, Skyway Airlines, were responsible for 37 percent of the passenger traffic at Milwaukee's Mitchell International Airport.

International Airlines

Food quality has long been a concern on several airlines outside the United States. Israel's El Al, for example, hired special consultants to improve its food, adopting a regional Mediterranean style. The airline maintains thirteen kitchens along its routes, which serve roughly 25,000 portions per day. A typical new-style El Al menu consists of Mediterranean appetizers with smoked salmon, roasted oregano-scented spring chicken with couscous, or lasagna Bolognaise with olives and basil, and fresh fruit pie.

Major airlines serve a wide variety of special-order meals, including kosher, vegetarian, Hindu, Muslim, low-fat, gluten-free, peanut-free and lactose-free options. Many airlines also offer so-called bland meals, containing no spices or seasonings, which are designed for people with allergies. Swissair offers a children's meal served in a small briefcase that includes games and snacks.

Caterers

Most airline food is provided not by the carriers themselves, but by independent contractors, such as LSG Skychefs, Host Marriott Services, and Dobbs International. In 1999, LSG Skychefs, which operates 210 kitchens, generated $2.7 billion in sales as it prepared food for 260 airlines. Marriott served 200 carriers and generated $1.2 billion in sales, and Dobbs served 100 airlines and generated $890 million.

Because food service is so important to passengers and because airlines serve 200,000 meals and snacks daily, airlines and airline food caterers give a great deal of consideration, evaluation, and planning into the meals they serve. Airlines receive more comments about the food on flights than about any other aspect of air travel, and the major complaints come when no meal at all is served on a flight.

In 1999, American Airlines launched its Flagship Service menu on all first- and business-class transcontinental flights, with menu items created by four noted chefs from across the United States. At about the same time, Swissair introduced its natural gourmet menu, created from all-natural, fresh foods that are easy to digest. Swissair uses only organically grown foods, and its meats and poultry are fed on natural grains and are free from chemicals or additives. The idea of adopting organic foods came from the airline's international passengers, who are extremely health-conscious and aware of their fat and protein intake. Also contributing to Swissair's move was an increasing trend toward more natural, environmentally friendly choices in food.

Passengers who sample Swissair's natural-gourmet menu might dine on salmon trout with wild garlic sauce, mixed rice with spelt, or sautéed veal with chanterelles and chives. Because Swissair has always emphasized Swiss national products in its cuisine, there are, of course, Swiss chocolates. Swissair's food service subsidiary, Gate Gourmet, supplies meals not only for the Swiss carrier but also for other airlines around the world, including Qantas in Australia. Gate Gourmet produces 48,000 meals per day for seventy carriers. Its bakery in Zurich makes 75,000 buns, croissants, pies, cakes, and other baked goods daily.

In December, 2000, Northwest Airlines and *Food & Wine* magazine initiated a partnership to collaborate on a selection of wine and champagne for Northwest's domestic first class and international business class. Northwest also expanded its on-board wine selection, acquiring its own small wine cellar offering eighteen varieties of wine.

Northwest Airlines, perhaps taking a cue from Midwest Express, also upgraded its food service. Recent new entrées introduced in Northwest's World Business Class include beef tenderloin with smoked pepper sauce, cheese-potato soufflé and squash medley, and oven-roasted chicken with wild mushroom sauce and blue cheese tortellini. North-

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west hired some of the best-known chefs in restaurants along its routes to create the new entrées.

In 2001, Las Vegas-based National Airlines became the world's first airline to use a revolutionary in-flight beverage cart that provides faster customer service while reducing the company's costs. The beverage cart, developed by Sterling Beverage Systems, uses the postmix technology commonplace in restaurants, but which had not been adopted in the airline industry. The Sterling cart was also expected to reduce airline costs, because less fuel is burned due to decreased cabin weight.

A Professorship of Airline Food

"Airline food is often a subject of ridicule, but meals in the sky are no laughing matter," according to Peter Jones, who, during 2001, was appointed as the world's first professor of airline food. Jones holds the appointment, which was funded by the International Flight Catering Association (IFCA), a group linking the several organizations that are involved in the airline-food business, at the University of Surrey in Guildford, Great Britain.

The appointment demonstrates the highly sophisticated business that airline catering has become. The daily delivery of hundreds of thousands of meals to airline passengers requires both culinary and logistical skill. The IFCA's intent is to train people who will continue to improve standards.

Despite these improvements, however, passengers should not have unrealistic expectations of airline food. Passengers may not always appreciate how much effort goes into the making of an airline meal. In the high-altitude environment of airline flight, even the most delicately prepared food is affected in taste, texture, and consistency. Meals must be prepared hours in advance, transported to the aircraft, and served in confined conditions with a minimum of equipment. Food served on airline flights has been kept at precisely controlled temperatures for hours and subjected to a barrage of bacteriological and quality control checks.

Adding to the complexity, airline crew also has its own food, often with different dishes for the captain and flight attendants. On several airlines, most notably the Asian carriers, crew meals vary according to the rank of each person eating them.

Computers are increasingly allowing airlines to personalize service. In a few years, passengers will be able to reserve their meals from a menu, as they do in restaurants.

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See also: Air carriers; Airline industry, U.S.; American Airlines; Flight attendants; Northwest Airlines; Qantas; Singapore Airlines; Swissair

Forces of flight

Definition: The so-called four forces—gravity, drag, lift, and thrust—that act upon an airplane in straight-and-level unaccelerated flight.

Significance: Weight and drag are forces of nature inherent of any object lifted from the ground and moved through the air. The forces of lift and thrust are artificially caused to overcome the forces of weight and drag and enable an airplane to fly.

Humans' first attempts to fly, inspired by birds, were limited until humans realized they could not fly like birds. Birds, with their very light weight, great strength, and complex biological design, can use their wings to create both lift and thrust to overcome the natural forces of weight and drag, and to maintain control. Humans, in contrast, had to invent a different approach to meet any success in aviation. The functions of lift and thrust had to be separated. For that, wings and engines were introduced. While wings produce lift, engines produce thrust.

Following the first flights made by Orville and Wilbur Wright in December, 1903, the pace of aeronautical development accelerated, and the progress made in overcoming the natural forces in the aviation industry in following decades was dramatic. The understanding of natural forces is thus as important for an airplane's aerodynamics as the creation of artificial forces to counterbalance these natural forces. The engine and propeller combination is designed to produce thrust to overcome drag. The wing is designed to produce lift to overcome weight, or gravity. In unaccelerated, straight-and-level flight, which is coordinated flight at a constant altitude and heading, lift equals weight and thrust equals drag. Nevertheless, lift and weight will not equal thrust and drag. In everyday vocabulary, the upward forces balance the downward forces, and forward forces balance the rearward forces. This statement is true whether or not the contributions due to weight, drag, lift, and thrust are calculated separately. Any inequality between lift and weight will result in the airplane entering a climb or descent. Any inequality between thrust and drag while maintaining straight-and-level flight will result in acceleration or retardation until the two forces become balanced. However, there are a couple of paradoxes surrounding this information. The first paradox is that in a low-speed, high-power climb, the amount of lift is less than the amount of weight. In this situation, thrust is supporting part of the weight. The second paradox is that in a low-power, high-speed descent, the amount of lift is again less than the amount of weight. In this situation, the drag is supporting part of the weight. In light aircraft, the amount of lift ordinarily is approximately ten times the amount of drag.

The motion of an aircraft through the air depends on the size of these four forces. The weight of an airplane is determined by the size and material used in the airplane's construction and on the payload and fuel that the airplane carries. The lift and drag are aerodynamical forces that depend on the shape and the size of the aircraft, air conditions, and the flight speed and direction relative to the air velocity. The thrust is determined by the size and type of the propulsion system used in the airplane and on the throttle setting selected during the flight.

The relative wind velocity acting on the airplane contributes a certain amount of force, called total aerodynamic force. This force can be resolved into two components perpendicular to each other along the directions of lift and drag. Lift is the component of aerodynamic force directly perpendicular to the relative wind velocity. Drag is the component of aerodynamic force acting parallel to the relative motion of the wind. Weight is the force directed always downward toward the center of the earth. It is equal to the mass of the airplane multiplied by the acceleration due to the gravity, or the strength of the gravitational field. Thrust is the force produced by the engine and is usually more or less parallel to the long axis of the airplane.

Weight

Weight, or gravity, is the force which always acts downward, toward the center of the earth. It is the total sum of the masses of all its components and contents multiplied by the strength of the gravity, commonly referred to as the number of g's. The weight may be considered to act as a single force, representing all its components and contents, through a single point called the center of gravity.

Weight is the most reliable force, which always acts in the same direction and gradually decreases as airplane fuel is used. The center of gravity shifts as the weight is redistributed.

Although the terms "mass" and "weight" are often confused with each other, it is important to distinguish between them. Mass is a property of a body itself and measures a body's quantity of matter. Weight, in contrast, is a force representing the force of gravity acting on a body. It is also loosely called gravity.

To illustrate the difference, one could describe an object that is taken to the Moon, where the force of gravity is weaker, about one-sixth that on Earth. On the Moon, the object will weigh only about one-sixth as much as it did on Earth. The mass of the object will be the same on the Moon or anywhere else. In other words, it will continue to have the same amount of matter.

Drag

When an object moves relative to a fluid, either a gas or a liquid, the fluid exerts a frictional force on the object. This force which is referred to as a drag force, is due to the viscosity, or stickiness, of the fluid and also, at high speeds, to the turbulence behind and around the object. To characterize the motion of an object at different speeds relative to the fluid and to understand the associated drag, it is useful to understand Reynolds numbers.

The Reynolds number depends on the properties, such as length and velocity, of the fluid and the object relative to the fluid. In case of an airplane, which flies through air, the Reynolds number for air is smaller than that for water because of the lower density of the air. For example, an object of one millimeter long moving with a speed of 1 millimeter per second through water has the same Reynolds number as an object 2 millimeters long moving at a rate of 7 millimeters per second in the air. The drag manifests itself differently for different Reynolds numbers associated to it.

When the Reynolds number is less than 1, as in the case of fairly small objects, such as raindrops, the viscous force is directly proportional to the speed of the object. For large Reynolds numbers, usually above a value between about 1 and 10, there will be turbulence behind the body, known as wake, and hence, the drag force will be larger and it increases as the square of the velocity instead of its linear dependence on the velocity. When the Reynolds number approaches a value of around 1,000,000, the drag force increases abruptly. For above this value, turbulence exits in the layer of fluid lying next to the body all along its sides. For streamlined objects, however, there will be less turbulence and, hence, less drag. The flow is said to be streamlined of laminar flow if the flow is smooth, such that neighboring layers of the fluid slide by each other smoothly.

There are several types of drag, subdivided and classified according to their action on an airplane. Pressure drag is the force pushing a horizontally moving object against the front vertical surface of the object. Friction drag is produced on a horizontally moving object by applying a force along the surface of the object. Friction drag is proportional to the viscosity of the fluid. Fortunately, air has rather low viscosity, so in most situations the amount of friction drag is small compared to that of pressure drag. In contrast, pressure drag does not depend very strongly on viscosity. Instead, it depends on the density of the air.

Both friction drag and pressure drag create a force proportional to the area involved and the square of the airspeed. Part of the pressure drag that a wing produces depends on the amount of lift it is producing. This part of the drag is called induced drag. The rest of the drag is called parasite drag. The part of the parasite drag that is not due to friction is called form drag, because it is extremely sensitive to the detailed form and shape of the airplane.

A streamlined object can have ten times less form drag than a nonstreamlined object of comparable frontal area. The peak pressure in front of the two shapes will be the same. However, the streamlined shape causes the air to accelerate, so the region of highest pressure is smaller, and more importantly, the streamlined shape cultivates high pressure behind the object that pushes it forward, thus canceling most of the pressure drag. This situation is called pressure recovery. An object moving through the air has a high-pressure region in front, but a properly streamlined object will have a high-pressure region in back as well. However, streamlining is never perfect; there is always at least some net pressure drag.

Induced drag also contributes to pressure drag whenever lift is being produced, even for perfectly streamlined objects in the absence of separation. The flow pattern near a nonstreamlined object is not symmetric fore and aft because the streamlines separate from the object as they go around the sharp corners of the plate. Except in the cases of very small objects or very low speeds, pressure drag is larger than friction drag, even for well-streamlined objects.

The pressure drag of a nonstreamlined object is much larger still. For this reason even the smallest parts of high-performance aircraft, such as fuel-cap handles, are precisely aligned with the airflow. An inevitable exception involves the air that has to flow through the engine compartment to cool the engine. A lot of the air has to flow through narrow channels. The resulting friction drag, called cooling drag, amounts to 30 percent of the total drag in some airplanes.

Unlike pressure drag, friction drag cannot possibly be canceled. It can, however, be minimized. The way to minimize friction drag is to minimize the total area, called wetted area, that has high-speed air flowing along it. The way to reduce form drag is to minimize separation by streamlining all parts.

It is often convenient to express the drag force as a dimensionless quantity by the coefficient of drag. In that case, the drag force is proportional to the coefficient of drag, the density of the air, the square of the true airspeed, and the relevant area, which is typically taken to be the wing area excluding the surface area of the fuselage.

In the mushing regime, most of the drag is induced drag. As the airplane goes more slowly, induced drag increases dramatically, and parasite drag becomes almost neglible. At high airspeeds, parasite drag is dominant, and induced drag becomes almost negligible. In a high-speed regime that includes normal cruise, the power required increases rapidly with increasing airspeed.

Parasite drag is the dominant contribution to the coefficient of drag, and it is more or less independent of airspeed. Induced drag decreases as the airspeed increases, but this is a relatively minor contribution in this regime. Ways of reducing induced drag include wing tapering, wingtip modification, and employing washout and a high aspect ratio. The aspect ratio is defined as the ratio between the span and the mean chord. The mean chord, in turn, is the ratio between the wing area and the wingspan.

Lift

Airplane wings and other airfoils are designed to deflect the air so that, although streamline flow is largely maintained, the streamlines are crowded together above the wing. Just as the flow lines are crowded together in a pipe constriction where the velocity is high, so the crowded streamlines above the wing indicate that the airspeed is greater than below the wing. Hence, according to Bernoulli's principle which states that velocity increases as pressure decreases, the air pressure above the wing is less than that below the wing, and there is a net upward force, which is called dynamic lift, or lift.

In fact, Bernoulli's principle is only one aspect of the lift on a wing. Wings are usually tilted slightly upward so that air striking the bottom surface is deflected downward. The change in momentum, a product of mass and velocity, of the rebounding air molecules results in an additional upward force on the wing. As the air passes over the wing, it is bent down. The bending of the air is the action; the reaction is the lift on the wing. To generate sufficient lift, a wing must divert air down. To increase the lift, either or both the diverted air and downward velocity must be incremented.

The downward velocity behind the wing is called downwash. The vertical downward airspeed varies as the angle of attack. The angle of attack is the angle of the chord line. The direction of the relative airflow on the wing, along the chord line, or chord length, is the distance from the loading edge of the wing to the trailing edge. As the wing moves along while the air is diverted at the rear end of the wing, it is pulled up at the leading edge, also giving rise to upwash. This upwash contributes negatively to the lift. Turbulence also plays an important role in contributing to the lift.

Like drag, lift can also be expressed in a dimensionless quantity in terms of the coefficient of lift. In that way, the lift force is proportional to the coefficient of lift and the density of the air, the square of true airspeed and relevant area. The coefficient of lift is a ratio that basically measures how effectively the wing turns the available dynamic pressure into a useful average suction over the wing. The dynamic pressure is the product of the air density and the square of the velocity. This is the difference between total pressure and static pressure. The total pressure is the pressure in air that has been brought to rest from the free stream, and the static pressure is the ambient pressure at the same level as the aircraft. In actual flight, pilots are not free to make any amount of lift they want. The lift is nearly always equal to the weight multiplied by the load factor; the coefficient of lift depends directly on the load factor, and inversely, on the square of the airspeed. Because of the airspeed squared, the airplane must fly at a very high coefficient of lift in order to support its weight at low airspeeds.

As there is a center of gravity, there is also a center of pressure, which is a point through which the resultant lift acts. The center of pressure changes with change of wing shape. A number, called the lift-drag ratio, is considered best when it produces the most efficient speed for maximum range with minimum drag.

Thrust

A force pushing an airplane, or any object, forward is called thrust. The thrust is produced by the engines of the airplane or by the flapping of a bird's wings. The engines push fast-moving air out behind the plane, by either propeller or jet. The fast-moving air causes the plane to move forward, countering drag.

Since the Wright brothers first flew in 1903, aeronautical engineers have created a multitude of airplane types, every one of which has dealt with the same four forces of weight, drag, lift, and thrust. All people have to deal with the challenges of stability with respect to these forces. Flying faster than the speed of sound has its own special demands, but the underlying forces of weight, drag, lift, and thrust remain the same.

In some sense, it is easier to fly in space, which is devoid of air, than it is to fly in air. However, spaceflight has its own special challenges. In space, one must deal with only two forces, weight and thrust. Thrust provides the force to lift a rocket into space. Once in orbit, a spacecraft no longer needs propulsion. Short bursts from smaller rockets are used to maneuver the spacecraft. To change its orientation, a spacecraft applies torque, a twisting force, by firing small rockets called thrusters or by spinning internal reaction wheels.

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See also: Aerodynamics; Aeronautical engineering; Airplanes; Gravity; History of human flight; Microgravity; Orbiting; Propulsion; Roll and pitch; Spaceflight; Wind tunnels

Steve Fossett

Date: Born on April 22, 1944, in Garden Grove, California

Definition: Prominent balloonist, aviator, and yachtsman who has set many world records for flight.

Significance: Ever since his twenties, Fossett engaged in daredevil adventures, sailing marathons, flying jet planes, climbing mountains, and racing automobiles. His most publicized and spectacular feats have been in ballooning.

Steve Fossett is a millionaire stockbroker who engages in adventurous hobbies. As a youngster, he started rock climbing. As a college student at Stanford University, he climbed mountains and swam the Hellespont in Turkey—a classical test of strength and endurance that he swam both ways.

After earning his master of business administration degree at Washington University in St. Louis, Missouri, Fossett moved to Chicago, where he made his fortune. However, he continued to engage in dangerous adventurous sports, continuing to try, despite many failures, until he succeeded. "I always thrive under pressure," he claimed. In the late 1990's, he concentrated on sailing and ballooning, sports in which he believed he could set world records. In

January, 1997, he attempted to be the first person to circumnavigate the world in a hot-air balloon. He competed against three teams, the British Virgin Group of Richard Branson, an Australian team, and a Swiss team. Compared to the millions that his competitors were spending, Fossett's bare-bones *Solo Spirit* balloon was relatively inexpensive, at $300,000.

Fossett's 1997 flight failed when he had to land in northern India after six days, but he set a record for endurance and distance. His balloon traveled at heights of 18,000 to over 28,000 feet. With a broken heater, temperatures in the balloon were 15 degrees Fahrenheit. Fossett failed in a second attempt, in August, 1998, when he had to land in Russia. Later that year, he began his third attempt in North Africa, but he was forced to land in the Pacific after China refused permission to fly over their airspace. A rival team of Bertrand Piccard and Brian Jones, however, accomplished the feat shortly afterward. Fossett then sought to set sailing records in his Play Station Maxi Catamaran. In February, 2000, along with copilots Darrin Adkins and Alex Tai, Fossett set the around-the-world record for medium-weight airplanes in his Citation X two-engine business jet. The trip took 41 hours, 13 minutes, and 11 seconds, about 6 hours less than the previous record. His average speed was 559 miles per hour. The same year, he set the U.S. coast-to-coast records for private planes in both directions in his Citation.

His August, 1998, balloon flight set the record for the longest solo aircraft flight and the second longest balloon flight. He also holds the record for several other distance and speed flights in his private plane.

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In August of 2001, Fossett made a fifth attempt at a transglobal balloon flight, but bad weather forced him to land in southern Brazil, just one day after he had reached the halfway point of his trip. Despite the curtailed effort, however, Fossett still managed to set a new record for the longest solo balloon flight, with a trip lasting 12 days and 13 hours. With Fossett's failed attempt, the solo transglobal balloon record remained unclaimed.

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See also: Balloons; Richard Branson; Lighter-than-air craft; Record flights; Transglobal flight

Franco-Prussian War

Date: From 1870 to 1871

Definition: A war fought between France and Prussia over the issue of Spanish succession.

Significance: The Franco-Prussian War was one of the first uses of air power in warfare, though pigeons played a more important role than balloons.

Background

On July 19, 1870, France declared war on Prussia after unsuccessful negotiations between the two nations concerning who would be the next Spanish king. The Prussians were backing a candidate in Spain friendly to them, but the French, fearful of being surrounded by a Prussian-Spanish alliance, called for negotiations. After the talks failed, the Prussian premier, Otto von Bismarck, deliberately angered the French by insulting their government in the famous Ems telegram. French emperor Napoleon III had been assured that France's army was so powerful it could never be defeated. Early in the war, however, the French suffered massive defeats at the hands of the Prussians, and on September 1, 1870, the French army surrendered. Napoleon III, who had become ill while fighting with his troops, was taken prisoner.

Hot-air Balloons

In Paris, the French set up a provisional government of national defense that took away Napoleon's power and established the Third Republic. The Prussian army then surrounded and laid siege to Paris, totally blockading the new government from the rest of France. The leaders of the Third Republic needed a way to communicate with its armies outside of Paris. On September 22, a solution was provided from above. A number of large hot-air balloons, which had been built for an international exposition in 1867, were found in a sad state of disrepair. One balloon, the *Neptune*, was patched together and piloted out of the city. The astonished Prussians watched, powerless to bring the balloon down. After three hours in the air, the balloon's pilot landed in friendly territory with messages for the commanders of the remaining French army.

Over the next several days, four more balloons took off safely and reached their destinations without being shot out of the sky. A means of sending messages to the countryside had been established, and the minister of the post office officially established a regular "Balloon Post."

Carrier Pigeons

It soon became apparent that balloons, at the mercy of the wind, could not be effectively steered in a desired direction. Although dirigibles, motor-powered balloons, were being tested at the time of the siege, they were not yet available for service. Balloons flew out of Paris, but, because of the wind patterns, they could not return.

Postal officials tried various solutions to the problem. They once sent five sheepdogs out of the city by balloon with the intent that the dogs could be sent back with mail tied to their backs, but none of the dogs were ever seen again. They floated hollow metal balls with messages inside down the River Seine, but none was ever recovered.

A Parisian carrier pigeon owner's club, L'Esperance, contacted the government to suggest that urban pigeons could be sent away with messages bound to their legs and could then be sent back to Paris with new messages. Government officials initially laughed at the idea. However, the club secretary eventually found a willing listener at the Central Telegraph Offices, the wires to which had been cut by the Prussians early in the siege. A pigeon loft was built on the roof of the Telegraph Office on September 4, 1870. Before the system could work, however, pigeons would have to be taken out of Paris and trained to return to their new loft.

On September 10, the first pigeons were taken out of Paris by balloon and flown to the city of Tours in southern France. Members of L'Esperance began rounding up the limited supply of available carrier pigeons, most of which were untrained. The principal supplier of pigeons was the club's president, Mr. Cassier, who had fifty-two birds in his loft. Of all fifty-two birds that saw service in the war, only two survived. During the remaining five months of the siege, hundreds of carrier pigeons were taken out of Paris by balloon.

Once the pigeons arrived in army headquarters at Tours, they were fed, rested, and prepared for the 130-mile return flight to Paris. Before they were released, the pigeons had messages placed in small metal containers attached to their legs. More than three hundred pigeons left Paris by balloon during the siege, but only fifty-nine successfully made the return flight to Paris. The others fell into Prussian hands or were blown off course by severe weather, particularly in the winter months of January and February, when only six of sixty-five pigeons safely made the journey back to Paris. The weather and the Prussians were not the pigeons' only enemies, however. Hawks killed some, as did human hunters with shotguns seeking food for their families. The pigeon service was ended on February 1, 1871, after the Prussians lifted their siege.

The pigeons had an important impact on the morale of the Parisians, even though France lost the war and signed a humiliating peace treaty. The fifty-nine pigeons that successfully made the return flight carried more than 95,000 messages to Paris. The citizens of Paris even built them a monument after the war through private contributions.

Microfilm Messages

One interesting result of these pigeon flights was the development of the first microfilm messages. A Parisian photographer developed a method of taking pictures of official messages and reducing them in size by using his camera. These microfilms made it easier for pigeons to carry large numbers of documents that would have been too heavy on paper. The microfilm was placed in tubes attached to one of the bird's legs. With this method, pigeons could carry twenty or more messages at a time rather than one or two. To improve their chances of getting through Prussian lines, the same messages were sent by several pigeons at the same time. Carrier pigeon flights thus played a major role in the Franco-Prussian War and aided in the survival of the people of Paris.

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See also: Balloons; Birds; Buoyant aircraft; Lighter-than-air craft; Reconnaissance

Frequent flier miles

Definition: Marketing tools used by airlines to keep and maintain loyal customers.

Significance: Frequent flier miles and other frequent traveler programs (FTPs) are a vital part of an airline's strategic marketing plan to gain the repeat business of an airline's most profitable customers.

Airline Reward Programs

Programs designed to reward loyal customers for their patronage are not new, having their roots in trading stamps and coupon books issued by grocery stores and gas stations to create brand loyalty and product differentiation.

Prior to the Airline Deregulation Act of 1978 that eliminated the U.S. government's control over airline operations, the U.S. government established airline fares and routes, and airlines emphasized service and prestige to gain potential customers. However, after the Airline Deregulation Act was passed, airline routes were opened to competition, and airlines could adjust their fares to meet market conditions.

Deregulation caused an immediate and tremendous flurry of activity among start-up carriers. New airlines marketed their seats based solely on price. Consequently, many large carriers began to lose market share among their most profitable customers, frequent business travelers who paid the highest fares.

In response to this loss, American Airlines became the first airline to offer a frequent flier program in 1981. This program, AAdvantage Travel Awards, offered customers "miles," or points, based on the distances they flew. Customers could trade in accumulated miles for free flights or upgrades on the airline. The program, initially targeted as a promotion to a few top customers, grew rapidly in both popularity and profitability and proved successful in capturing repeat business. Other domestic U.S. airlines quickly followed American Airlines' example, as did non-U.S. airlines, and soon nearly all airlines had a frequent traveler program or were tied into one.

Role of Technology

Two major technological innovations made FTPs possible: the computer reservations system (CRS) and the sophisticated computer technology that allows the CRS system to exist. Early CRSs were used by airlines to track internal airline bookings. Although all major airlines had automated their systems by the 1970's, travel agents could not access information on all available flights between destinations without great difficulty, because these systems were not linked.

The first CRS used by travel agents that expanded flight availability information from that of a single airline to that of all airlines was American Airline's Semi-Automated Business Research Environment (SABRE) system, developed in conjunction with IBM in the 1960's and marketed to travel agenices beginning in 1975. Other airlines developed similar programs that competed with SABRE for acceptance by travel agents. The substantial increase in the number of existing flights made possible by airline deregulation accelerated the acceptance of computer reservation technology.

The airlines' heavy reliance on computer technology to keep track of seats and fare distributions propelled the evolution of CRS technology. In the early 1980's, tremendous leaps in computing technology enabled the increasing sophistication of CRSs. Passengers' travel histories could be tracked with greater detail and easier access than ever before. The most frequent customers could be easily identified, and marketing programs could be geared directly to them.

The increase in air travel fueled expansion in other service industries tied to air travel. Hotel, rental car, and credit card companies and others tied into the CRS programs offered superior service to the frequent customer. The CRS system has become a multidimensional tool that enables travelers to easily plan, price, and book almost any aspect of travel worldwide.

CRS as an FTP Tool

With information about ticket buyers gained through CRS bookings, the airlines could track their most valued customers, those who traveled frequently on high-yield markets. Initially, the airlines were able to search their databases to track bookings and correlate tickets sold with telephone numbers and customers' names. These became the first members of the airlines' frequent flier programs. As FTPs became more sophisticated, customers could be identified by means of rating systems that varied between airlines. The airlines define a set of guidelines by which a customer is rated, and the highly valued core customers are tracked to determine how they are generating revenue for the airline.

Expansion of FTPs

Ever innovative, American Airlines enlisted hotels and rental car companies as partners in its mileage program, giving additional points to customers who used the associated company's services. This arrangement enabled customers to accumulate their awards more quickly. By the end of 1981, most major U.S. airlines had frequent flier programs with other service partners. The battle to win the business of the lucrative frequent traveler had begun in earnest. A few airlines, hotels, and rental car companies were unenthusiastic about the mileage awards programs and dismissed them as a short-lived gimmick. However, their quick acceptance by consumers and the fierce competition of those airlines vying for the business traveler's business soon proved to be disastrous to the bottom line of those airlines that did not participate.

Airlines integrated their FTPs with companies as diverse as credit card companies, telephone companies, hotels, cruise lines, and many types of retailers. Airline marketers continue to pursue different avenues of mileage programs to keep their FTPs dynamic and diverse.

Cost of FTPs

FTPs generate both administration costs and direct costs. Administrative costs include the tracking and marketing of the program to customers. Direct costs are incurred when a customer seeks to redeem the award for travel. These costs include variable passenger expenses, or the incremental costs—such as meals, beverages, fuel, reservations, and handling—of carrying an additional passenger. They also include the additional cost incurred if passengers were to redeem travel on the airlines' FTP partner. Displacement costs are those incurred by the elimination of a seat from an otherwise fare-paying passenger. These costs are sometimes partially offset by the revenue of a traveling companion. Diversion, or dilution, costs are incurred when the redeeming passenger would have purchased a ticket on the airline, regardless of having an award. Many of these costs are controlled by limiting the number of seats per flight available for reward programs.

FTP Marketing Benefits

Marketing to proven loyal customers is a cost-effective use of a business's limited marketing dollars. FTP awards have become so widely accepted that they now form a core part of airlines' products and are expected by customers.

However, airline rewards continue to evolve. Airline officials realize that the number of miles a customer accumulates over time is not the single best indicator of that customer's value to the company. A customer who infrequently travels long distances may generate more miles on the airline than another customer who travels more frequently on short routes, but the short-haul customer may generate more income to the airline's bottom line. More frequent, short-haul travelers are more valuable to the airline not only because they buy more tickets but also because the short-haul, business-route tickets they buy tend to have a higher margin of profit for the airline.

As a response, the airline industry has shifted from simply selling seats toward a more customer- or relationship-based marketing strategy, realizing the customer's value over the long term. Loyal customers are rewarded for their value to the airline, further increasing their satisfaction. The types of awards offered to frequent travelers have also evolved. Initially, awards were granted in the form of free flights or upgrades from a coach seat to a business-class or first-class seat. Research into frequent traveler's preferences has shown that special recognition, preferred service, and privileges such as exclusive lounges or other perks are highly valued. As technology advances, the ability to track an individual's purchasing behavior and preferences has enabled airlines to individually market different types of award.

Frequent traveler programs are an integral part of an airline's strategic marketing. Customers expect rewards, and the airlines compete fiercely for their loyalty. As the travel industry expands and the need for travel services rises, FTPs will continue to evolve to meet the customers' demands.

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See also: Air carriers; Airline Deregulation Act; Airline industry, U.S.; American Airlines; Mergers; Ticketing

G

Yuri Gagarin

Date: Born on March 9, 1934, in Klushino, near Gzhatsk, Smolensk Oblast, Soviet Union; died on March 27, 1968, near Moscow, Soviet Union

Definition: Russian cosmonaut whose 108-minute Earth orbital flight on April 12, 1961, represented humankind's first space travel.

Significance: As pilot of the Soviet orbital mission Vostok 1, Gagarin ushered in the space age by proving that a human being could endure the rigors of liftoff, reentry, and weightlessness and still perform the manual operations essential to space flight.

After a primarily vocational education, Russian cosmonaut Yuri Alekseyevich Gagarin entered pilot training at the First Chkalov Orenburg Military School for Pilots. In the autumn of 1957, he graduated with high honors from Orenburg and joined the Soviet Air Force as a junior lieutenant. From late 1957 until the spring of 1960, he served as a military fighter pilot in the Arctic. In 1960, he was selected as a member of the first group of Soviet cosmonauts.

On the morning of April 12, 1961, Gagarin literally flew into history on board the spaceship Vostok 1, which launched at 9:07 A.M. Moscow time. The flight was automated for fear that the weightlessness of space might disable the pilot. A key was available in a sealed envelope in case it became necessary to take control in an emergency. In a preflight speech, Gagarin commented that he had always waited for this moment and that he was glad to "meet nature face to face, in an unprecedented encounter." The rocket accelerated to a peak of 5 g's, indicating that Gagarin felt five times his normal weight. Fourteen minutes after liftoff, Gagarin reported that the capsule had achieved Earth orbit. He then tested his food and water samples and reported no side effects to the weightlessness. During the 108-minute flight, he made one elliptical Earth orbit, the apogee of which was about 203 miles above sea level. The orbital speed was approximately 17,000 miles per hour. The payload included life-support equipment as

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well as communications equipment that relayed information on Gagarin's condition. As planned, at about 20,000 feet, Gagarin ejected and descended under his own parachute and landed southwest of the Saratov region, near Smelovka, Saratskaya.

Following his historic flight, Gagarin received many honors in recognition of his Vostok mission. He was named a hero of the Soviet Union and was awarded the Order of Lenin and the K. E. Tsiolkovsky Gold Medal of the U.S.S.R. Academy of Sciences. Later, a crater on the far side of the Moon was named after him. On March 27, 1968, Gagarin was killed in an accident while test piloting a MiG-15 aircraft near Moscow. The event caused a great deal of shock and spawned numerous conspiracy theories and rumors within the Soviet Union, whereas Western powers alleged that Gagarin had been drunk at the time. Two years after his death, he was posthumously inducted to the International Aerospace Hall of Fame.

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See also: Astronauts and cosmonauts; History of human flight; Russan space program; Spaceflight

Roland Garros

Date: Born on October 6, 1888, in Saint Denis, France; died on October 5, 1918, near Vouziers, France

Definition: French pilot and aviation pioneer who was the first person to fly an airplane across the Mediterranean and is credited with being the first fighter pilot.

Significance: Garros helped to devise an apparatus that allowed a machine gun to fire effectively between the blades of an airplane's moving propeller, and he successfully tested the device against German aircraft in World War I.

Roland Garros was born in 1888 and was an avid sportsman who developed a passion for aviation. He entered air races, placing second in the 1911 Paris-to-Rome competition and in April, 1913, winning the International Air Rally of Monaco. He also set several world altitude records, and on September 23, 1913, made history by being the first person to fly cross the Mediterranean. With the outbreak of war in 1914, he joined the French Air Corps as a lieutenant.

At the beginning of World War I, military planes mainly flew observation missions. Then pilots began to use rifles or revolvers to fire at enemy aircraft and ground troops. When a machine gun was mounted to the plane, a second man was needed and he could fire the gun only from the rear, so that the bullets would not hit the blades of the moving propeller. Pilots and aircraft designers alike quickly realized the urgent need to develop a forward-firing machine gun that enabled the pilot to aim his aircraft and gun in the same direction. Frenchman Raymond Saulnier, of the Morane-Saulnier aircraft company, had designed steel plates that would fit on the propeller blade to deflect most of the mounted gun's bullets. Garros calculated, however, that 7 percent of the bullets could still hit the propeller. Determined to make the deflector shields more effective, Garros worked to improve on Saulnier's invention by adding small steel wedges to the propeller blades. Garros then had his plane fitted with the new deflection plates and with a Hotchkiss machine gun with its trigger connected by a wire to the cockpit. On April 1, 1915, Garros was ready to test the new device in combat. He encountered a German reconnaissance plane, aimed his machine gun and shot down the Albatros B-II. During the next two weeks, Garros shot down four more German planes.

The Germans were unable to explain how Garros managed to fire his machine gun successfully through the propeller blades until April 18, 1915, when Garros was forced to land his aircraft behind German lines. The established practice of the time was that a downed pilot would burn his aircraft as quickly as possible to prevent its falling into enemy hands. Garros's plane, however, was too damp and did not burn. After they captured Garros's plane, the Germans studied it carefully and soon determined the specific workings of the propeller deflectors. Under the direction of Dutch aircraft designer Anthony Fokker, the Germans fitted their planes with similar yet slightly improved devices and thus launched the era of aerial combat.

The Germans treated Garros respectfully and placed him in an elite prisoners' camp. He remained a prisoner of war until 1918, when he managed to escape to Holland. He then traveled back to France and returned to aerial combat.

Garros was shot down and killed on October 5, 1918, at Vouziers in the Ardennes region, where he was buried. The French commemorated the aviation pioneer in 1928 by naming their new international tennis stadium in Paris the Roland Garros Stadium.

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See also: Airplanes; Fighter pilots; Military flight; Record flights; World War I

Gemini Program

Date: From December 7, 1961, to November 15, 1966

Definition: America's crewed spaceflight program that placed humans into Earth orbit.

Significance: The Gemini Program placed humans into Earth orbit and taught astronauts how to track, maneuver, and control orbiting spacecraft; dock with other orbiting vehicles; and reenter Earth's atmosphere and land at specified locations, all necessary to the execution of an Apollo mission.

Evolution of the Gemini Program

Prior to the formation of the National Aeronautics and Space Administration (NASA), a number of crewed space concepts had been investigated within the military. After the Soviet Union launched the world's first artificial satellite, Sputnik 1, on October 4, 1957, the U.S. reaction could easily be described as one of panic, with fear centering on the suspicion that the Soviet Union would assume technological leadership over the free world.

The United States' first attempt to send a satellite into space failed miserably. Vanguard 1 blew up on the launch pad in December, 1957, before the eyes of the world. On January 31, 1958, an Army-based group including Wernher von Braun successfully placed Explorer 1 into orbit. Within months, President Dwight D. Eisenhower, with Congressional approval, created NASA as a civilian space agency. Its first major endeavor was the Mercury project, the goal of which was to send an astronaut into orbit before the Russians. However, the Soviets scored another major first when, on April 12, 1961, they launched cosmonaut Yuri Gagarin into space. He completed one Earth orbit before safely returning to Earth, landing within the Soviet Union. The Soviets led the space race thanks to their proficiency with heavy-lift boosters, a strength they continued to exploit for many years. This strength played a major role in Gagarin's achieving orbit before NASA's Mercury astronauts.

On May 5, 1961, Alan Shepard became the first American to enter space. Shepard launched atop a Redstone rocket, which did not have sufficient thrust to lift his Mercury capsule into orbit. Shepard flew a fifteen-minute-long suborbital profile, arcing up to 115 miles altitude and splashing down in the Atlantic Ocean off the coast of Cape Canaveral. Just three weeks later, President John F. Kennedy committed NASA to sending a man to the Moon and back before the year 1970.

To achieve this goal, NASA initiated the Apollo Program. However, the proposed three-man Apollo vehicle was far too big a step over the existing primitive single-astronaut Mercury spacecraft that could orbit the earth for only a brief period. Further, the Mercury spacecraft was incapable of orbital maneuvers of the type necessary for achieving Apollo's goal using what was termed a lunar orbit rendezvous (LOR) technique. LOR involved having the Apollo spacecraft separate into two portions, one that remained in lunar orbit and another that took two astronauts wearing protective pressure suits down to the lunar surface. This separation necessitated a rendezvous after lunar exploration, so that all three astronauts could reunite for the journey back to Earth. Apollo missions would last between eight and fourteen days and would require very precise reentry maneuvers in order to bring the crew safely through a narrow corridor in the earth's atmosphere where the spacecraft would survive reentry heating.

The Gemini Program was therefore developed as an interim means whereby all of the techniques necessary for Apollo missions could be assessed and refined in low-Earth orbit. Gemini astronauts would build up experience with orbital maneuvering, living for prolonged periods of time in weightlessness, rendezvous and docking separately launched target vehicles, and controlled reentries involving splashing down near recovery forces. Whereas the Mercury spacecraft carried one astronaut and the Apollo spacecraft would carry three, Gemini was designed to build on the Mercury experience with a modular spacecraft capable of flying two astronauts for up to two weeks in duration.


Astronaut Gordon Cooper is recovered after the splashdown of the Gemini V space capsule on August 29, 1965. (NASA)

Gemini Flight Operations

The first two Gemini missions were uncrewed test flights to rate the Titan II launch vehicle and to qualify critical Gemini spacecraft systems. Gemini 1 was launched successfully from Cape Kennedy on April 8, 1964. A Gemini spacecraft mock-up was placed in orbit as a result of proper Titan II booster performance. The spacecraft was meant neither to be separated from the booster's second stage nor returned to Earth.

Gemini 2, which included the first fully operational test spacecraft, was launched on January 19, 1965. It followed a suborbital profile designed to stress the Gemini spacecraft heat shield's ability to manage reentry heating. The spacecraft was safely recovered from the Atlantic Ocean.

Gemini 3 launched on March 23, 1965, with astronauts Virgil "Gus" Grissom and John W. Young aboard. Over the course of three orbits, the astronauts performed three different maneuvers to change the spacecraft's orbit, the first time that orbital maneuvers were executed on a crewed spacecraft. Russian cosmonauts had flown aboard Vostok and Voskhod capsules that had been largely automated in nature.

Just prior to the Gemini 3 mission, the Russians had scored a major advance when cosmonaut Alexei Leonov departed his Voskhod 2 spacecraft for a brief walk in space. The next Gemini mission, Gemini IV, attempted the first extravehicular activity (EVA) performed from a NASA spacecraft. Gemini IV launched on June 3, 1965, with astronauts James A. McDivitt and Edward White aboard. McDivitt attempted to fly close to the spent Titan II booster's second stage after spacecraft separation, consuming a great deal of fuel in the process. Because the mission was meant to last four days, a NASA first, it was decided to halt that maneuver to save fuel. On the mission's third orbit, White opened his hatch and proceeded to exit from the spacecraft using a small gas-powered thruster gun to move about while remaining tethered to Gemini IV by a life-support umbilical. White quickly depleted his gas supply, but he spent a total of twenty-three minutes floating about before returning to Gemini IV's cabin. After four days, McDivitt flew a manually controlled rolling reentry, and Gemini IV splashed down within range of recovery forces in the Atlantic Ocean. Gemini IV began NASA's evolutionary buildup toward a two-week-long mission, and its astronauts spent as much total time in space as had that astronauts of all previous NASA crewed flights combined.

Gemini V launched on August 21, 1965, with astronauts L. Gordon Cooper and Charles "Pete" Conrad on board. This mission marked the first use of fuel cells utilizing liquid oxygen and hydrogen to produce electrical power. Problems with systems associated with the fuel cells surfaced early in flight, forcing the cancellation of a rendezvous exercise and a powering-down of the spacecraft. Those pressure problems diminished later in the flight, and Cooper and Conrad were able to remain aloft in Gemini V for nearly eight full days before returning to Earth, splashing down in the Atlantic Ocean with no major physiological problems encountered during their record-setting flight.

The next Gemini mission was a planned rendezvous and docking with an uncrewed Atlas-Agena docking target. The original flight plan called for the liftoff of the Agena docking target on top of an Atlas rocket about an hour before that of the Gemini VI spacecraft. Once the Agena had reached the correct orbit, Gemini VI would be launched. Over a period of time, Gemini VI would catch, rendezvous, and join or dock with the Agena. Both of these vehicles would be launched from Cape Kennedy, Florida, from separate launch pads.

The first launch attempt of Gemini VI was made on October 22, 1965. Unfortunately, the Agena suffered a failure shortly after it separated from the Atlas booster and was lost. Astronauts Walter Schirra and Thomas Stafford were already in their spacecraft, but, with no Agena target in space, Gemini VI was scrubbed in favor of proceeding with Gemini VII, a two-week-long flight of astronauts Frank Borman and Jim Lovell in December, 1965. Gemini Program managers decided to alter Gemini VI's mission, renaming it Gemini VI-A, and to use Gemini VII as a target with which to rendezvous if Cape Kennedy personnel could refurbish the launchpad sufficiently quickly following Gemini VII's launch to permit a second Gemini liftoff within a two-week period.

Gemini VII was launched on December 4, 1965, and entered stable orbit. An attempt to launch Gemini VI-A on December 12 resulted in an engine shutdown on the pad, but the crew was safe. Then, on December 15 with the booster refurbished, Gemini VI-A lifted off and began a four-orbit chase, closing to within a foot of Gemini VII's nose. Even without docking, this dual flight verified the capability of astronauts to execute the maneuvers needed for Apollo. Also, the Gemini VII crew proved that astronauts could survive weightlessness during the longest Apollo flights. Gemini VI-A returned to Earth, splashing down in the Atlantic Ocean on December 16. Gemini VII executed its reentry on December 18, landing close to the same recovery vessel that had recovered Gemini VI-A.

Gemini VIII launched on March 16, 1966, with astronauts Neil Armstrong and David Scott on board. Their liftoff came one orbit after an Atlas booster delivered an Agena to orbit. Armstrong and Scott executed a rendezvous over the course of four orbits and docked to their Agena vehicle. Within one half-hour, Gemini VIII and its Agena entered a rolling motion that threatened structural stability. Armstrong undocked and backed away from the Agena. As the problem involved a Gemini VIII thruster firing uncontrollably, the roll rate increased, forcing Armstrong to regain control by firing other thrusters dedicated for reentry. Gemini VIII had to be terminated early, and Armstrong and Scott splashed down in a backup recovery zone in the Pacific Ocean after only seven orbits.

After Gemini IX's Agena target, launched on May 17, 1966, failed to reach orbit, the mission was postponed. An alternate target called an Augmented Target Docking Adapter (ATDA) was launched on June 1, 1966, but the crewed Gemini flight, now renamed IX-A, could not follow. Two days later, astronauts Stafford and Eugene Cernan launched from Pad 19. When Gemini IX-A approached the ATDA after a three-orbit rendezvous, the astronauts found the ATDA's forward shroud had not cleanly separated from the docking mechanism. They used the ATDA for several different rendezvous exercises, but no docking was possible. Cernan attempted a spacewalk meant to last one full orbit, but he ran into difficulties working on a jet backpack he intended to test-fly up to 100 feet away from Gemini IX-A. His visor fogged over, and he had to terminate the EVA and return to the cabin. Gemini IX-A splashed down in the Atlantic Ocean after 45 orbits.

Gemini X included a pair of rendezvous exercises involving the Agena VIII target vehicle and an Agena launched one orbit before astronauts John W. Young and Michael Collins. Gemini X and Agena X were launched on July 18, 1966. After docking Gemini X and Agena X together, a rocket firing of Agena X's main engine propelled the docked complex toward rendezvous with Agena VIII. Collins performed a tethered EVA in the proximity of Agena VIII and also performed another spacewalk while standing up in his seat to perform astronomical observations. This marked the first time that all major objectives of the Gemini Program were demonstrated in one single mission. Gemini X splashed down in the Atlantic Ocean on July 21.

Gemini XI and its Agena were launched on September 9, 1966. Astronauts Conrad and Richard F. Gordon completed a rendezvous on their first orbit and docked to Agena XI. Gordon performed a stand-up spacewalk and an umbilical EVA, the latter requiring early termination, after Gordon overstressed his life-support chest pack's ability to keep him cool. Using Agena XI's propulsion system, Conrad and Gordon were able to temporarily boost their spacecraft up to a record 850-mile altitude. They splashed down in the Atlantic Ocean after executing the first computer-controlled reentry.

Gemini XII and its Agena were launched on November 11, 1966. Astronauts Lovell and Edwin "Buzz" Aldrin performed several rendezvous and docking exercises, expanding NASA's experience base. Perhaps the most important aspect of the final Gemini mission involved Aldrin's three periods of spacewalking, two of the stand-up variety and one umbilical. He spent a total of almost five and one-half hours outside the spacecraft and demonstrated methods that overcame problems encountered by earlier Gemini spacewalkers. Gemini XII landed on November 15 in the Atlantic Ocean.

Historical Context

From March, 1965, to November, 1966, Gemini astronauts flew ten crewed missions, greatly expanding NASA's crewed space flight experience beyond that of the original seven Mercury astronauts. During that period, not a single Russian cosmonaut flew in space, and NASA finally overcame the early Soviet lead in space technology. Gemini flights investigated virtually all aspects of an Apollo mission and laid the foundation for the successful achievement of a crewed lunar landing in July, 1969.

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See also: Aerospace industry, U.S.; Apollo Program; Neil Armstrong; Astronauts and cosmonauts; Mercury project; National Advisory Committee for Aeronautics; National Aeronautics and Space Administration; Russian space program; Alan Shepard; Spaceflight

John Glenn

Date: Born on July 18, 1921, in Cambridge, Ohio

Definition: The first U.S. astronaut to orbit the earth (1962) and the world's oldest astronaut (1998).

Significance: Glenn is a symbol of the evolution of the American space program. His first space mission restored American pride in the space race with the Soviet Union, while his last space mission demonstrated that the elderly can make important contributions to society.

Early Life

Reared in New Concord, Ohio, John Herschel Glenn, Jr., developed a great love and respect for his parents, who taught him that he had unlimited possibilities, and that, with hard work, he could achieve whatever goals he set for himself. His mother, an elementary school teacher, taught Glenn to love reading and learning. When Glenn was eight years old, he accompanied his father, a plumbing contractor, on a job to Cambridge, Ohio. During this trip, Glenn's father arranged for his son's first flight on an airplane, after which Glenn was hooked on flying. Model airplanes became his favorite hobby, and he dreamed of someday becoming a pilot.

In high school, Glenn participated in football, basketball, and tennis; played the trumpet in orchestra; and served as a school newspaper reporter and student body officer. After graduating from high school in 1939, he enrolled in Muskingum College to study chemical engineering. He also entered a civilian pilot training program and earned his flying license in 1941. Upon the U.S. entry into World War II (1939-1945), Glenn decided it was his patriotic duty to enlist for naval aviation training. After graduation, Glenn received a commission in the U.S. Marine Corps Reserve. By March, 1943, he had earned his wings and was promoted to a Marine second lieutenant. He married his childhood sweetheart, Annie Castor, on April 6, 1943.

War Experience

Assigned to Marine Fighter Squadron 155, Glenn spent a year flying F-4U Corsair fighters on a variety of bombing and reconnaissance missions against Japanese garrisons in the Marshall Islands. He flew fifty-nine combat missions and was hit by enemy fire five different times. After returning to the United States, his principal duties were as a flight instructor. He was promoted to the rank of captain in July, 1945. In December, 1946, he was assigned as a member of Marine Fighter Squadron 218 to patrol North China in support of General George C. Marshall's World War II peace terms. From June, 1948, until December, 1950, he served as an instructor in advanced flight training in Corpus Christi, Texas.

During the Korean War (1950-1953), Glenn flew jets in ground-support missions for the Marines and in air-to-air combat as an exchange pilot in the new Air Force F-86 Sabre jets, completing a total of ninety missions between February and September, 1953. Glenn had many close calls that often caused him to return to base with a seemingly unflyable aircraft. In the last nine days of fighting in Korea, Glenn downed three Soviet-built MiG-15's in fierce combat along the Yalu River.

For his military service during World War II and the Korean War, Glenn received four Distinguished Flying Crosses and eighteen Air Medals. He rose steadily through the ranks, becoming a captain in 1945, a major in 1952, and a colonel in 1959. In 1954, he was assigned to the Navy's test pilot school in Patuxent River, Maryland. Upon graduation, he served as a project officer on a number of aircraft. On July 16, 1957, he set a record for the first coast-to-coast, nonstop, supersonic flight in an F-8U Crusader jet fighter, flying from Los Angeles to New York in three hours and twenty-three minutes. For this event, Glenn received his fifth Distinguished Flying Cross.

Space Flight and Politics

Spurred by the success of the Russian satellite Sputnik, the United States established Project Mercury in 1958. Glenn was named as one of the seven Mercury astronauts in April, 1959. Motivated by his deep religious faith, hard work ethic, and tenacious devotion to duty, he helped win the widespread public support that the space program needed.

Glenn was selected to serve as backup pilot for the suborbital flights of Alan Shepard and Virgil "Gus" Grissom in 1961. He was then chosen as the first American to orbit the earth, orbiting three times in the *Friendship 7* on February 20, 1962. The mission restored American pride in the space race with the Soviet Union.

After convalescing from a severe inner-ear injury caused by a fall in February, 1964, Glenn retired from the Marines in January, 1965. He was elected to four consecutive terms as a U.S. senator from Ohio, beginning in 1974. He made an unsuccessful bid for the Democratic presidential nomination in 1984. On the thirty-fifth anniversary of his historic flight (February 20, 1997), Glenn announced that he would retire from the Senate at the end of his fourth term in 1998.

The Oldest Astronaut

While Glenn sought additional funding for the National Aeronautics and Space Administration (NASA) in 1995, he reviewed some documents on the physical changes that happen to astronauts in orbit. He was amazed at the similarities between the effects of zero gravity on the body and the natural aging process on Earth. Consequently, he began petitioning NASA for the opportunity to go back into space and study the effects of weightlessness on older Americans. After much perseverance, on January 15, 1998, he was granted his wish of going back into space.

After a thirty-seven-year hiatus from space flight, Glenn spent months of training, experimenting, baseline medical tests to become the oldest person to travel into space. As a member of the nine-day space shuttle *Discovery* mission from October 29 to November 7, 1998, the seventy-seven-year-old Glenn conducted numerous experiments that focused on osteoporosis and the immune system's adjustments to the aging process. Glenn's contributions demonstrated that the elderly can still make important contributions to society. Glenn stands out as a symbol of courage, honor, and lifelong devotion and service to his family and his country.

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See also: Apollo Program; Astronauts and cosmonauts; Korean War; Marine pilots, U.S.; Mercury project; Model airplanes; National Aeronautics and Space Administration; Alan Shepard; Space shuttle; Spaceflight; Supersonic aircraft; Test pilots; World War II

Gliders

Definition: Any one of a number of types of winged, heavier-than-air craft, having no motive power other than gravity. Sailplanes are a specific type of glider than can ascend as well as descend.

Significance: Gliders were the predecessors to motorized flight. Information gained from experiments with gliders made motorized flight possible.

A glider is launched from a raised elevation and is capable only of forward movement through air while at the same time losing altitude. The relation between forward momentum and loss of altitude is a glider's sink rate, and gliding is the motion of the craft's controlled descent. The history of glider development is essentially the process of experimentation to minimize a glider's sink rate, while giving the glider pilot increasing control over the movement or flight of the glider while airborne. Eventually, after centuries of experimentation, aviation technology developed to the point where gliders could be constructed and flown in ways that permitted the glider pilot to slow and even reverse the rate of descent. The process of flying a glider using the energy from thermal air currents to regain altitude lost by the downward force of gravity is called soaring. The type of glider capable of being flown in such a way is termed a sailplane. It is basically a high-performance glider designed specifically for soaring. Post-World-War-II gliders are more correctly called sailplanes to distinguish them from earlier gliders, regardless of size and precise configuration, that were not capable of regaining lost altitude in a controlled manner after they had been launched.

Earliest History

The process of experimentation with gliders that led to modern sailplanes took place over the course of centuries. As long as humans have watched birds in flight, humans have wanted to imitate them. Many of the earliest attempts at human flight are thinly documented or are mythological. One of the earliest stories of human flight is the account of Daedalus and his son Icarus. As related in *Metamorphoses* (c. 8 C.E.; Eng. trans. 1567), a collection of tales by the Roman writer Ovid, Daedalus was imprisoned by the Cretan king Minos. While watching sea gulls in flight, Daedalus got the idea to fashion wings from discarded gull feathers held together with candle wax. Using these birdlike wings, Daedalus and Icarus escaped. Daedalus wisely kept to a course midway between earth and heaven, but Icarus flew too close to the sun. The wax holding his wings together melted and he plummeted to his death. This cautionary tale of Daedalus and Icarus set the stage for much later thinking about human flight. Most people were of the opinion that humans had no business trying to fly, but there was a small group of adventurers and inventors who disregarded this opinion.

Medieval Attempts at Flight

There are numerous undocumented passages in medieval historical sources stating that humans achieved flight aboard or attached to gigantic kites, perhaps similar to present-day hang gliders. The Italian mathematician Giovanni Danti is reported to have tried to fly over Lake Trasimeno in Italy in the late 1500's. John Damian, another Italian, reportedly constructed a pair of wings and jumped off the wall of a castle belonging to King James IV of Scotland. He plummeted to Earth, breaking his leg. Leonardo da Vinci, a fifteenth century Italian artist, scientist, and inventor, seriously examined the possibility of human flight. Using comparative zoology and architectural and mathematical studies, da Vinci concluded that humans were too heavy to be kept aloft by feathered wings modeled on the wings of birds. Da Vinci thought that batlike wings in which the skin is stretched over a lightweight skeleton was more likely to sustain the weight of a human in flight. Da Vinci also designed rudimentary parachutes and a type of ornithopter or bird-imitating flapping machine that is considered an early prototype to the modern helicopter. Although da Vinci's flying inventions are theoretically possible, it was almost three hundred years before they were actually built, tested, modified, and put into practice.

Nineteenth Century

The Englishman Sir George Cayley systematically examined the problems associated with human flight. In 1809, he published the results of his experiments with small, uncrewed glider models, each of them with V-shaped wings and a tail stabilizer. Using his horses to supply the forward momentum, Cayley performed a brief, barely controlled glider flight in 1853. William Henson tried to develop Cayley's experiments further by adding a steam-powered motor to the air craft. Such an engine made the aircraft far too heavy to get off the ground, but Henson improved Cayley's glider designs, eventually designing a fixed, single-wing glider with a bird-tail-shaped tail, a rudder, and landing gear. Henson's friend John Stringfellow built a small model glider with a small steam engine that could fly under specific circumstances, but he did not build a model big enough to carry the weight of a human. F. H. Wenham, another Englishman, also studied birds to investigate possibilities for human flight. Wenham concluded that a slightly arched wing set at an angle, rather than a flat wing surface, could lift more weight. He also thought that a connected series of shorter, arched wings rather than one set of long, flat wings might sustain a person in flight, if only a means could be found to lift the craft off the ground initially.

Frenchmen Jean-Marie Le Bris and Felix Du Temple both built uncrewed, motorless gliders. Le Bris fashioned his glider in the shape of an albatross and Du Temple constructed the first propeller-driven aircraft to lift off from the ground under its own power. Neither craft could stay aloft for more than a few seconds nor could their flight path be controlled. In the late nineteenth century, the German Otto Lilienthal built numerous single-winged gliders, each with a fixed tail for stability. The pilot stood in the center of the glider with the glider frame attached around his waist. By making over two thousand flights off a small hill, Lilienthal learned how to move his weight to steer the glider. His longest flight was approximately 200 feet. On August 9, 1896, Lilienthal attached a small motor to his glider and launched himself off the hill. The wind shifted and he crashed, suffering fatal injuries. Percy Pilcher, a Scotsman who had known Lilienthal, modified his own triplane glider based on Lilienthal's experiments. Pilcher conducted numerous glider flights, one as long as 750 feet, before being killed in a glider accident in September, 1899. A naturalized American, Octave Chanute, was also influenced by Lilienthal's experiments. He designed numerous gliders and tested them on the beach at Lake Michigan near Chicago, Illinois. He had two-, three-, and five-winged models with rear stabilizers, each controlled in flight by shifts in the pilot's weight. Chanute kept careful records of his experiments with equilibrium while aloft, information he shared with the Wright brothers.

Early Twentieth Century

Wilbur Wright and his brother Orville Wright grew up primarily in Dayton, Ohio. They initially made their living repairing bicycles while pursuing aeronautical experiments as a hobby. Beginning with a series of kites, the Wright brothers developed a system of wing-warping that greatly increased the pilot's ability to control the flight of an aircraft. The Wright brothers spent part of each year from 1900 to 1905 at Kitty Hawk, North Carolina, testing gliders they had designed in Dayton. The 1900 glider weighed 52 pounds and had 18- by 5-foot wings. It was not substantial enough to lift a pilot in a controlled flight. In 1901, the glider was much bigger, having 22- by 7-foot wings. The longest piloted flight, by Wilbur, was 400 feet. During the winter of 1901, the Wright brothers reworked information from Chanute and Lilienthal in order to solve problems with both lift and control. Using this new information, the 1902 biplane glider weighed 116 pounds and had a 32-foot wingspan. It incorporated various design changes to provide more lift, including a forward monoplane elevator, as well as a fixed rudder linked to the wing-warping or shaping system that allowed the pilot to control the glider's flight. The longest flight of the 1902 testing session was 622 feet, lasting 26 seconds. The original patent issued to the Wright brothers covered the modifications included in the 1902 glider design. Returning to design experiments, the Wrights constructed a glider that could carry a 12-horsepower engine and have two propellers. On December 17, 1903, Wilbur Wright flew 852 feet, staying aloft for 59 seconds, the first documented pilot-controlled motorized flight in history. The Wrights continued to refine their aircraft designs in 1904 and 1905, gradually increasing both the length of and control over motorized flights. In 1911, Orville returned briefly to gliders, setting a glider flight record of 9 minutes, 45 seconds.

World War II

Once motorized flight had been demonstrated, gliders seemed rather primitive. All the major powers in World War I used motorized airplanes, not gliders. After the end of World War I, however, attention returned to gliders. The Treaty of Versailles ending the war prohibited the Germans from building new planes with engines. The treaty did not mention the building of motorless gliders. Thus, throughout the 1920's and early 1930's, thousands of young German men learned to fly as glider pilots. They formed the core of the Nazi Luftwaffe in World War II. In 1930, the three Schweizer brothers—Bill, Paul, and Ernest—began to build gliders for sale to enthusiasts in the United States. In 1932, the Soaring Society of America was founded to regulate the small but growing hobby in America. *Soaring Magazine*, still in publication, debuted in 1937.

The Germans were the first to recognize the potential military applications of gliders. The first military glider capable of carrying troops and equipment was the DFS-230. On May 11, 1940, ten DFS-230's carrying seventy-eight glider troops attacked and captured Eben Emael in Belgium, due in large measure to the element of surprise. Other countries quickly took notice. The United States produced thousands of small TG-2 and TG-3 gliders, as well as jumbo gliders such as the Laister-Kauffman CG-10A Trojan. The British also built large numbers of various types of gliders to use in aerial observation, as well as in troop and equipment transport.

The idea of parachute troops or airborne infantry was in its infancy in early World War II. Rather than trying to coordinate hundreds of individual soldiers in parachute drops, the conventional wisdom of the time thought it made more sense to airlift troops in platoons in gliders. Unfortunately, glider pilots and troops suffered very high casualty rates, in excess of 50 percent. The Germans tried an unsuccessful glider assault on Crete. Many gliders were blown off course, some crashed, some landed intact but far from the designated landing zone. On July 9, 1943, the Allies tried a joint American-British glider assault on Sicily. Of the 144 troop gliders involved in the assault, 69 landed in the ocean rather than on land, 10 were apparently shot down, only 12 were able to land intact, and only 4 of those landed within the designated landing zone. The Allies also tried glider assaults in Burma, with similar disastrous results.

Post-World War II

After Word War II, many military pilots turned to gliding as a recreational pursuit. Inexpensive military surplus gliders were readily available. By the mid-1950's, there was a large enough recreational market to spur further refinements in glider design. Invented in 1928, the variometer, a piece of equipment that allowed the pilot to measure even small differences in altitude, became standard on every glider, which became technically sailplanes, able to both ascend and descend. National and international championships are held annually for different design classifications of sailplanes, with various contests for speed, altitude, duration of flight, distance covered and accuracy in landing at a designated spot. All rules and standards concerning sailplane construction and classification, as well as sailplane pilot training requirements in the United States, are regulated by the Federal Aviation Administration.

Victoria Erhart

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See also: Aerodynamics; Sir George Cayley; Octave Chanute; Forces of flight; Hang gliding and parasailing; Heavier-than-air craft; Otto Lilienthal; Luftwaffe; Military flight; World War II; Wright brothers

Robert H. Goddard

Dates: Born October 5, 1882, in Worcester, Massachusetts; died August 10, 1945, in Baltimore, Maryland

Definition: Inventor of rocket components.

Significance: Goddard pioneered rocket technology in the early twentieth century.

Robert Hutchings Goddard was born on October 5, 1882, in Worcester, a middle-class suburb of Boston, Massachusetts. He graduated from Worcester Polytechnic Institute in 1908, and continued his graduate education at nearby Clark University, where he earned his M.A. in 1910 and his Ph.D. in 1911.

By 1914, Goddard had applied for and won two patents; one for a liquid fuel rocket, the second for a multistage rocket. These awards gave him a standing in the scientific community and eventually led to some financial support from the Smithsonian Institution.

His report *A Method of Reaching Extreme Altitudes* was published by the Smithsonian in early 1920. The publi-

Robert Goddard conducted rocket experiments in his own backyard, gaining a reputation as something of a mad scientist, until his theories were proved viable and he was recognized as one of the founders of modern spaceflight. (NASA)

cation drew attention beyond scientific circles due to Goddard's suggestion that jet propulsion could be the technology to achieve escape velocity and fly to the Moon. He was mocked for this idea and became something of an embarrassment to his family. This and other proposals earned him the nickname of "Moon Man" in the popular press.

His backyard experiments became well known and feared. However, before pressure from the authorities, the public, and his family prevailed on him to relocate, on March 16, 1926, he successfully launched the first liquid fuel rocket at Auburn, Massachusetts. It traveled 184 feet in 2.5 seconds. In the same year, Fritz Lang produced the motion picture *The Woman in the Moon*, based on the efforts of Goddard and a German rocket hobbyist. Interestingly, the film foreshadowed the German V-2 series. This movie was seen by virtually all scientists who became the backbone of the German and later the U.S. space program.

In 1929, Goddard and his small team of assistants moved their testing operations to Roswell, New Mexico. Here, isolated from the world and after many failures, he achieved success in 1930 when he and his team fired an 11-foot, liquid-fueled rocket to an altitude of 2,000 feet at a velocity of over 500 miles per hour. In 1932, a critical step came with a gyroscopically controlled rocket. Goddard's list of rocket achievements is impressive, including: components of a ramjet engine via a rocket fuel pump, regenerative cooling of combustion chambers, instrument payloads and recovery systems, guidance vanes, and gimbaled engines.

By March, 1935, Goddard was launching gyroscopically controlled rockets to 7,800 feet at over 700 miles per hour. His paper "Liquid Propellant Rocket Development," a primer on rocket technology, was published by the Smithsonian in 1936. With the threat of war looming in Europe, Lieutenant John Sessums visited Goddard in New Mexico to assess the military value of Goddard's rocket work. He concluded that it was of little or no value. In 1940, Goddard offered his research, patents, and facilities for use by the military, an offer that was ignored.

Goddard died at the end of the war on August 10, 1945. He survived long enough to see his dream realized in the German V-2 effort. The technical foundation he established was impressive, and he registered more than two hundred patents. On May 1, 1959, he was honored when the National Aeronautical and Space Administration named the space center at Greenbelt, Maryland, for him.

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See also: Engine designs; Propulsion; Ramjets; Rocket propulsion; Rockets; National Aeronautics and Space Administration

Goodyear blimp

Also known as: Lighter-than-air craft
Date: First flight on May 24, 1917
Definition: A lighter-than-air craft that achieves lift by filling the balloon-type structure with 6 million cubic feet of helium.
Significance: Early airships provided the U.S. Navy with reconnaissance and aircraft carrier capabilities while modern blimps are used primarily for television coverage and commercial advertising. Capable of staying afloat for up to eleven days at a time, the Goodyear blimps could fly from the United States to Europe and back again without refueling.

History

Goodyear established an Aeronautics Department in 1910 for the purpose of manufacturing and marketing rubber-impregnated fabrics and coatings for airplanes. By 1912, the company had constructed its first balloon, and in 1916 it purchased 720 acres of land southeast of Akron, Ohio, for the construction of the Wingfoot Lake Airship Base. After the United States entered World War I in 1917, the U.S. Navy ordered sixteen B-type airships, nine of which Goodyear manufactured. The first airship flew on May 24, 1917. The following year the Navy placed an order for ten C-type airships. The Navy took over the Wingfoot Lake facility from 1918 to 1921 for the training of pilots and further experiments and testing of the aircraft.

Between the wars, Goodyear built two airships, the *Wingfoot Express* and the *Pony*, which used hydrogen instead of helium. In 1925, Goodyear entered the commercial market. A single-engine helium-inflated *Pilgrim* preceded the 86,000-cubic-foot, twin-engine, TZ-type blimp. Each new airship resulted in the production of larger envelopes. During the 1930's, the U.S. Navy ordered two giant rigid airships from Goodyear. The aircraft, measuring over 200 yards long and requiring 6.5 million cubic feet of helium to ascend, relied on an internal metal frame to maintain its shape. The USS *Akron* and the USS *Macon*, used as aerial aircraft carriers equipped with small planes that could be deployed and retrieved, operated for two years before being destroyed during storms.

The next generation of blimps, built in the 1940's and 1950's, functioned as surveillance airships along coastal areas after the attack on Pearl Harbor. In the post-World War II period, Goodyear purchased several airships back from the Navy and outfitted them with neon night sign panels equipped with a grid for a running sign. Goodyear continued to manufacture airships for the Navy, constructing the largest nonrigid airship in 1960. Modifications to the airships since 1960 include major car and power plant changes and a 147,300-cubic-foot envelope. In 1966, the Goodyear blimp at the Indy 500 auto race included four running night signs in color. In 1972, the company moved

Goodyear Blimp Technical Statistics

Stars and Stripes and *Spirit of Goodyear*

Length: 192 feet
Width: 50 feet
Height: 59.5 feet
Volume: 202,700 cubic feet
Maximum Gross Weight: 12,840 pounds
Maximum Speed: 50 miles per hour
Cruise Speed: 30 miles per hour
Power Plant: Two 210-horsepower fuel-injected, air-cooled aircraft piston engines
Propellers: Two-blade constant speed, 78 inches
Passengers: 5 plus pilot
Operating Altitude: 1,000-3,000 feet, 10,000 feet maximum
Car: Aluminum and welded steel tube
Maximum Car Length: 22.75 feet
Fins, Rudders, and Elevators: Polyester fabric over aluminum and welded steel
Empennage: "+" configuration
Envelope: Neoprene-impregnated polyester fabric, two-ply
Night Sign Lights: Over 165,000 LEDs with over 256 colors
Landing Gear: Fixed

its facility from Akron to Spring, Texas. In 1986, additional alterations to the blimp included the use of twin vectorable turbine engines with ducted propellers, "X" fins, and a 247,800-cubic-foot envelope. Between 1917 and 1996, Goodyear produced 347 airships. By 2000, Goodyear maintained five airships worldwide: the *Eagle* in the City of Carson, California; the *Spirit of Goodyear* in Akron, Ohio; the *Stars and Stripes* in Pompano Beach, Florida; the *Spirit of Europe*; and the *Spirit of the Americas*, based in Saõ Paulo, Brazil.

Goodyear Blimp Technical Statistics

Spirit of Europe and *Spirit of the Americas*

Length: 130 feet
Width: 34 feet
Height: 44 feet
Volume: 70,000 cubic feet
Gondola Length: 14 feet
Gondola Width: 5 feet
Seating: 5 maximum
Engines: Two 68-horsepower Limbach L-2000
Fuel Capacity: 60 gallons
Maximum Speed: 53 miles per hour
Maximum Flight Capacity: 15 hours
Turning Radius: 750 feet diameter

Construction

Goodyear has manufactured three types of airships. The rigid airship has an internal frame of aluminum alloy that supports the balloon, but the weight of the frame requires the construction of long structures to maintain a proper weight-to-volume ratio. The semirigid airship incorporates a rigid lower keel and a pressurized envelope above. The nonrigid airship, the most advanced of the three types, uses the internal pressure of the gases to maintain the shape of the envelope and has no internal framework.

The anatomy of the blimp includes nose cone battens that stiffen the nose of the airship, helping to distribute the weight when the craft is moored and preventing damage to the nose of the ship. Behind the nose is the forward ballonet, an airbag within the envelope, which releases air through valves during ascent and lets air out through the scoops during descent. The air scoops take air from the props to fill the ballonets when additional air is required. When the airship is not flying and the engines are idle, the air scoops receive air from an electric blower. Four air valves control the release of air from the ballonets. The helium valve, located in the Goodyear logo on the ship, acts as a safety valve for the helium gas within the main envelope. Two inside envelopes, called catenary curtains, each 30 degrees off center, are attached by suspension cables and are sewn into the main envelope. The aft ballonet works in conjunction with the forward ballonet to achieve a nose-up or nose-down position. The ship is controlled by rudders (vertical fins) used for steering and elevators (horizontal fins) used to control the ascent and descent of the craft. Attached underneath the envelope is a car-passenger compartment measuring approximately 23 to 35 feet long and capable of holding a pilot and six passengers.

Propulsion is achieved by one of two different types of engines. Two 6-cylinder, gasoline-powered airplane engines that generate 210 horsepower can reach a top speed of 50 miles per hour. The second system uses two turboprop engines that generate a combined total of 840 horsepower and can reach speeds of 65 miles per hour. The average rate of speed maintained by both types usually averages 30 to 40 miles per hour.

The exterior of the Goodyear blimps are covered by 3,780 light boards with red, blue, and green light-emitting diodes capable of altering intensity to produce a total of 256 colors. Although one pilot operates the aircraft, the ground crew consists of fifteen individuals who work as aircraft mechanics, electronic technicians, or riggers. The ground crew follows the blimp across the country on a bus which functions as a traveling command and control center.

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See also: Blimps; Buoyant aircraft; Dirigibles; Lighter-than-air craft; Manufacturers; Military flight; Reconnaissance

Gravity

Definition: The force that all objects in the universe exert on all other objects as a result of their mass.

Significance: The origin of weight and the cause of the downward acceleration ("falling") of unsupported objects, gravity must be overcome by lift in order to sustain aerial flight, and must be properly exploited during spaceflight to successfully achieve orbit.

Gravitational Force

Physicists identify four fundamental forces that account for all known physical phenomena: gravity, electromagnetism, the strong nuclear force, and the weak nuclear force. Gravity is the weakest of the four, despite its overwhelming influence in everyday life, and it has a cosmic role in controlling the structure and evolution of the universe. Gravitation is dominant on a cosmic scale because it is long range, extending to infinity. The strong and weak nuclear forces, while much stronger than gravity, are of very short range and confined to the interior of the atomic nucleus. Electromagnetism also extends to infinity, but electric charges, which are the source of electromagnetic forces, come in both positive and negative forms that by and large cancel each other out, leaving only a relatively tiny net effect. Gravity, by contrast, is always attractive, therefore always additive and reinforcing. With a sufficient amount of mass, gravity can be made arbitrarily large. It is only because of the tremendous mass of the earth that gravity becomes the dominant force in everyday life.

Sir Isaac Newton in 1684 recognized that the gravitational force between two widely separated bodies must be proportional to the mass of each and weaken as the square of the distance between them. The gravitational force of the earth on an object is called its weight, and Newton's law states that one object twice the mass of another will weigh twice as much. It is on this basis that the mass of an object can be measured using devices such as balances and scales that actually determine weight. The law also specifies that weight will diminish with distance, so that objects at high altitudes will weigh less than they do at sea level. This loss of weight is real and easily measured with modern instruments. It must be stressed, however, that there is no corresponding loss of mass.

Because gravity extends to infinity, weight never vanishes completely and there is no such thing as true weightlessness. What is typically thought of as "weight" is actually the counterforce of the ground that supports objects and prevents them from falling due to the gravitational force. The "weightlessness" experienced by astronauts in orbit is actually free fall. In the 1580's, Simon Stevin experimentally discovered that all objects fall in a gravitational field at exactly the same rate, a result whose importance was first recognized and widely disseminated by Galileo Galilei in 1638. Astronauts in orbit are continuously falling toward Earth, but the spacecraft enclosing them is falling in exactly the same direction at exactly the same rate. As there is no relative motion, the astronauts float in the cabin as though gravity has gone away.

Orbital Motion

Orbital motion is a combination of free fall with a large velocity at right angles to the direction of fall. Absent the gravitational force, a satellite would move away from Earth in a straight line that would eventually carry it off toward infinity. The gravitational force pulls the satellite from this straight-line motion onto a path that curves around Earth and closes onto itself repetitively. This is an orbit.

Newton's law of gravitation explains Johannes Kepler's three laws of orbital motion: satellites travel in ellipses with the gravitational source (the primary) at one focus of the ellipse; a line joining the primary to the satellite sweeps out equal areas in equal times as the satellite moves around the orbit; and the cube of the average distance from the primary to the satellite is proportional to the square of the orbital period.

Moving objects possess energy of motion called kinetic energy, equal to one-half of their mass multiplied by the square of their velocity. Satellites in orbit are continuously speeding up as they fall toward the primary, thereby gaining kinetic energy, and slowing down as they coast away from it, losing kinetic energy. Since the total amount of energy in a system, kinetic plus potential, can never increase or decrease, the gain or loss of kinetic energy must be balanced by a gain or loss from another source called gravitational potential energy. The gravitational potential energy of two objects mutually attracted by a gravitational force is proportional to the product of their masses divided by the distance between them.

An object in free fall decelerates as it coasts upward, eventually coming to a stop when all of its kinetic energy has been converted to potential energy. It then starts to fall downward, converting potential energy back to kinetic energy and accelerating as it does so. Because the gravitational force weakens with distance, the amount of additional kinetic energy needed to reach ever-greater heights is limited. Objects moving fast enough to have kinetic energies that exceed this limit will never stop rising and will coast away from Earth forever. The velocity associated with this energy is referred to as the local escape velocity. Escape velocity at Earth's surface is approximately 7 miles per second (11 kilometers per second).

The total energy of a satellite determines the size of its orbit, its orbital speed, and its orbital period through Kepler's second and third laws. Satellites in low-Earth orbit travel at slightly less than 5 miles per second (7.7 kilometers per second). The atmosphere at that altitude is extremely thin but still capable of exerting significant drag on objects traveling at such high velocities. Drag is a dissipative force which converts kinetic energy to heat and ordinarily slows objects down, but satellites under the influence of drag drop closer to the earth, converting potential energy to kinetic energy as they do so, and surprisingly end up traveling faster. When the total energy is no longer sufficient to maintain orbit, the satellite reenters the atmosphere.

In order for the satellite to reach the ground at rest, all of its orbital kinetic and potential energy must be converted into heat. Temperatures become so great that the air around the reentering satellite becomes hot enough to glow. In uncontrolled reentry, too much of the heat builds up within the satellite and the satellite vaporizes, a fate common to small meteors. Crewed spacecraft control reentry and survive by discharging the heat overboard.

Gravitational Effects

The gravitational pull of the Moon is felt daily in the rising of the tides. Additionally, as Earth rotates underneath the tides, it pulls the bulge of water from west to east, working against the pull of the Moon. This produces a small tug on the Moon in the direction of its orbital motion and slightly increases the Moon's total energy. As a consequence, the Moon's orbit increases in size a small but measurable amount. The orbital period of the Moon increases as a result, and the month gets slightly longer. Correspondingly, the drag of the tides on the ocean floor slows down Earth, increasing the length of the day.

Although Earth and the Moon appear to be made of hard, rigid rock, each is flexible enough to bend in response to their mutual gravitational attraction. This allows tides to rise in the rock itself. Rock tides on Earth contribute to the braking effect of the ocean tides, but are very small in comparison. Earth's gravity also raises rock tides on the Moon, which have, over billions of years, slowed the Moon's rotation down to the point that the length of the lunar day exactly equals the orbital period: one month. As a consequence, the Moon always keeps one face toward Earth, and humankind is only privileged to see the other side of the Moon through photographs taken from lunar orbit.

This curious circumstance is called tidal locking and it is not at all rare. A majority of the natural moons in the solar system are tidally locked to their parent planet. Tidal locking is the inevitable result of the gravitational interaction of one flexible body orbiting another. When deliberately used by satellite designers to keep one end of an oblong satellite pointed toward Earth, it is referred to as gravity-gradient stabilization. (Space shuttle pilots put the shuttle into gravity-gradient stabilization during sleep periods so that noisy thruster firings to maintain attitude can be avoided.)

General Relativity

Although gravity was the first force to be mathematically described by physicists, it remains the least understood. Stevin's and Galileo's observation that all objects fall at exactly the same rate in response to the gravitational force inspired Albert Einstein in 1915 to go beyond Newton's law of gravitation to propose the theory of general relativity. Based on Einstein's theory of special relativity, which unites space and time into a four-dimensional universe, general relativity describes gravity as the result of localized space-time curvature in this four-dimensional universe.

General relativity predicts that clocks at high altitudes will run faster than identical clocks at low altitudes. This prediction has been verified and this phenomenon had to be included in the design of the Global Positioning System (GPS) in order to achieve required accuracy and precision. Very accurate and stable atomic clocks flown on GPS satellites consistently run faster than identical clocks on the ground.

General relativity also explains the cosmological expansion of the universe and the bizarre properties of black holes. The expansion of the universe was discovered by

Edwin Hubble in 1925 through measurement of the frequency shifts of light emitted by distant galaxies. Almost all proved to be moving radially away from the Milky Way, with a speed of recession proportional to distance away: A galaxy twice as far away as another recedes from Earth twice as fast. This shocking phenomenon proved to be a direct and natural expectation of the general theory of relativity.

Apparently, the universe originated billions of years ago in a big bang that flung matter outward in all directions. Over the course of billions of years, gravity pulled the matter into clumps out of which galaxies, stars, and planets formed. Because the galaxies attract each other gravitationally, the expansion should slow as time goes by. If the universe does not contain enough matter to make the local escape velocity of the galaxies everywhere greater than the current recession velocity, then the expansion will go on forever. If the universe does contain enough matter, then the expansion will eventually slow to a halt and the universe will contract back into a single mass, possibly to explode again and expand into a brand new and different universe.

Black holes are objects whose surface gravity is so strong that in regions inside what is called the escape horizon, the local escape velocity is greater than the speed of light. As a basic tenet of special relativity is that nothing can travel faster than light, nothing that ever falls through the escape horizon can ever get out again. A second consequence is that anything that falls through the escape horizon continues to fall all the way to the center of the black hole where it and all other infalling matter are crushed to zero volume and infinite density. It appears that the laws of physics themselves cease to hold under these conditions.

Gravity and Unified Field Theory

Certain aspects of general relativity have not been reconciled with quantum theory, the branch of physics that explains the behavior of objects at atomic and sub-atomic levels. Physicists have succeeded in uniting the theory of electromagnetism and the theory of the weak nuclear force into one theory of electroweak interactions. They are confident that eventually the theory of electroweak interactions and the theory of the strong nuclear force will be united into a grand unified theory. The ultimate quest of theoretical physics is a single theory uniting this eventual grand unified theory with general relativity, capable of explaining all four fundamental forces, and by extension, everything in the universe.

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See also: Forces of flight; Microgravity; Orbiting; Satellites; Spaceflight

Guernica, Spain, bombing

Date: April 26, 1937

Definition: The bombing of a small town in northern Spain by units of the German Condor Legion during the Spanish Civil War (1936-1939).

Significance: An operational test of the German Luftwaffe's strategy of Blitzkrieg, the bombing of Guernica created an international outcry and was also a portent of the mass bombings of civilians during World War II.

On April 26, 1937, Guernica, a Basque town in northern Spain with a population of about 7,000 people, was almost totally devastated. Fire and explosions destroyed most of the town's wooden houses, its two hospitals, and its surrounding farmhouses and village areas. Many civilians were burned to death in their houses, while survivors who ran into the streets were machine-gunned to death.

Among the few structures that survived unscathed was Casa de Juntes, the repository of a valuable historical archive. The church of Santa Maria was largely untouched, as was the famous Guernica oak tree, where the kings of Spain had traditionally taken an oath to respect the rights of their subjects, who in turn pledged their allegiance.

Events Leading to the Guernica Bombing

Mid-July, 1936: The Spanish Civil War begins.
Late July, 1936: The first units of the German Condor Legion arrive in Spain.
March 31, 1937: Nationalist General Emilio Mola begins a military campaign against Republican armies in northern Spain.
April 25, 1937: Condor Legion chief of staff Wolfram von Richthofen formulates plan for attack on Guernica.
April 26, 1937, 3:45 P.M.: Condor Legion planes leave airports in Vitoria and Burgos for the attack on Guernica, with the Rentería Bridge as the purported target.

Political Background

The destruction of Guernica became one of the most famous events of the Spanish Civil War, in which a Republican government consisting of parties on the Spanish Left was challenged by the conservative Nationalist armies of General Francisco Franco. The civil war continued the century-old struggle between monarchists and republicans in Spain. King Alfonso XIII had left the country in 1931, and in the 1936 elections, a Popular Front of socialists and other leftist parties had taken parliamentary control. There were fears within the Spanish military that the Popular Front was a communist-supported political device that might introduce communism into Spain. In response to the anticlerical traditions of the Spanish Left, much of the hierarchy of the Spanish Catholic Church also opposed the Spanish Republic.

In July, 1936, General Franco, commander of Spanish troops in Morocco, assembled a Nationalist force to oppose the Republic. This began a civil war in which much of the Spanish army, landowners, businesspeople, and the Church opposed the Republic, while agricultural workers, urban workers, and portions of the middle class supported it. Also siding with the Republican government were many Basques who, although one of the most devoutly Catholic segments of the population, had historically sought independence.

The war, seen by some as one of fascism versus communism, drew assistance from a number of other countries. The Republicans drew volunteer fighters from a variety of nations, including the United States and the Soviet Union. Nazi Germany and Fascist Italy supported the Nationalists, although Franco discouraged discussion of this fact.

Germany's Condor Legion

In military terms, the most significant aid from Nazi Germany was some 50,000 troops of the Condor Legion, a unit of the German Luftwaffe, or air force, assigned to fight in the civil war. Hermann Göring, chief of the Luftwaffe, sent the Condor Legion on the condition that it would remain under German command.

Although Nationalist leaders denied it, it was at their request that Nazi Germany had sent the Condor Legion. Although the Legion included tanks and antiaircraft batteries, its main value in the Spanish Civil War lay in its air power, consisting of four bomber squadrons of twelve bombers each, plus four fighter squadrons. It was the most powerful air arm ever assembled, exceeding the firepower of the combined air forces of World War I (1914-1918).

The role of the Condor Legion in the destruction of the Republican-controlled Guernica was not immediately clear. When Nationalist forces occupied the town several days after the disaster, they blamed the Republican forces for the devastation, claiming to find evidence that Republican forces had used explosives and arson to cause the damage. The German minister of war repeatedly cabled the Condor Legion asking who was responsible for the attack, and the Legion's radio operator in Spain was ordered to reply, "Not the Germans."

Even the international press took sides. British newspapers gave wide coverage to the incident, but some European newspapers were slow to report it. Others virtually ignored the incident, and in countries such as France, where there were fears that the war might spread into other parts of Europe, press reports sometimes reflected the editors' political inclinations. Some accepted the Nationalist claims that Guernica had been vandalized by Republican forces. In the United States, press reports of the destruction appeared quickly, even in those newspapers, such as those of the Hearst chain, that had editorially thrown their support to Franco.

Von Richthofen's Role

In their book *Guernica: The Crucible of World War II* (1975), Gordon Thomas and Max Morgan-Witts reported on the results of examination of archival files in Freiburg, Germany, and of interviews with more than forty survivors of the Guernica disaster and some dozen surviving members of the Condor Legion. Although many records were destroyed in World War II, the family of Wolfram von Richthofen, a cousin of Manfred von Richthofen, the famous "Red Baron" of World War I, and one of the commanding officers of the Condor Legion, allowed Thomas and Morgan-Witts to examine von Richthofen's papers. The authors concluded that German planes had indeed attacked Guernica and that some of the key decisions leading to the attack were made by von Richthofen.

Although he was not an admirer of Göring, von Richthofen had accepted Göring's offer of a planning position in the new German Air Ministry during the 1930's. Responding to a personal appeal from Franco, German chancellor Adolf Hitler had pledged to aid the Nationalist cause. Shortly after the Condor Legion arrived in Spain in late 1936, von Richthofen was appointed chief of staff. He was especially interested in the idea of sudden, overwhelming air attacks delivered with speed and precision, attacks that would later be known as Blitzkrieg. The Spanish Civil War became an opportunity for the Germans to test such theories of aerial warfare.

In March, 1937, General Emilio Mola, commander of the Nationalist armies in northern Spain, began a campaign against the Basque strongholds in that part of the country. Some 50,000 Nationalist troops participated in the campaign against Republican forces greatly weakened by an inability to buy arms and ammunition abroad. As Republican forces retreated, northern towns such as Guernica became filled with refugees and retreating soldiers. The normal population of Guernica swelled by several thousand.

Von Richthofen, responding to reports of Republican troops retreating from Vizcaya toward Bilbao, identified as a possible target a bridge that the troops would have to cross, the Rentería Bridge in Guernica. Meeting with Spanish field commanders and representatives of the Italian air force in Spain, von Richthofen emphasized that the retreating Republican forces had been slowed, if not halted, in the narrow canyons approaching Guernica, creating a bottleneck that provided bombing opportunities. Von Richthofen's immediate superior, General Hugo Sperrle, who had criticized the effectiveness of Nationalist forces, viewed bombing as a way to compensate for the deficiencies of his Nationalist allies.

The degree of Nationalist complicity in, or advance knowledge of, the bombing of Guernica remains unknown. Before planning the attack in detail, von Richthofen met with Juan Vignon, General Mola's chief of staff. Although there appears to be no detailed record of the conversation, von Richthofen is quoted as saying "Anything that moves on that bridge or those roads can be assumed to be unfriendly." When the town of Durango had been bombed by Legion planes on March 12, 1937, it had been on Sperrle's orders. At that time, von Richthofen had posted a memorandum noting that while targets were always military, bombing might be done "without regard for the civilian population." Sperrle, however, expressed unhappiness at the degree of civilian casualities at Durango, including fourteen nuns killed in their convent.

Details of the Bombing

For the three-hour attack on Guernica, a force of 43 bombers and fighters was assembled on airfields at Vitoria, some 50 miles away, and at Burgos, more than 120 miles away. Together, these planes would carry 100,000 pounds of incendiary, shrapnel, and high-explosive bombs. Among the planes selected for the mission was the Junkers Ju-52 bomber, considered less accurate because of its outdated bomb sights and because its spherical bombadier's chamber had to be lowered from the floor of the airplane for bombing runs, contributing to instability.

Although six Heinkel He-51 fighters participated in a diversionary attack on the town of Munditibar, the primary target of the day was Guernica. An experimental squadron of new Heinkel He-111 bombers, more maneuverable than the Ju-52 bombers and able to deliver incendiaries at 200 miles per hour, was regarded as too valuable to be used as the main force in the bombing. The Heinkels acted instead as pathfinders. The commander of the experimental squadron, Rudolf von Moreau, flew over Guernica in a new Heinkel bomber first, dropping his load of bombs on the Rentería Bridge after determining that there were no antiaircraft defenses. After this run, he joined the remainder of the experimental squadron for a bombing run over the town. They were protected by six Messerschmitt Bf-109 fighters.

A squadron of Messerschmitt fighters also provided protection for the Ju-52 bombers, the central wave of the attack, forming a protective umbrella above them. The Junkers bombers attacked in waves with a one-mile gap between them. They bombed in chains of three aircraft and flew in "V" formations at an altitude of about 6,000 feet, a height that would likely cause a large number of misses. To maintain the element of surprise, the bombers approached the bridge from the side, rather than straight on.

This mode of attack convinced many on the ground that the civilian casualties were not accidental. In fact, on the Republican side, much attention was given to a photograph of the first run of Junkers bombers approaching Guernica, taken by Father Eusebio Arronategui of Guernica. The photograph, which shows Junkers bombers approaching three abreast, was regarded as evidence that civilians, and not the narrow Rentería Bridge, were the main target. After passes by the bombers, the Messerschmitt fighters returned and attacked Guernica. One eyewitness said he saw the Messerschmitts flying north to south through the town and "firing all the time." A squadron of He-51's carried out low-level attacks using machine guns and dropping smaller bombs.

When a member of the Condor Legion complained about the use of incendiary bombs, he was told that von Richthofen wanted the mission to proceed, and quickly. The choice of the relatively inaccurate Junkers bombers, the bombing heights utilized, and the high amount of explosive power sent on the mission, 400 pounds for every square yard of the target bridge, later raised questions about the lack of concern shown for damage to civilian centers. Interviewed thirty-seven years later, some members of the Condor Legion insisted that they did not know that Republican troops were present in Guernica and that their bombs were sent off target by unexpectedly high winds. Many survivors disagreed, insisting the lack of wind allowed them to contain some of the fires.

It is known today that a valid military target, the Unceta Munitions Factory, was operating within Guernica, but the management of the plant was so pro-Franco that Republican soldiers had been posted throughout the plant to keep an eye on production. There appears to have been no discussions about the plant among the German pilots.

Aftermath

Upon their return to Germany in May, 1939, the troops of the Condor Legion were greeted personally by Göring, who announced that the "volunteers" would receive medals. In June, the entire force, some 15,000 strong, paraded through Berlin, led by von Richthofen and Sperrle. Hitler, in a welcoming speech, hailed the "heroes of Spain" for "teaching a lesson to our enemies." Von Richthofen, who participated in German air attacks against Poland in 1939, became, at 47, the youngest field marshal in the German air force.

Captured by Allied troops in southern Germany in 1945, Sperrle was among the Nazis included in the war crimes trials at Nürnberg in 1948. When a former Basque minister of justice, Jesús Leizaola, asked that the bombing of Guernica be added to the list of charges, the tribunal refused, insisting that all charges be confined to activities during World War II. Sperrle eventually was acquitted of all charges against him. At the trials, Göring commented that the Spanish Civil War had been an opportunity for him to "try out" his new air force.

The bombing of Guernica became the single-most famous event of the Spanish Civil War. Although other Spanish towns were bombed during the war, Guernica created a special controversy. The apparently systematic destruction of a town that was seen mainly as a communications center served as a precursor of World War II bombing policies and treatment of civilians. Because the town itself was of questionable military importance, the event came to be viewed as an attempt to terrorize civilians, particularly the Basques. Although the incident underlined the extent to which Franco's German and Italian allies were involved in the war, the Spanish general reportedly would not allow the subject to be discussed in his presence, at least not in public.

When, in 1937, the Spanish artist Pablo Picasso was asked by the Spanish government to contribute a work for the country's pavilion at the Paris Exhibition, he entered *Guernica*, a melange of distorted and grotesque faces, bodies, and animals that was viewed as a condemnation of both the bombing and war in general. Picasso's work guaranteed that the name "Guernica" would not fade into memory.

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See also: Bombers; Luftwaffe; Messerschmitt aircraft; Military flight; Spanish Civil War; World War II

Guidance systems

Definition: Systems that aid in navigation, that is, in finding and keeping to a route and schedule.

Significance: Guidance systems enable an aircraft to fly its route safely, even when visibility conditions are less than favorable.

The purpose of guidance systems is to aid in navigation. It is a simple point but one that can easily be lost in the overall complexity of some new guidance systems. Navigation has simple, specific objectives. The navigator should select a route and a schedule. There should be a continuous succession of points against which the navigator can check the progress of the voyage. Next, the planned movement is executed; that is, the craft is kept to the route or course set. Guidance systems enable these simple but important tasks to be accomplished accurately.

External Observation Guidance Systems

Guidance systems comprise many parts, including instrument landing systems (ILS), air traffic control (ATC) systems, radar and database systems, and voice communication controls. Satellite landing systems are increasingly important in providing landing guidance. From the earliest days of air flight to the present, there have been consistent improvements in guidance systems.

The constant monitoring and correction of position is termed a closed loop. Finding the aircraft's position is achieved by measuring distance or direction or both. Additionally, guidance systems need to measure altitude. The transmission of sound and light waves, as well as other electromagnetic waves, is used in this process.

There are guidance systems to aid in speed measurement, altitude, and every other possible variable for flight. High-speed computers aid in the process, warning pilots and navigators when an aspect of the flight requires attention. The Kalman filtering system weights each datum according to its expected quality. It aids in the process of dead reckoning, speed, and direction, as well as continuously updating the craft's position. It also determines the speed of the plane, its heading, rate of climb or descent, and how each of these must be maintained or adjusted to stick to the flight plan.

Air traffic controllers keep a dead reckoning check on each aircraft, using strips that show the height, speed, and timing of each plane. The strips break down the flight plan of each aircraft. Radio navigation uses signals in a true beam system. Narrow beams about 3 feet long are used for landing, even in near-zero visibility. Improved microwave systems allow for even narrower beams and aid instrument landing systems.

Laser guidance systems provide pilots with a visual navigation flight path from as far as 20 miles from the runway, with the precision of an advanced instrument landing system. Best of all, the installation of laser guidance and cold cathode technologies to replace or enhance conventional landing light systems requires no additional aircraft equipment, and is cheaper to maintain than conventional lighting. For example, the lifetime cost of cold cathode lights is only 20 percent of that of incandescent lights. The combination of enhanced vision technologies with the latest ground proximity warning systems dramatically reduces the number of controlled-flight-into-terrain accidents.

Inertial Guidance Systems

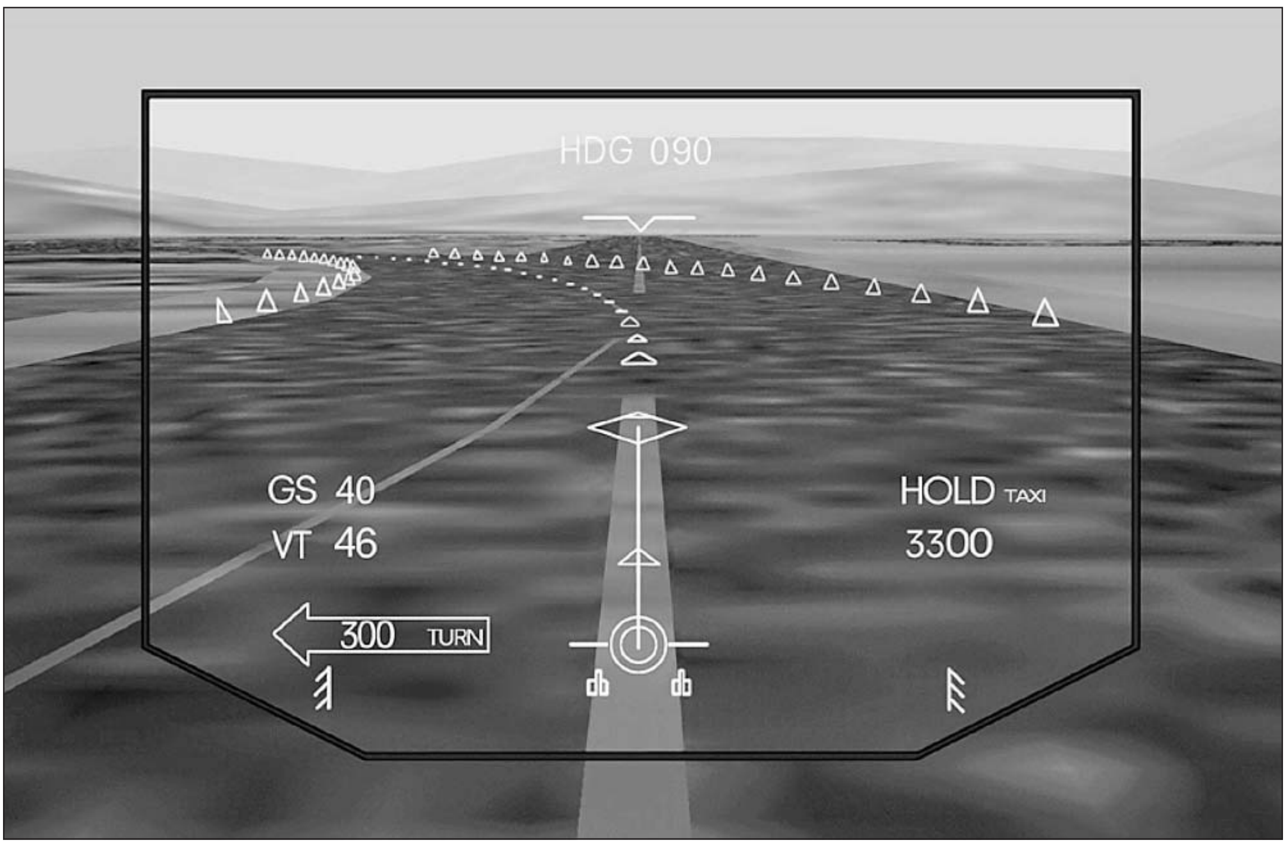
Inertial guidance is a method of navigation used to guide rockets and airplanes, submarines, and other vehicles. Unlike other methods of navigation, inertial guidance does not rely on observations of land or the stars, on radio or radar signals, or on any other information from outside the vehicle. Instead, a device called the inertial navigator provides the guidance information. An inertial navigator consists of gyroscopes, which indicate direction, and accelerometers, which measure changes in speed and direction.

The principles of inertial guidance have been known since the early 1900's. Gyroscopes have been used as compasses on ships since that time. They can be set so that they point constantly in one direction, such as toward the North Star. Unlike magnetic compasses, these gyrocompasses always indicate true north and are not affected by steel. In 1923, the German engineer Max Schuler described a method for establishing a vertical line that would not tilt when a vehicle changes speed or direction. If the line tilts, it cannot be used to measure distance. Schuler's theory is used to build electronic systems that prevent tilting of the vertical line. During World War II, German scientists built an inertial guidance system that guided their V-2 rockets against England. In the late 1940's and early 1950's, Charles S. Draper and other scientists at the Massachusetts Institute of Technology built the first highly accurate inertial guidance systems. Space shuttles and other spacecraft are also equipped with inertial navigators. Inertial guidance systems are required on U.S. commercial overseas flights.

The advantages of inertial guidance can be explained by the example of an airplane flight. To reach its destination, an airplane must both fly in the correct direction and cover the correct amount of distance. Without inertial guidance, a pilot has to rely on compasses or on signals from radio beacons at known positions on the ground to be sure the airplane is flying in the right direction. With inertial guidance, pilots need only consult the navigation equipment inside the airplane. They can find their way in spite of poor visibility, faulty communications, and the absence of landmarks. In time of war, enemies cannot jam an inertial guidance navigation system with false or confusing information.

The inertial navigator automatically measures changes in a vehicle's speed and direction, and sends the information to the computer. The computer calculates the effect of all the changes and keeps track of how far and in what direction the vehicle has moved from its starting point. Three gyroscopes inside the inertial navigator spin in different directions on axles. The axles are placed so that they form 90-degree angles with each other, like three edges of a box meeting at a corner. The axles keep their directions as long as the gyroscopes continue to spin. Each gyroscope is supported by gimbals (movable frames) so that it stays in position as the vehicle rolls, pitches, or turns. Together, the gyroscopes establish an inertial reference system (a stable set of lines). The accelerometers detect changes in the vehicle's motion in reference to the stable lines defined by the gyroscopes. The inertial navigator measures how far a vehicle has traveled by recording the changes in the position of a vertical line. This line indicates the direction to the center of the earth. Vertical lines from any two points on the earth meet at the center of the earth. The angle between the lines indicates the distance between the points. Each minute (one-sixtieth of a degree) of angle indicates a surface distance of one nautical mile (6,076.1 feet, or 1,852 meters). New York City is 3,006 nautical miles from London. Therefore, a pilot flying from New York City to London knows the airplane has gone far enough when the vertical line of the inertial navigator has moved through an angle of 3,006 minutes (50 degrees, 6 minutes).

Inertial guidance systems are subject to errors that grow over time. In some systems, a computer periodically combines the system's outputs with an independent source of



Guidance system technology helps pilots safely take off and land their planes in bad weather, when visibility is low. (Rockwell Collins) position, such as a radio beacon. This procedure helps minimize the size of navigation errors.

Gyroscopes

Gyroscopes are essential in the working of inertial guidance systems. The gyroscope functions as a compass when the gyroscope is considered to be mounted at the equator of the earth. The spinning axis lies in the east-west plane; the gyroscope continues to point along the east-west line as the earth rotates. Laser gyros provide guidance in the most advanced aircraft systems. These gyros are not really inertial devices. Instead, they measure changes in counter-rotating beams of laser light, caused by changes in the aircraft's direction. The electrically suspended gyro, another advanced system, uses a hollow beryllium sphere suspended in a magnetic cradle. There are also fiber-optic systems in the works to aid in navigation.

The gyroscope also aids in the automatic pilot program of a plane through detecting and correcting variations in its selected flight plan, and it supplies corrective signals to the ailerons, elevator, and rudder. There are, in fact, a number of gyroscopes to detect changes in altitude, barometric pressure, and other factors. These gyroscopes transmit electrical signals to a computer, which combines and amplifies them, and then transmits these corrective signals to servomotors attached to the control surfaces of the aircraft. The pilot is thus able to use an autopilot to make corrections and to combine navigation and radio aids, such as inertial navigation systems, Doppler radar navigation systems, and radio navigation beacons. The autopilot can also couple beams of instrumental landing systems used in airport runways.

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See also: Air traffic control; Airplanes; Airports; Autopilot; Avionics; Communication; Doppler radar; Flight plans; Instrumentation; Landing procedures; Radar; Satellites; Takeoff procedures

Gulf War

Also known as: Persian Gulf War

Date: From January 16, 1991, to February 28, 1991

Definition: U.S. and U.N. aerial operations in which Iraqi command control centers, supply depots, and reinforcement forces were repeatedly bombarded for five and one-half weeks in retaliation against Iraq's invasion of Kuwait.

Significance: The 1991 Gulf War demonstrated the overwhelming and decisive role of air power in modern warfare. As the first major international crisis following the Cold War, the war demonstrated that a cooperative effort between the United States and the Soviet Union, along with the support of China, could enable the United Nations to quell a world crisis in a volatile area such as the Middle East.

Background and Overview

At 2:00 A.M. on August 2, 1990, Iraqi military forces occupied the tiny, oil-rich nation of Kuwait, Iraq's Arab neighbor on the Northern Persian Gulf. Ordered by Iraqi president Saddam Hussein, the invasion employed hundreds of tanks and surprised nearly the entire world. Within twenty-four hours, Iraq had taken complete control of Kuwait and moved thousands of Iraqi troops to Kuwait's Saudi Arabian border. Industrialized nations, such as the United States, that depended heavily on Kuwaiti and Saudi petroleum immediately terminated its foreign policies that had previously benefited Iraq. The United States and the United Nations organized a coalition of thirty-nine countries, including Egypt, France, Great Britain, Canada, Australia, Saudi Arabia, and Syria, that expelled Iraq within just six weeks and restored Kuwaiti independence without stripping Hussein of power. The United States made the unusual request that other countries contribute financially to the campaign. More than fifty-three billion dollars was received, with Saudi Arabia and Kuwait the largest donors. Several countries donated resources but not personnel.

Military Buildup

Immediately following the Iraqi occupation of Kuwait, King Fahd of Saudi Arabia invited U.S. troops onto Saudi soil for protection against further aggression. This coalition, termed Operation Desert Shield, deployed 1,800 combat aircraft, 3,500 tanks, and 670,000 troops (425,000 of which were American), into the Gulf region by mid-January. The coalition also had moved 200 warships in the Gulf region, including six U.S. aircraft carriers and two battleships. By contrast, Iraq mobilized between 350,000 and 550,000 troops into Kuwait and southern Iraq, along with 550 aircraft, 4,500 tanks, and a small navy.

Had Hussein taken advantage of his initial military leverage and invaded Saudi Arabia in August, 1990, no military force in the immediate area could have deterred him. Any immediate American retaliation would have been limited to air and missile attacks from the USS *Independence* aircraft carrier in the Gulf and by B-52 bombers stationed on Diego Garcia Island, 2,500 miles away in the Indian Ocean. Hussein's unexplained delay gave U.S. president George H. W. Bush time to organize the largest deployment of air power and troops since World War II. Fifty thousand air and ground troops were sent to bases in Saudi Arabia in addition to three aircraft carrier fleets: the *Independence*, the USS *Eisenhower*, and the USS *Saratoga*. The number of American troops in the region had increased to more than 200,000 by November, after which Bush tried to scare Hussein into retreating by doubling the size of the American force.

Operation Desert Storm began with 539,000 American troops in the Gulf, along with 270,000 other coalition troops. There were 545,000 Iraqi troops in and around Kuwait. U.S. general H. Norman Schwarzkopf commanded the non-Arab units and Saudi general Khalid Sultan commanded the Arab units.

Air Power Strategies

The primary goal of the coalition air command was to destroy Iraq's ability to launch either offensive or defensive air campaigns. Secondary goals included the elimination of Iraq's weapons facilities and the disruption of Iraq's ability to gather information about coalition forces and to communicate internally. Coalition aircraft first bombed the Iraqi capital of Baghdad before attacking strategic military targets throughout Iraq and Kuwait. The allies focused their heaviest bombing on Iraqi troops, artillery centers, tanks, transportation routes, and supplies of ammunition, food, fuel, and water, as Hussein attempted to shield his military behind civilians. Iraq then launched crude Scud missiles at populated areas in Israel and Saudi Arabia, enraging many by killing civilians.

Operation Desert Storm

Hussein was given a deadline of January 15, 1991, to exit Kuwait. When he made no attempt to honor this deadline, Operation Desert Shield was upgraded to the military offensive Operation Desert Storm.

On January 16, 1991, at 6:40 P.M. eastern standard time, the White House announced that "the liberation of Kuwait has begun." Intensive air attacks continued for five and one-half weeks, concluding with a ground assault that began on February 23, 1991, at 8:00 P.M. eastern standard time, and lasted for exactly one hundred hours. The United States flew most of the campaign's sorties, and the British, French, and Saudis flew most of the rest. The coalition deployed unprecedented technological weapons systems, such as the unmanned Tomahawk cruise missile, the antimissile version of the Patriot antiaircraft system, and advanced infrared targeting that illuminated Iraqi tanks buried in the sand. Iraqi forces were overwhelmed by the use of new aircraft such as the British Tornado and the U.S. F-117A stealth fighter.

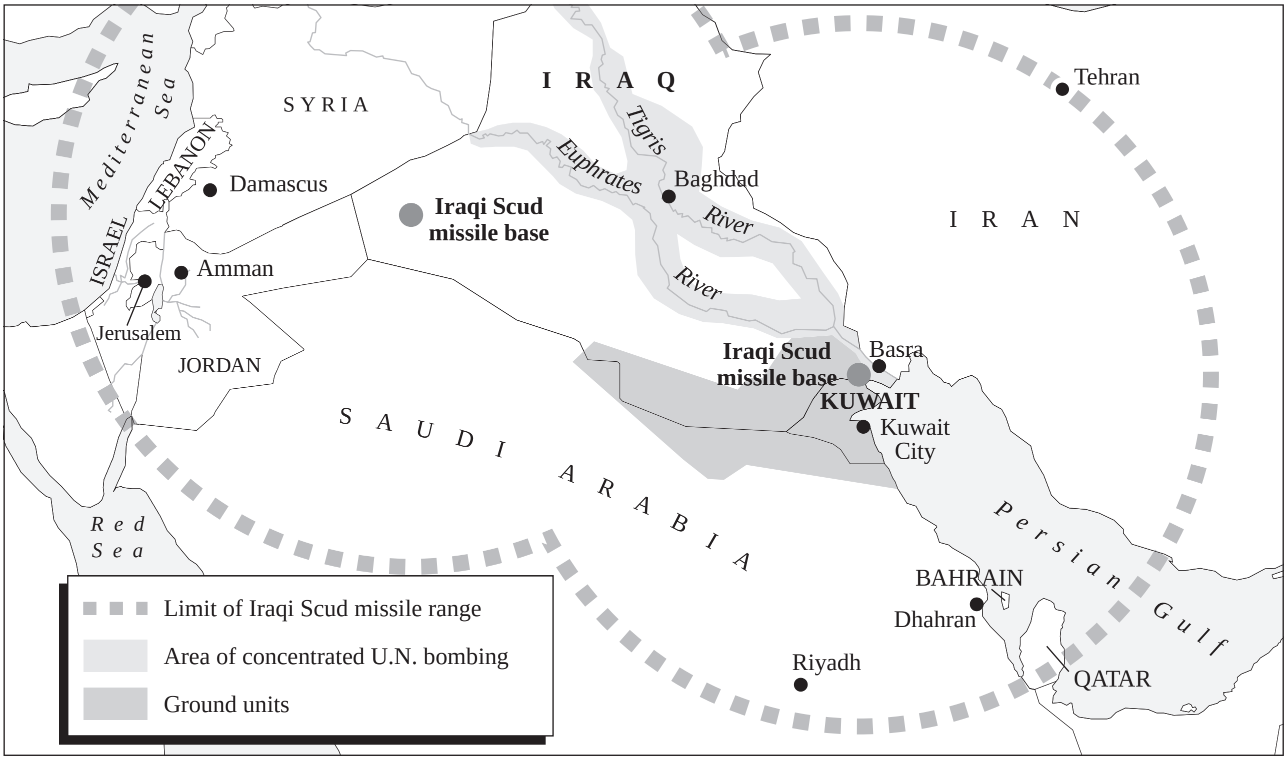
Other new technology included coalition smart bombs, which utilized previously untested laser guidance systems and accounted for 7 percent of all bombs dropped. Modern media coverage enabled the entire world continually to view coalition bombing raids. As Hussein desired, Iraq's long-standing neighbor and enemy, Iran, did not make a stand. As the bombing intensified, Iraq evacuated to Iran 137 aircraft, all of which Iran kept after the war.

For its initial thirty-seven days, Operation Desert Storm was almost exclusively a war of air bombardment. Iraq's military installations, communications facilities, air bases, armed forces in the field, missile launchers, weapons-producing factories, and nuclear production facilities were relentlessly bombed by more than 100,000 sea-launched sorties and missiles from the Persian Gulf. The Iraqi air force had surprisingly been grounded by Hussein after only the one day of bombing. Iraq's only offensive effort after its initial invasion of Kuwait was to launch eighty-five Scud missiles against Israel and Saudi Arabia. They resulted in a relatively minimal loss of life. Some were intercepted by American Patriot antimissile rockets, and others broke up upon reentry or missed their targets.

Operation Desert Saber

The land offensive Operation Desert Saber was launched on February 23, 1991, and lasted for four days. Deployment of ground troops was restrained until nearly the entire Iraqi infrastructure, including bridges, highways, electric power systems, water filtration plants, and airports, had been destroyed. With thousands of Iraqis already

Gulf War, 1991



dead, surviving troops surrendered by the tens of thousands. The few Iraqi troops, including many of the elite Republican Guard, who continued to fight while retreating, shot their surrendering comrades in the back. When President Bush ordered a cease-fire on February 27, Kuwait was liberated, and the most extensive air bombardment and land offensive since World War II was over. Bush's early termination of the ground war was later criticized, as Baghdad was able to rescue a substantial amount of military equipment, which was later used to suppress postwar Shiite and Kurdish rebellions as Hussein remained in power.

Military Warcraft

Initial air attacks led by the United States included Tomahawk cruise missiles launched from warships in the Persian Gulf, F-117A stealth fighter-bombers armed with smart bombs, and F-4G Wild Weasel aircraft loaded with antiradar missiles. These attacks permitted F-14, F-15, and F-16 fighter-bombers, and F/A-18 Hornet fighters to gain air superiority. Bombing missions were timed to reduce the effectiveness of Iraqi ground radar defenses. The A-10 Thunderbolt, with its Gatling gun and heat-seeking or optically-guided Maverick missiles, effectively provided support for ground units. Other essential coalition support was provided by the AH-64 Apache, Black Hawk, AH-1 Cobra, and Super Cobra helicopters, which fired laser-guided Hellfire missiles, the E-3A airborne warning and control system (AWACS), and a modernized fleet of older B-52G's. The coalition's 2,250 combat aircraft, including 1,800 U.S. planes, were no match for Iraq's 500 Soviet-built MiG-29's and French-made Mirage F-1's. Coalition combat missions dropped more than 88,000 tons of bombs. Precision-guided missiles, night-vision devices, an infrared navigation and target designation system, and target sensors enabled round-the-clock bombing by the coalition. Ground-based firepower included the multiple-launch rocket system, the M-2 Infantry Fighting Vehicle, the M-60A3 main battle tank, the M-109 self-propelled howitzer tank, the M-1A1 main battle tank, and ninety Patriot missile launchers.

Casualties and Aftermath

Immediately following the Gulf War, the United States Defense Intelligence Agency estimated that 100,000 Iraqi soldiers had been killed, 300,000 wounded, 150,000 deserted, and 60,000 taken prisoner. U.S. representatives later stated these estimates could be off as much as 50 percent following claims by various human rights organizations of significantly different numbers. U.S. casualties included 148 killed in action, 407 wounded, and 121 killed in nonhostile activities, such as friendly fire.

Coalition bombing severely damaged Iraq's transportation systems, communication systems, and petroleum and other industries. Much of Iraq's electric power and clean water were destroyed, resulting in many civilian deaths from lack of food or medical treatment. Severe environmental pollution resulted after Hussein ordered approximately six hundred Kuwaiti oil wells set afire. The blazes took more than twelve months to extinguish and caused severe air pollution. Huge amounts of Kuwaiti oil were dumped into the Persian Gulf as the war ended. Postwar economic sanctions continued to cause great hardship to the civilians of Iraq and neighboring countries, as efforts to strip Hussein of power repeatedly failed. The operation had another, unintended effect: The presence of U.S. troops angered Osama bin Laden and other Islamic fundamentalists. The terrorist attacks of September 11, 2001, that killed more than five thousand were tied to the Gulf War.

Following Gulf War duty, many veterans complained of physical and psychological ailments, including memory loss, fatigue, and joint pain, collectively known as Gulf War syndrome. In 1996, the Pentagon warned five thousand veterans of the war that these symptoms might have been caused by exposure to nerve gas during an attack on a weapons depot.

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See also: Aircraft carriers; Apache helicopter; Eagle; Hornet; Missiles; Stealth fighter; Stratofortress

Gyros

Also known as: Gyroplanes, gyrocopters, autogyros, autogiros

Definition: An aircraft that, during most of its flight, derives a substantial part of its lift force from a free-spinning rotor system not provided with any form of direct power drive.

Significance: Historically, the gyroplane is significant in that its invention preceded that of the helicopter and was largely responsible for the helicopter's success. The need for hinges at the root of helicopter blades was first successfully accomplished in the gyroplane. Many homebuilt sport gyroplanes exist in the United States and throughout the world. The gyroplane's success as a homebuilt aircraft is largely due to its simplicity as compared to that of the helicopter.

Terminology

As recognized by the Federal Aviation Administration (FAA), "gyroplane" is the correct generic term for a type of aircraft that, during most of its flight, derives a substantial part of its lift force from a free-spinning rotor system not provided with any form of direct power drive. The term "gyrocopter" is actually a proprietary name originally used by Bensen Aircraft Corporation to designate its B8-M Gyrocopter. The B8-M was the predecessor of most amateur-built sport gyroplanes. "Autogyro" is an older term, often used for this type of aircraft, but it, too, is actually a proprietary name used by the Autogyro Company of America, which built some of the first gyroplanes. "Gyro" is a nickname applied to all these types of aircraft.

Features

The gyroplane is any type of aircraft that relies primarily on an unpowered, freewheeling (or autorotating) rotor as the main source of lifting force and has a separate propeller and engine combination providing forward thrust. Modern gyroplanes look much like helicopters with conventional-appearing tail surfaces. An example of a gyroplane is the Air and Space 18-A, which has these typical characteristics.

The gyroplane was invented by Juan de la Cierva, an early twentieth century civil engineer born in Spain. Cierva's first successful flight was made near Madrid, Spain, on January 9, 1923. The first gyroplane to be certified by the FAA in the United States was the Pitcairn PCA-2 gyroplane, which, at that time, was called an autogyro. Early gyroplanes looked much like double-wing aircraft with the top wing removed and replaced with a rotor. They had a conventional engine and propeller in front for forward thrust, a small lower wing for auxiliary lift and control, and conventional-looking tail surfaces, with a large rotor on top of the fuselage for primary lift.

The performance features of gyroplanes are a combination of those of helicopters and fixed-wing aircraft. The rotor is usually in autorotation, turned by the wind, much like the blades of a windmill that has been turned edgewise to the wind. There must be airflow through the rotor to keep it turning, and thus the gyroplane requires separate forward propulsion to keep it moving through the air. For this reason, gyroplanes cannot hover or take off and climb vertically like a helicopter. Although they can make fully controlled vertical descents, the speed is somewhat high, and landings are not performed in this manner. A gyroplane can fly very slowly and has a very short landing roll. Most gyroplanes temporarily use the engine to spin up the rotor before the takeoff run, thus allowing a very short takeoff roll. Engine power is removed from the rotor just before takeoff. A few gyroplanes also have a jump-takeoff capability. In a jump takeoff, the rotor is oversped with the rotor blades in a low pitch setting while the gyroplane is sitting on the ground. Power is then removed from the rotor and transferred to the forward propulsion system. The blade pitch is then rapidly increased to the normal cruise flight setting, and the gyroplane literally jumps off the ground, perhaps 10 to 15 feet into the air before transitioning to forward flight.

Amateur-built sport gyroplanes are often single-seat, open-cockpit aircraft that look much like flying lawn chairs, with a rotor on top and engine, propeller, and tail surfaces in the rear. An example of this type of gyroplane is the Brock KB-2.

Rotor Systems

A gyroplane's rotor "disk" is the tip path plane swept out by the individual rotor blades as they spin. The rotor disk is approximately perpendicular to the rotor shaft. A fundamental difference between the rotor disks of helicopters and gyroplanes is that a gyroplane rotor disk is tilted slightly rearward when viewed from the side. This angle provides both upward lift and rearward drag that must be overcome by the forward propulsion system. The individual rotor blades of a gyroplane are set at a low-pitch angle, which allows them to operate in autorotation. In a helicopter, the rotor disk is tilted slightly forward, providing upward lift as well as a component of the forward thrust for propulsion. The helicopter's engine spins the rotor and must provide the torque necessary to turn the rotor. Because the rotor blades of a helicopter have a higher pitch angle than those of a gyroplane, they require a power input in order to rotate.

A number of different rotor systems are in use in gyroplanes. All gyroplanes must have hinges on the blades where they attach to the rotor hub. In forward flight, the blade moving into the wind (advancing blade) would create more lift than the blade moving away from the wind (retreating blade). Without hinges, this would cause a dissymmetry of lift that would tend to roll the gyroplane over. This was the source of many problems in early attempts at rotary wing flight. Hinging the individual rotor blades allows them to flap up and down slightly as they move into the wind and away from the wind. This equalizes the lift and allows controlled flight.

Smaller gyroplanes usually have a rotor system that consists of two blades rigidly attached together. The two blades are hinged to the rotor shaft at their center, much like the pivot on a seesaw, and allow the blades to flap as a unit to equalize the lift. In larger gyroplanes, with three or more rotor blades, each blade is individually hinged to the rotor hub, so the blades can flap up and down slightly as they rotate. Flapping stops designed into the rotor hub prevent the flapping motion from becoming excessive and keep the blades from drooping excessively when the gyroplane is on the ground and the rotor is not turning.

Propulsion

The forward propulsion in gyroplanes is usually provided by a conventional reciprocating engine turning a pusher propeller located behind the rotor mast and ahead of the tail surfaces. The pusher propeller arrangement has three advantages over an arrangement with the engine and propeller mounted in front, known as a tractor arrangement. First, the pusher propellor system allows for a more bal-

Performance Specifications for Two Gyroplane Models

	Air & Space 18-A	*Brock KB-2*
Number of rotor blades	3	2
Rotor diameter	35 feet	22 feet
Overall length	19.8 feet	12 feet
Overall height	9.7 feet	6.6 feet
Seating capacity	2	1
Engine horsepower	180 @ 2,700 rpm	90 @ 4,100 rpm
Gross weight	1,800 pounds	600 pounds
Empty weight	1,280 pounds	230 pounds
Fuel capacity	28.4 gallons	10 gallons
Takeoff run	50 feet, run or jump	300 feet
Landing roll	Short roll or full stop	0 to 10 feet
Minimum level speed	20 miles per hour	20 miles per hour
Maximum speed	100 miles per hour	95 miles per hour
Cruising speed	95 miles per hour	70 miles per hour
Maximum rate of climb	700 feet per minute	1,000 feet per minute
Endurance	3 hours at 65 percent power	2 hours at 65 percent power
Service ceiling	12,000 feet	13,500 feet

anced gyroplane design, with cabin and crew weight in front of the rotor mast and the engine weight behind the rotor mast. Second, it provides better forward visibility for the pilot. Third, in the pusher propeller arrangement, the propeller slipstream hitting the tail surfaces provides better directional control and stability. Most early gyroplanes of the 1930's vintage had propellers pulling from the front. Some gyroplanes have rotary Wankel-type engines, and one, the Groen Brothers Hawk 4 Gyroplane has a gas-turbine engine driving a three-bladed propeller.

Tail Surfaces

The tail surfaces, or empennage, on a gyroplane are used more for stability than for control purposes. As do fixed-wing aircraft, gyroplanes display a wide variety of tail surface designs. Conventional tail designs, as well as V-tail, H-tail, and triple-tail designs can be found. Vertical stabilizers usually have rudders on them that can be deflected to cause the nose of the gyroplane to yaw to the left or right. Large rudder surface areas are usually used to take advantage of the propeller slipstream to provide yaw control at low forward speeds. Unlike in an airplane, the horizontal tail surfaces of a gyroplane are not usually movable, but rather are fixed surfaces provided for stability. Because a gyroplane can fly very slowly, relatively large tail surfaces are usually necessary for stability at low speeds. For this reason, it is not uncommon to see double or even triple rudders on a gyroplane, used to increase the total surface area without having a single, excessively large tail. Occasionally a large single vertical fin is used if it is centrally placed in the propeller slipstream.

Control Systems

The main flight controls of a gyroplane consist of a joystick, rudder pedals, and a throttle. Variations of these do occur. The throttle controls the engine power output and thus the forward thrust of the propeller, much as in a conventional fixed-wing aircraft. This arrangement is different from that of a helicopter, in which the throttle controls the engine power input to the main rotor, usually operating at a constant rate of revolutions per minute.

A gyroplane's joystick, also called a cyclic stick, controls the tilt of the rotor disk either by tilting the rotor shaft or by individually changing the pitch of the blades as they cyclically rotate (hence the term cyclic pitch). Tilting the stick to the left effectively causes the rotor disk to tilt to the left, causing a sideward component of rotor thrust that makes the gyroplane turn and bank to the left. Tilting the stick to the right does just the opposite. Pulling back on the cyclic stick tilts the rotor disk more rearward, causing an increase in rotor thrust due to the increased angle of attack to the airflow. This makes the gyroplane climb, assuming that sufficient thrust is produced by the propeller. Pushing forward on the cyclic stick tilts the rotor disk more forward, causing a decrease in rotor thrust and making the gyroplane descend. In essence, the cyclic stick controls the mechanical operation of the main rotor much the same as it would in a helicopter, but because the rotor is unpowered, it causes the gyroplane to respond much like an airplane to similar control stick inputs. Some gyroplanes have an overhead stick that requires movement in directions just the opposite of a joystick to control the rotor.

Rudder pedals operate the rudder as they would in an airplane, causing a yawing motion from right to left. In a helicopter, the rudder pedals are used to control yawing of the helicopter by changing the tail rotor blade pitch.

The gyroplane does not use a collective pitch lever in the same way a helicopter does. Instead, the collective pitch of the gyroplane's rotor blades is factory preset at an optimum angle for normal flight operation. Gyroplanes that have a rotor prespin or jump-takeoff capabilities will usually have a two-position collective pitch control. One position, with the blades in flat pitch, is used for rotor spinup while on the ground. The other position, for normal flight, is engaged just before starting the takeoff roll or making a jump takeoff. In a helicopter, a collective pitch lever is provided to manually change the pitch of all the rotor blades simultaneously, thus changing the rotor thrust as needed.

Typical Gyroplanes

The following gyroplanes designed for production have been developed in the United States or Canada: Kellet, Pitcairn, Umbaugh (later designated the Air and Space 18-A), the Canadian Avian, McCulloch J-2, and the Groen Brothers Aviation Hawk 4 Gyroplane.

Amateur-built sport gyroplanes can be licensed with the FAA in the experimental category if the aircraft is at least 51 percent amateur-built. A number of companies—including Air Command International, Joe Souza Gyroplanes, Barnett Rotorcraft, Ken Brock Manufacturing, Rotor Flight Dynamics, Rotor Hawk Industries, and Rotary Air Force—have developed sport gyroplane kits, which can be assembled in various combinations to suit the homebuilder's ability. The number of companies in the amateur-built field has proliferated so much that one must use care to select a well-proven and time-tested design.

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See also: Airplanes; Helicopters; Propellers; Propulsion; Rotorcraft; Rudders; Tail designs

H

Hang gliding and paragliding

Definition: Unpowered aircraft derived from sailplane gliders and double-surfaced sport parachutes. Hang gliders are kitelike; paragliders are made of airfoil cells inflated by passing through the air.

Significance: Hang gliders and paragliders utilize basic principles of aerodynamics to fly without an external power source. The same basics of gliding underlay the early development of heavier-than-air flight.

Traditional gliders, progenitors of hang glider and paraglider flight, are unpowered, heavier-than-air craft that attain sustained flight via the aerodynamic forces acting on them. Gliders look like airplanes but are much lighter; they have low ratios of weight to wing area; and their wings are much longer and narrower than those of powered aircraft. Gliders include primary, secondary, and cargo types. Primary gliders have girder frameworks with attached wings, controls, stabilizers, and open seats at the framework's front. Popular secondary gliders (sailplanes) have fuselages and cockpits, and look like airplanes with very long, narrow wings. Cargo gliders (CGs) are towed by powered planes and carry heavy commercial loads in tow, which they can land where powered craft cannot.

Modern sailplanes lose only a few feet of altitude per second and ascend air currents, rising just 2 to 3 miles per hour. Beginning in the 1870's, pioneer aeronauts built successful gliders to define efficient wing and control system design. The best known is the German Otto Lilienthal, who studied air buoyancy and resistance, wing shape, and tail stabilization. In 1891, his crewed craft, capable of flying after a downhill run into the wind, made the first of thousands of flights. American glider pioneers Octave Chanute, the Wright brothers, and John Montgomery made many glider innovations.

Most modern glider design arose in post-World War I Germany. Its aircraft engineers, forbidden by treaty to build powered aircraft for military use, explored the great efficiency of light gliders with single, long wings and the weather conditions that optimized soaring flight. They found that strong ridge or thermal upcurrents provided the motive power gliders needed. Ridge currents form when steady winds blow against ridges or hills, but are limited to areas near their windward edges. Thermal currents (thermals) form by heat rising from the ground and are always present under cumulus clouds.

For traditional flight, a glider is accelerated to the speed needed to overcome gravity by means of a catapult or by being towed by a winch, automobile, or powered airplane. After launch, the craft disengages from the towline at a desired height and the pilot seeks thermals. The pilot turns into a thermal, and after reaching the maximum altitude possible seeks the next useful thermal. Good gliders move 20 miles horizontally for each mile of altitude attained and can stay aloft for many hours.

Hang-Gliding Essentials

Although some hang gliders have small engines, most hang gliding is unpowered flight in a kitelike craft based on the structure of the sailplane. The name derives from the fact that early pilots hung onto the gliders. The designed evolved so that hang gliders have an aluminum frame, a fabric sail, and a comfortable harness for the pilot. In order to take off, the pilot dives from a hill, cliff, or mountain. The hang glider was born in the 1960's, based on designs by Francis Rogallo of the National Aeronautics and Space Administration (NASA) for flex-wing parachutes for space vehicle reentry. Many design variations followed, and hang gliding, first merely a recreational activity, has become a competition sport, with flight-duration, distance, and altitude-gain events. Annual world championships are governed by the International Aeronautical Federation. The hang glider's limited ability to maneuver and handle wind change, as well as the fact that pilots fly without protective body coverings, make the sport somewhat dangerous.

Hang glider construction begins with a light, strong airframe of aluminum tubes which support a sail (its airfoil) made of Dacron or another polymer, creating two joined wings. The airframe has five parts. First, a leading-edge tube (LET) runs along the front edge of the wings. The sail wraps around the LET and is secured to it. A crossbar tube connects the LET of each wing and the third part of the airframe, a keel. The keel runs from the glider nose to the center of its rear end, above the pilot. The fourth and fifth parts of the frame are the king post and control bar. They connect to the airframe where crossbar and keel intersect. The

The Aerodynamics of Gliding

Heavier-than-air craft must conquer gravity before controlled flight is possible. Three forces are involved. The first, thrust, is caused in conventional aircraft by engines and in gliders by catapults, tows, or jumps. Thrust enables forward motion of the aircraft as long as it exceeds the second force, drag, which is caused by air viscosity. The third force, lift, is the key to flight. It operates upward, at a right angle to the direction of aircraft motion. Thrust is supplied by airfoils (wings), designed so the angle of attack, at which they meet the passing airflow, causes more rapid airflow past the upper airfoil surface than past its lower surface. This lowers air pressure above the airfoil, compared to that below it, engendering lift that raises properly designed aircraft into flight.

To properly split passing air, an airfoil has a rounded leading edge and a sharp trailing edge. Unsymmetrical airflow is produced by a curved, or cambered, airfoil shape and the angle of attack at which it meets approaching air. The importance of the angle of attack is shown by its use and misuse during flight. An aircraft's angle of attack is changed by altering the airfoil's position in space. Angles of attack of up to 15 degrees provide increased lift, enabling faster climbs but slowing airspeed. When this angle is excessive, air eddy currents atop airfoils cause large lift decreases, which make aircraft drop toward the ground in stall. This stall may cause a crash unless the pilot quickly decreases the angle to safe values.

king post rises vertically from the keel and supports the glider when it is on the ground. The triangular control bar is used for support in flight, and is used by the pilot to guide the glider's movement. Usually, ten stainless-steel cables tie the airframe tubes together, supporting the hang glider's load. There are six "positive" wires running from the base of the control bar to the airframe and four "negative" wires running from the top of the king post to the airframe. They support the glider in its normal flight and in rare inverted flight. A third set of wing wires support the LET at all times.

Hang glider sails are made of polymer panels joined to create airfoils when stretched out on an airframe. Often a sail has riblike battens to help the airfoil keep its shape and to reduce drag. The hang glider is controlled by moving the pilot's weight by means of the control bar. Forward pulls drop the glider nose and cause acceleration or dives. Back pulls raise the glider nose, slow it down, and can cause stall. Lateral pulls to right or left tilt the respective wing, causing right or left turns. These movements, when well choreographed, allow expert hang glider pilots to carry out complex aerial maneuvers.

Prolonged hang glider glide, especially in cross-country glides, uses ridge currents and thermals to provide lift. Whether in short flights or cross-country soars, hang glider pilots wear comfortable supine or prone harnesses fastened to the glider. Harnesses suspend the pilot near the point where keel, crossbar, control bar, and king post meet. The harness is made of padded Dacron cloth with a seat-beltlike support of nylon webbing. Harnesses allow for comfortable flight, weight movement in any direction needed for control, and the carrying of emergency parachutes.

Paragliding

Paragliding began in France in the 1980's with canopies derived from double-surfaced Parafoil sport parachutes made of airfoil cells inflated by passing through the air. Paragliders are much longer than they are wide, and their wind-catching cells are inflated by gentle breezes. Their light weight and canopy softness make paragliding safer than hang gliding. The paraglider pilot, attached to a canopy by a seat harness, launches from a hill or another gentle slope using a canopy preinflated by the wind. The canopy behaves like an airfoil and can stay aloft for hours, a primary aim of paraglider enthusiasts. Paragliding is under control of the Fédération Aéronautique Internationale (FAI) hang-gliding commission.

A paraglider wing contains ten to seventy cells, joined side-by-side and closed along the entire trailing edge. The cells have inflation ports at the leading edge. Their walls also have interior ports that allow air to pass between them to maintain even internal pressure. Airfoil shape is maintained by this pressure, created by air entering the leading-edge ports kept open by stiff Mylar reinforcements. As long as the ports are clear, the airfoils keep their shape, and after full inflation, the internalized air stays put.

About 30 percent of paraglider lift is "plate lift," created when passing air is met with the leading edge higher than the trailing edge, and 70 percent is "induced lift," created by an airfoil shape which makes air pass over its top more slowly than underneath. The lines connecting airfoil and pilot are placed carefully to suit two requirements. First, many attachment points help keep the wing in an efficient shape when loaded. Second, as the lines cause drag, their number is minimized as much as possible. Also, paraglider operation depends on the match between pilot weight and aerodynamic forces. For optimization, the lines are joined to the harness by two to four pairs of webbing straps (risers).

As long as air flows evenly past the airfoil, lift keeps a paraglider moving upward, while gravity moves it forward and down. A paraglider descends slowly, due to the counterthrust of lift. Climb is only possible upon flight through thermal or ridge currents moving upward faster than a glider is dropping. Drag, due to pilot weight and the nonairfoil components, increases with the square of paraglider speed. Drag is also due to inequities of air passage around airfoils. Total drag is calculated by adding number values of the two drag types. The lift-to-drag ratio identifies the glide performance of the wing. A lift-to-drag ratio of five to one indicates that in still air, a paraglider moves forward 5 feet for every foot of descent.

The basic controls of paragliders are brakes. When they are not used, motion is straight forward at the best glide speed possible. Speed adjustment uses the brakes one-quarter on for minimum-sink speed and fully on to stall in a light-wind landing. Pulling the brakes causes the trailing edge to curve down, increasing camber and angle of attack. This increases lift but can cause stalls.

To steer, pilots pull down the brake on the side to they wish to turn into, increasing drag on that wing half. They can also assist steering by leaning in the direction of a turn. As to speed adjustment, most often it is useful to glide at less than the fastest glide speed. This is done by pulling the brakes down equally on both sides to increase the angle of attack. Speed increase is more difficult and uses a speed system, a foot stirrup connected to the front risers. Pushing on the stirrup shortens the front risers, reducing the angle of attack and increasing speed. Regardless, paragliders are slow aircraft and have only a small speed range.

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See also: Aerodynamics; Forces of flight; Gliders; Heavier-than-air craft; Ultralight aircraft

Harrier jets

Also known as: Harrier I, Harrier II (GR7 and AV-8B), Harrier II Plus

Date: First flight on August 31, 1966

Definition: Single-engine, vertical and short takeoff and landing (V/STOL) aircraft designed in Britain and manufactured in Britain and the United States.

Significance: Versatile aircraft used primarily by the United States, Great Britain, Spain, and Italy, Harrier jets can take off from aircraft carriers or land bases without the traditional reliance on runways. Used for air and ground support during combat, reconnaissance, fleet air defense, and maritime attack.

Development

In 1957, the British manufacturer Hawker-Siddley Aviation built the first Kestrel, the design of which would later be used for the Harrier jets. The construction of a prototype of the Harrier proceeded without government funding until after the development of an engine capable of vertical lift. In 1960, the British Royal Air Force expressed interest in the aircraft providing funds for continued research and development. Four additional planes were ordered after the potential for North Atlantic Treaty Organization (NATO) allies became apparent. The Harrier, a small ground-attack aircraft capable of vertical takeoffs achieved by the use of four swiveling nozzles on a Pegasus engine, flew for the first time on August 1, 1966. After the successful completion of the flight tests in Great Britain, six planes arrived in the United States for evaluation, with the National Aeronautics and Space Administration (NASA) examining two of them. Manufactured by British Aerospace, the Harrier I included two models, the Sea Harrier FA2 and the AV-8A. Both the Royal Air Force and the United States Marine Corps deployed the Harriers for defense and attack missions. The Sea Harrier, used primarily by the British Royal Navy as a defense fighter, utilized the Blue Vixen Radar that offered beyond visual range (BVR) capability and was able to shoot airborne and seaborne targets with its four AIM-120 BVR missiles. Capable of achieving speeds as high as Mach 1.3, the Harrier I had a wing span of 25 feet, 3 inches, a length of 46 feet, 5 inches, and a height of 11 feet, 10 inches. The British Royal Navy deployed the Sea Harrier during the Falkland Islands War in 1982. In the year 2000, the Harrier I was still being used by the Indian Navy and the Royal Thai Navy.

Second-Generation Harriers

By 1973, Hawker-Siddley and McDonnell Douglas Aircraft, an American contractor, initiated improvements on the original Harrier that resulted in the development of a composite wing structure. The original Pegasus motor, manufactured by Rolls Royce, continued to power the aircraft even though the maximum payload increased. The Harrier AV-8B flew for seven minutes at an altitude of 130 feet on November 9, 1978, at Lambert International Airport in St. Louis, Missouri. Before the production of the Harrier AV-8B commenced in 1981, the aircraft underwent extensive testing during a three-year period. The plane, measuring 46 feet 4 inches in length, with a wingspan of 30 feet 4 inches, is equipped with forward-looking infrared (FLIR) sensors, and the pilot can utilize night vision goggles, making the Harrier effective during both day and night missions. The aircraft is outfitted with free fall, retarded, cluster, and laser-guided bombs, air-to-air Sidewinder missiles, air-to-surface Maverick, HARM, and ALARM missiles, and a 1-by-25-millimeter Aden Cannon for the Royal Air Force or a 1-by-25 millimeter GAU-12 cannon for the United States Marine Corps. In addition to low-level missions at subsonic speeds, the Harrier II is also deployed for some medium-level operations where its accurate angle rate bombing system (ARBS) can be effectively utilized. British and NATO forces utilized the Harrier II in Bosnia and Serbia. The United States Marine Corps and the British Royal Navy deployed the Harrier II during Operation Desert Storm in 1991, where the eighty-

A Harrier jet, a vertical and short takeoff and landing (V/STOL) aircraft, rises straight into the air.

six aircraft flew 3,380 combat missions during forty-two days, dropping more than 6 million pounds of ordnance.

Harrier II Plus

Although the Harrier II proved effective, the United States and two of its NATO allies, Italy and Spain, cooperated on the development of the Harrier II Plus, which first flew on September 22, 1992. Manufactured by McDonnell Douglas and British Aerospace, the new aircraft relied on a more powerful engine, the Rolls-Royce Pegasus F402-RR-408, and included the advanced APG-65 radar system and avionics that allow the plane to fly a variety of missions during night or adverse weather conditions. Initially, the United States purchased twenty-seven, Italy sixteen, and Spain eight Harrier II Plus aircraft. Capable of engaging multiple targets simultaneously, the Harrier II Plus operates with free fall, retarded, cluster, and laser guided missiles, medium range air-to-air missiles (MRAAM) and short range air-to-air missiles (SRAAM), antishipping missiles, air-to-surface missiles, electronic counter measure (ECM) pods, and a 25-millimeter GAU-12 cannon. Since 1992, the United States Marine Corps has initiated a program to remanufacture all of its Harrier II planes, upgrading the systems to comply with the specifications of the Harrier II Plus. Boeing delivered the first Harrier II Plus in July, 1993, with the first updated Harrier II arriving in 1996.

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See also: Aircraft carriers; Boeing; Fighter pilots; Gulf War; Marine pilots, U.S.; Royal Air Force; McDonnell Douglas; Vertical takeoff and landing

Heavier-than-air craft

Definition: A vehicle driven through the air by a self-carried power source, supported by air pressure against the wings or rotors, and controlled in flight path and destination by the pilot.

Significance: Heavier-than-air craft, such as airplanes and helicopters, are faster, more controllable, and safer than lighter-than-air craft, and thus have become the dominant instrument in aerial transportation and warfare.

Early Experiments

In religion, mythology, legend, and imagination, human levitation and flight are old and familiar concepts. Birds, bats, and insects were visible proof that flying through the air with wings was possible in nature, and for centuries humans imitated birds by attempting to fly with flapping, birdlike wings carried by human arms. These "ornithopters," frequently launched from hillsides, towers, or barns, formed a long and frequently farcical or fatal tradition in humankind's attempt to fly.

Some early Greek physicists appreciated that a compressed jet of air could be a motive force, but saw no practical way to achieve this. During the Renaissance, Leonardo da Vinci sketched out a few ideas regarding helicopters and propellers, but with no suggestion for a power source. Still, the evidence that moving air could exert a tangible and useable force on sails, kites, and windmills was plain enough. In the eighteenth century, some "whirling arm" experimenters, such as John Smeaton, began to quantify the lift and drag forces exerted by moving air upon flat surfaces. In France, Launoy and Bienvenu devised a model helicopter in 1784. Late eighteenth century technology developed steam as a power source, but by 1783 Jacques-Étienne Montgolfier's balloons had captured public interest and also had given the French the premier place in aeronautics development.

Practical Applications

Significant heavier-than-air research was done in early nineteenth century England by Sir George Cayley, an inventor, scholar, and publicist whom many authors describe as "the father of modern aviation." Cayley's studies and experiments confirmed that a curved-wing, or cambered, surface supplied more lift than did a flat one, that low pressure on the upper surface exerted considerable lift, and that air pressure on an adjustable plane surface in an airstream varied in extent and location. He drew attention to the problem of stability, and also built model helicopters and gliders. One glider was capable of supporting his coachman in a short airborne hop. The pioneer pilot's verdict was "Please, Sir George, I wish to give notice. I was hired to drive, not to fly." Cayley's extensive publications were not widely known in his lifetime, but they had later influence. Cayley's English followers, such as William Samuel Henson and John Stringfellow, attempted an aerial steam carriage, but of greater importance was the first wind tunnel, built in 1871 by Francis Herbert Wenham and John Browning.

Frenchmen dominated aeronautical study and experimentation in the nineteenth century, but their more elaborate machines were less successful than a device of great simplicity. In 1871, Alphonse Pénaud employed twisted rubber as a power source for a model aircraft. His "planophore" was a stick fuselage holding curved and angled monoplane wings with their extremities tipped up, a vertical rudder, and a pusher propeller at the rear, powered by a twisted rubber band directly under the fuselage. In an apparently simple toy, Pénaud incorporated the essentials of airplane structure, including lift, inherent stability, and elementary vertical and horizontal control. The major challenge remained to find a better power source. One key to the progress of aviation was the development of the internal combustion engine by Nikolaus August Otto, Gottlieb Daimler, and Carl Benz.

Gliders and Powered Craft

In the 1890's, hang gliding was greatly developed and popularized by the exploits of Germany's Otto Lilienthal. The author of *Des Vogelflug als Grundlage der Fliegekunst* (1889; *Bird Flight as the Basis of Aviation*, 1911), Lilienthal believed that gliders copying bird wings would lead to successful powered flight. From 1891 to 1896, he built five monoplane gliders and two biplane gliders and made two thousand flights with them, measuring lift and drag. These glides of up to 750 feet in distance drew spectators, reporters, and photographers. The "German bird-man" was a hero to the air-minded, especially in the United States, and remained an inspiration even after his August 9, 1896, fatal crash.

Other European aviation pioneers were concentrating on powered flying machines. Alexander Feodorovich Mozhaiski attempted a steam-powered hop in 1884. In the 1890's, Victor Tatin and Charles Rivet built a steam-powered model plane, which in one test flew about 460 feet. Clément Ader claimed to have flown about 50 meters in 1890 in his steam-powered *Eole* and to have surpassed this distance on October 14, 1897, with a flight of 300 meters in his government-financed *Avion III*. Whether this was a continuous flight or the total length of a series of hops in unclear, but the French army observers were less impressed than Ader was, and the project was dropped.

In the 1890's considerable press attention was given to the construction and testing of a £30,000 steam airplane by Sir Hiram Maxim. It had a lifting area of 4,000 square feet, two 180-horsepower steam engines, twin propellers of 17.8 feet, a 1,800-foot launching track, and a total weight of 8,000 pounds. On July 31, 1894, with a steam pressure of 320 pounds per square inch, this monster barely left the ground, colliding with the guard rails. Maxim's craft had ample power, but lacked all the other requirements for flight. This experiment was not pursued further and made no advance in aviation technology, but it did keep attempts to fly in the public mind.

At the turn of the century, European aviation interests were turning to semirigid powered airships of increasing size, culminating in the German zeppelin. Hang gliding was continued, however, by Percy Pilcher, a Lilienthal disciple and English engineer. Pilcher was briefly joined by Lawrence Hargrave of Australia for testing some of the latter's box-kite designs. Pilcher's career was ended by a fatal crash in 1899. The next major experiment in heavier-than-air flight was made in America.

American Experiments

The gliding school of aviation in America was continued, encouraged, and publicized by Octave Chanute, a French-born American civil engineer. He improved glider design, using the ideas of Lilienthal, Pilcher, Hargrave, and others. Collecting information on past and current aviation experiments in the United States, France, and England, he developed the Chanute biplane glider using the Pratt truss used in bridge building. Augustus Moore Herring acted as Chanute's assistant and pilot for several hundred glides launched from the Indiana dunes in 1896 and flew up to 350 feet. In 1900, Chanute was contacted by the Wright brothers and gave them information and encouragement, while he was also in communication with the telephone inventor Alexander Graham Bell and the Smithsonian secretary Samuel Pierpont Langley regarding their own aviation projects. Thanks largely to Chanute, meetings and publications began to connect American aeronautical researchers into an informal group of scientific minds.

Langley, secretary of the Smithsonian Institution and respected in academic circles as America's leading expert in aeronautic science, succeeded in the 1890's in constructing steam-powered model airplanes. In 1898, during the Spanish-American War, he succeeded in gaining a grant from the U.S. Army for building a human-lifting, power-driven, controllable airplane. The result was the Pénaud-type aerodrome, with tandem wings, a tailpiece rudder, and twin-pusher propellers driven by a water-cooled gasoline engine of radial design, with five cylinders providing 52 horsepower.

On October 7, 1903, at Widewater on the Potomac River, witnessed by officials and the press, the 850-pound craft, with Charles Manly as pilot, was propelled from the roof of a houseboat, and in *The Washington Post*'s description, "simply slid into the water like a handful of mortar." *The New York Times* decided that a practical flying machine "might be evolved . . . in from one to ten million years." After a repetition of this failure on December 8, one congressman described Langley's aerodrome as a "mud duck which will not fly fifty feet." The U.S. Army quickly cancelled Langley's project, and he died in 1906 a disappointed man. However, the Smithsonian Institution until 1948 prominently displayed the great aerodrome as "the first aircraft in history capable of flight with a pilot and several hundred pounds of useful load."

Events in the History of Heavier-Than-Air Craft

1784: The French design a model helicopter.
1891: German Otto Lilienthal helps to develop and popularize hang gliders.
1900: Influential engineer Octave Chanute advises Orville and Wilbur Wright, Alexander Graham Bell, and Samuel Langley in their aviation projects.
1903: Samuel Langley makes unsuccessful attempt at flight in his *Aerodrome*; the Wright brothers succeed at Kitty Hawk with their *Flyer.*
1908: Orville Wright wins U.S. Army contract to produce military aircraft.

The First Successful Flight

Wilbur Wright and his brother Orville were bachelors, living with their father, Milton Wright, a bishop in the United Brethren Church, and their sister Kate in Dayton, Ohio. The brothers operated a shop for building, selling, maintaining, and repairing the popular safety bicycles of the 1890's. Their joint interest in aviation may have been sparked by a childhood gift of a toy helicopter. It was certainly inspired by Otto Lilienthal, whose personal role in practical gliding they admired, and whose inductive, step-by-step approach to airplane design they followed. The Wrights were competent enough in algebra, solid geometry, trigonometry, and physics to understand the aeronautical problems involved in aviation, and as practical mechanics they were able to do most of the production themselves, saving expense and minimizing errors. They attacked the task in stages, concentrating first on the problem of wing lift, then on mastering flight control, and finally on adequate propulsion.

In May, 1899, Wilbur Wright wrote to the Smithsonian Institution requesting titles of books and articles on flying, and a current list was sent to him. The following August, the Wrights built their first aircraft, a biplane box kite 5 feet wide, with a fixed-tail plane, in order to test wing twisting, later called wing warping, as a method of controlling side roll. In May, 1900, Wilbur wrote to Chanute to exchange ideas on gliding, and the Wrights' later gliders somewhat resembled Chanute types.

In September, 1900, the off-season in the bicycle trade, the Wrights took a camping vacation at Kitty Hawk, a sparsely inhabited stretch of sand dunes and mosquitoes on the Outer Banks of North Carolina. Here they flew their *Glider I*, mostly as a kite. The following year, a larger model, *Glider II*, failed to achieve the lift and drag results reported by earlier experimenters. The Wrights decided to check existing aeronautic tables with their homemade wind tunnel. These tests indicated that the Smeaton coefficient and the Lilienthal and Chanute tables from which they had been working were significantly inaccurate. Developing their own (confidential) tables, the Wrights built their successful 1902 *Glider III*. This craft included the mechanical linkage of wing warping to rear rudder control, which formed the chief basis of their 1902 patent application, granted in 1906. By a process of research, experiment, and checking for flaws, the Wrights developed an air frame which solved the problems of lift and flight control. The Wrights were then ready to attempt powered flight in 1903.

Much of their 1903 season, however, was consumed by problems and delays. Not finding a gasoline engine meeting their lightweight, high-power needs, they designed their own four-cylinder, water-cooled, in-line engine, weighing about 150 pounds, producing 12 horsepower, and linked by bicycle chains to a pair of pusher propellers. Marine propellers being entirely unsuitable, the Wrights used their wind tunnel to design propellers as "moving wings" traveling in a forward spiral. Altogether, testing the new machine, *Flyer I*, at Kitty Hawk was delayed until December 17, 1903. That day's consecutive flights were Orville's initial hop of 120 feet, Wilbur's of 175 feet, Orville's flight of 200 feet, and Wilbur's flight of 852 feet into a wind of 20 to 27 miles per hour for 59 seconds. These straight-line distances at a low level were not revolutionary, but to take off and be airborne under power for nearly a minute was new in the annals of aviation. There were photographs and five witnesses, but the press generated only a few garbled reports.

In 1904, the Wrights practiced on a new *Flyer II* with a slightly larger engine, flying at Huffman Prairie near Dayton. These low-altitude flights culminated in successful circles and, on November 9, a flight of five minutes. The 1905 *Flyer III* had a wing area of 503 square feet, a 40-feet, 6-inch span, and wing camber of 1 in 20. Its wings were horizontally flat, with a built-up elevator and rudder, and with an engine of about 20 horsepower. Another series of Huffman Prairie flights included one of 24 miles in 38 minutes. The local audience and photographs increased, and as one foreign visitor put it, "Dayton knows the Wrights fly, but America isn't sure."

The 1905 *Flyer III* represented the completion of the Wrights' project to build a human-carrying, powered flying machine capable of controlled flight. The Wrights offered the plane to the U.S. Army, then the British, French, and Germans. Their asking price of $250,000 or more was too steep for the war departments, who shrewdly suspected that the Wrights were reluctant to demonstrate their machine for fear of easy copying. Octave Chanute's 1903 Paris lecture on the Wrights' gliding experiments, Wilbur Wright's U.S. lectures, and visits to the Wrights by European observers gradually spread the conviction that powered aviation was indeed at hand.

Improving the Wright *Flyer*

Meanwhile, powered glider hops, particularly of box-kite construction types, increased in Europe. Some models were advertised for sale as "Wright-type flyers." The popular Brazilian sportsman Alberto Santos-Dumont was hailed for his 1906 flight at Bagatelle, France, as the "the first to fly." The Wrights brought a flyer plane to Europe in 1907, but left it in storage, deciding that in 1908 Orville would compete for a U.S. Army contract, while Wilbur would demonstrate the model which they left in France.

In 1908, Orville won the U.S. Army contract to considerable public acclaim, while in France, Wilbur had a Cinderella experience. Ridiculed for weeks for his lengthy delays in assembling and repairing the stored plane, Wilbur's August 8 demonstration flight at Le Mans, with circles, figure eights, and graceful landings under complete control, came as a revelation to Europeans who had not gotten beyond short, straight-line hops. Aviators, press, and public hailed Wilbur Wright as a hero and companies were quickly formed in France, Britain, and Germany to build Wright biplanes under license.

The 1908 Wright *Flyer* clearly outclassed its European counterparts in construction, performance, and controllability. However, at the Rheims air exhibition of 1909, there were several French types which had improved on the Wright *Flyer*. Henri and Maurice Farman offered stable biplanes, and Louis Blériot showed the monoplane type with which he would cross the English Channel to become the French hero of the year. Gabriel Voisin promised quick delivery and reliable construction. Leon Levavasseur's *Antoinettes* were becoming popular. Glenn H. Curtiss upheld the United States' reputation by winning the Gordon Bennet Speed Trophy. All these represented some form of advancement over the 1908 Wright machine. Several nations also established airplane sections in their armies in 1909.

The year 1910 saw a great increase in the number of airplane manufacturers, but a more modest growth in airplane sales. Clearly, even the largest firms would not survive without large government orders for military purposes, so patriotic public agitation was organized to that end. This brought about a major change in production types. Pre-1914 war departments wanted planes which excelled in range, stability, load, and altitude, solid and simple in design, built for careless handling with easy maintenance and repair under wartime conditions. From 1911 on, Europe's war departments were deciding which plane types and which manufacturing firms would survive, and trying to find a remedy for the French predominance in the light engine market.

By 1913, airplanes had wheeled landing gear, more efficient tractor propellers were replacing pusher types, and cantilevered wings were the key to larger monoplanes. Monocoque fuselage construction made possible the airliners of the future, and ailerons were beginning to replace wing warping, which would clearly not be practical with the heavy wings of a large plane. Also, Igor Sikorsky had already built a four-engine plane and would later build a practical helicopter. None of these improvements on the Wright *Flyer* matched the difficulty or importance of the problems of flight which the Wright brothers had solved, but they marked modern aviation as a field of constant and rapid change.

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See also: Airplanes; Sir George Cayley; Octave Chanute; Glenn H. Curtiss; Leonardo da Vinci; Forces of flight; Gliders; Hang gliding and paragliding; Helicopters; History of human flight; Samuel Pierpont Langley; Otto Lilienthal; Propellers; Alberto Santos-Dumont; Igor Sikorsky; Wing designs; Wright brothers; Wright *Flyer*; Ferdinand von Zeppelin

Helicopters

Also known as: Choppers, helos, whirlybirds, copters

Definition: Any rotary-wing aircraft having powered, fixed rotors that provide lift and propulsion for the aircraft.

Significance: The helicopter was the first operational vertical takeoff and landing (VTOL) aircraft and remains the most prevalent.

Configurations

The helicopter is the principal VTOL aircraft in service throughout the world. The name "helicopter" was coined by a Frenchman, Viscomte Gustave de Ponton d'Amecourt, circa 1863. Helicopters can be distinguished from other rotary-wing aircraft by the fact that their rotors are fixed in position on the aircraft fuselage and simultaneously provide lift and propulsion. The vast majority of modern helicopters have either one or two rotors that provide lift and propulsive force.

Although helicopters can take off and land vertically, their maximum forward speed is much lower than that of fixed-wing aircraft. This limitation is due to the fact that the rotor or rotors must provide both propulsion and lift. Under high-speed flight conditions, the vibratory forces on the rotor blades become very large, thereby limiting the top speed of the helicopter. In order to increase the top speed, some helicopters, known as compound helicopters, have been equipped with auxiliary means of propulsion, such as propellers or jet engines.

Helicopters are built in a variety of configurations, including the single-rotor, the tandem, the coaxial, and the side-by-side helicopters. The single-rotor helicopter is the most common configuration currently in use. It can be identified by the single main rotor that provides thrust and propulsion, as well as pitch and roll control. A smaller tail rotor usually provides antitorque directional yaw control. However, other devices may be used instead of a tail rotor.

Another common configuration is the tandem helicopter. The tandem helicopter has two large rotors, one at the forward end of the helicopter and the other at the aft end. The two rotors rotate in opposite directions, thus eliminating the need for an antitorque device, such as a tail rotor. This configuration is particularly well-suited for the transport of heavy cargo, because the two rotors can accommodate large changes in the aircraft center of gravity due to the cargo load.

Less common configurations include side-by-side and coaxial helicopters. Like the tandem helicopters, side-by-side helicopters have two main rotors, but one is located on the right side of the aircraft, and the other is located on the left side. The rotors rotate in opposite directions, again eliminating the need for a tail rotor.

A variant of the side-by-side helicopter is the synchropter, on which the two rotors are placed close together, so that the rotors intermesh. The synchropter has the advantage of being able to take off and land in more confined areas than either a side-by-side or tandem helicopter, because the close proximity of rotor masts reduces the area required for clearance around the rotors.

The coaxial helicopter has two counterrotating rotors that share a common mast. Because the rotors rotate in opposite directions, no tail rotor is needed for this configuration either. Coaxial helicopters also have the advantage of being able to land in more confined areas than any other configuration, because the swept area of the rotors is the smallest of all configurations.

Missions

Because helicopters are able to take off vertically, hover in midair, and land vertically, they are ideal vehicles for a wide variety of missions. They do not require prepared landing areas, so they can take off and land in forest clearings, on the tops of buildings, and on ships at sea. As a result, they can be used in civil and military applications for which fixed-wing aircraft are unsuitable.

The transportation of passengers is one of the primary missions of helicopters. The largest civilian user of helicopter transportation is the petroleum industry. Helicopters regularly transport petroleum workers to and from offshore oil platforms, because they are much faster and more cost effective than boats. Many large corporations use helicopters to ferry their executives between sites. Commercial helicopter operators in scenic locations, such as the Grand Canyon and Hawaii, regularly carry passengers on sight-seeing tours, although increasingly stringent noise regulations have somewhat curtailed their business.

Commercial helicopter airlines have not been economically viable, despite the obvious advantages of ferrying passengers between airports and between airports and inner-city heliports. The U.S. military services, particularly the Army and the Marines, make extensive use of helicopters for troop transport. Naval helicopters are often used for ship-to-shore and ship-to-ship transportation of personnel. In all services, helicopters are used for the insertion and extraction of special-operations forces at remote sites.

Cargo transportation is another important helicopter function. In the logging industry, helicopters are used to transport logs from remote areas either directly to a mill or to rivers in which the logs are floated to a mill. Construction projects often use helicopters to transport heavy equipment, such as heating, ventilation, and air conditioning units, to the tops of tall buildings. The Statue of Freedom, atop the U.S. Capitol Building, was removed by helicopter in 1993 for restoration and was later replaced in the same manner. Helicopters with large buckets slung beneath them are used to transport water from nearby lakes to the site of a forest fire. On the military side, the Army and Marines use helicopters to transport supplies and even small- and medium-sized vehicles from rear areas to troops in the field. The Navy uses helicopters to transport supplies from shore to ships at sea and between ships at sea.

Many police departments, particularly in large cities, use helicopters for airborne patrol and surveillance. Because they operate at altitude, helicopters have a wider field of view than ground patrols. In cases of pursuit, it is much easier for a helicopter to keep a fleeing suspect in view and safer for the ground units and the general public. In addition, when on patrol, a helicopter can often reach the crime scene more rapidly than can a ground unit. In a similar application, radio and television stations use helicopters for acquiring traffic reports and news gathering. News helicopters can often reach the scene of a news event more rapidly than can ground vehicles.

Another mission for which helicopters are particularly well-suited is search and rescue. Although this is primarily a military mission, police departments and the U.S. National Park Service will use helicopters to find and rescue hikers, campers, and others who find themselves in dangerous situations. The U.S. Coast Guard is very active in search and rescue, patrolling the waters off the coast of the United States. A typical Coast Guard rescue mission would be to extract passengers from foundering sailing vessels. Combat search-and-rescue missions are flown primarily by the Air Force and the Navy to locate and return aircrews of aircraft downed in combat. During the Vietnam War, the Jolly Green Giant (CH/HH-3E) helicopters were a welcome sight for many pilots who had been shot down while flying over North Vietnam.

Combat close air support and antiarmor are purely military missions. Close air support involves using helicopters to support friendly ground troops by directing fire on enemy troops in the near vicinity. Helicopters used in antiarmor missions are equipped with ordnance that is capable of disabling or destroying tanks and other armored vehicles. The Marines use the AH-1 and the Army uses the AH-64 for these missions.

Flight Control

One of the first problems of helicopter flight control that must be solved is the question of how to keep the fuselage from rotating opposite the rotor. In order to spin the rotor, torque is applied by the engine to the rotor driveshaft. Therefore, the rotor has an angular momentum, which must be counteracted in some manner. If the angular momentum of the rotor is not equalized, the fuselage will begin to rotate in the opposite direction to the rotor rotation. Single-rotor helicopters equalize the angular momentum with countertorque devices, such as a tail rotor or a NOTAR (no tail rotor) system. The tail rotor is a smaller rotor mounted vertically at the end of a tail boom that generates a lateral thrust. The NOTAR system also generates lateral thrust but does so using the slipstream of the rotor and air ejected from a slot in the tail boom to produce the Coanda effect. Helicopters with more than one rotor, such as the tandem, side-by-side, and coaxial types, equalize the angular momentum by employing equally sized rotors rotating in opposite directions.

In order to fly a helicopter, the pilot must be able to control the translation of the aircraft in the vertical, lateral (side-to-side), and longitudinal (forward-and-back) directions, as well as rotation in roll, pitch, and yaw. The pilot's controls include a collective lever beside the pilot seat, a cyclic stick between the pilot's knees, and foot pedals. It is interesting to note that in helicopters, the pilot sits in the right seat and the copilot sits in the left. In fixed-wing aircraft, the pilot sits in the left seat, and the copilot sits in the right. This seating arrangement is an artifact from one of Igor Sikorsky's early helicopters, which had such "backward" seating.

To explain helicopter control, consider a single-rotor helicopter. The main rotor of a single-rotor helicopter produces a thrust, which acts in a direction roughly normal to the rotor disk. Therefore, in order to control the helicopter, the pilot must be able to control the magnitude and direction of this thrust. The magnitude of the thrust is controlled by the collective lever, which equally increases or decreases the pitch angle of all rotor blades, thereby increasing or decreasing the thrust. In order to control the direction of the thrust, the pilot must be able to control the orientation of the rotor disk. One way to change the orientation of the rotor disk is to physically tilt the rotor hub.

For very small helicopters, hub tilt is a practical control method. However, for larger helicopters, the rotor acts like a large gyroscope, which makes tilting the hub extremely difficult. The alternative is to increase the thrust on one half of the disk, while simultaneously decreasing the thrust on the other half. This cyclic change in thrust causes the rotor disk to tilt and does so with much less effort than hub tilt.

In all but a few modern helicopters, the pilot's cyclic stick, acting through a swashplate, is used to change the cyclic pitch of the rotor blades. The swashplate consists of two parts: a nonrotating plate and a rotating plate. The nonrotating plate, which is connected to the pilot collective and cyclic pitch controls, slides up and down for collective-pitch changes and tilts for cyclic-pitch changes. The rotating plate sits on top of the nonrotating plate and spins with the rotor. Pitch links, attached to the rotating plate and the rotor blades, mechanically change the pitch angle of the blades. Yaw control is obtained through the foot pedals, which are connected to the collective pitch controls for the tail rotor.

Helicopters use rotors rather than wings to achieve vertical takeoff and landing. (NASA)

History

Although the development of an operational helicopter is a relatively recent accomplishment, many of the concepts necessary for designing a practical helicopter have been known for a very long time. In fact, one could argue that a maple seed falling from a tree is nature's model for the helicopter. The Chinese top, which predates the Roman Empire, is perhaps humankind's first step toward modern helicopters. In addition, Leonardo da Vinci considered the possibility of vertical flight, and made a sketch of his concept for such a vehicle.

The development of a practical helicopter was made possible by overcoming three major technology barriers. The first barrier, and the easiest to overcome, was the design of a rotor system with rotor blades and a rotor hub that were strong but lightweight, with adequate aerodynamic efficiency. The second was to engineer a power plant with a sufficiently high ratio of power to weight, required in order to lift the aircraft off the ground. This barrier was overcome with the invention of the internal-combustion engine. The third technology barrier was to devise a method for controlling the helicopter in flight. The principles leading to controlled helicopter flight were developed gradually by helicopter pioneers.

Early helicopter pioneers tried a variety of power plants in their helicopter designs. During the latter half of the eighteenth century, Mikhail Vasilyevich Lomonosov in Russia, Launoy and Bienvenu in France, and Sir George Cayley in England provided power to their helicopters by using different spring mechanisms. While spring-driven power plants have a good ratio of power to weight, they cannot provide sufficient sustained power for long flights.

In the nineteenth century, steam-powered helicopters were designed by Horatio Frederick Phillips in England, d'Amecourt and Alphonse Pénaud in France, Enrico Forlanini in Italy, and Thomas Edison in the United States. In contrast to spring power, steam power could provide sufficient sustained power, but its ratio of power to weight was very low.

Like that of the airplane, the concept of the helicopter did not become truly feasible until the invention of the internal combustion engine. Developments leading to a practical helicopter began to be achieved not long after Orville and Wilbur Wright flew their first airplane, but the availability of an adequate power plant brought problems of control to the fore. Paul Cornu and Charles Renard in France, Emile and Henry Berliner in the United States, and Igor Sikorsky and Boris Yuriev in Russia made significant contributions prior to 1920.

Renard introduced the flapping hinge, which improved rotor control; and Yuriev introduced the antitorque tail rotor for yaw control. In 1907, Cornu made the first piloted, free-flight, vertical takeoff, but the aircraft had to be stabilized manually by a ground crew. In the 1920's and early 1930's, George de Bothezat in the United States, Etienne Oemichen and Louis-Charles Breguet in France, Raoul Pescara in Spain, Emile and Henry Berliner in the United States, Louis Brennan in England, A. G. von Baumhauer in Holland, and Corradino D'Ascanio in Italy, M. B. Bleeker in the United States, and Yuriev in Russia all built prototype helicopters. Unfortunately, all of these designs either had controllability problems or were too complex to be practical.

However, important contributions toward improved control were made by Bothezat, in differential collective pitch control; Pescara, in cyclic pitch control; von Baumhauer, in the area of the swashplate; and d'Ascanio, in servotab cyclic pitch control.

In 1936, German aircraft designer Heinrich Focke introduced the first practical helicopter, the Focke-Achgelis Fa-61, a side-by-side design in which all of the stability problems had been solved. In 1938, Hanna Reitsch flew the Fa-61 inside the Deutschland-Halle in Berlin, demonstrating its flying precision. In 1939, in the United States, Igor Sikorsky introduced the VS-300, a single-rotor helicopter, which may have been the world's first useful helicopter. Germany continued its development of the helicopter during World War II, and Anton Flettner's synchropter design, the FL-282 Kolibri, became the first production helicopter.

At about the same time, other individuals, including Arthur Young, Frank Piasecki, and Stanley Hiller in the United States, and Nikolai Kamov, Mikhail Mil, and Ivan Bratukhin in the Soviet Union were developing their own independent helicopter designs.

Modern Helicopters

The basics of helicopter design have not changed greatly since the early days of helicopters in the 1940's. However, technological improvements have been incorporated that make the modern helicopter safer, easier, and more efficient to fly. One of the most significant advances in helicopter performance resulted from the introduction of the gas-turbine engine. The maximum power-to-weight ratio achievable with piston engines by the end of World War II was approximately 1 horsepower per pound. However, by the 1960, turbine engines had achieved power-to-weight ratios of 3 horsepower per pound, and by 2000 they had achieved weight ratios of up to 6 horsepower per pound.

Helicopter rotor systems have also undergone significant changes. In the early years, rotor blades were made exclusively of wood, one of the principal materials used for aircraft construction. In 1944, Hiller introduced metal rotor blades on the XH-44, but it was not until 1952 that metal blades were delivered on a production aircraft, the Sikorsky S-52.

The use of composite materials for rotor blade construction began in the early 1960's, and, by the 1970's, the Messerschmitt-Bölkow-Blohm company in Germany had built all-composite blades for the BO-105 helicopter. Virtually every modern helicopter is now equipped with composite blades. The rotor hub has also undergone changes in the way that the blades are attached. Many helicopter rotors are fully articulated. That is, each blade has physical hinges, which allow the blade to flap out of the plane of rotation and lag in the plane of rotation. A bearing also allows the blade to pitch. The concepts of a hingeless rotor that eliminates the flap and lag hinges and a bearingless rotor, which is basically a hingeless rotor without a pitch bearing, have found their way into the designs of many modern helicopters.

Technological improvements, such as vibration control devices in the rotor system and the fuselage, have improved the comfort level for passengers, as well as the performance of the flight crew due to reduced fatigue. Crashworthy structural design, seats, and fuel systems have improved the safety of helicopters in emergency situations. Hydraulic control systems have replaced the mechanical control systems of early helicopters, and modern helicopters are often equipped with electronic flight control and stability augmentation systems to reduce pilot workload. Digital fly-by-wire and fly-by-light control systems, as well as glass cockpits, have begun to be introduced in advanced production helicopters.

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See also: Apache helicopter; Bell Aircraft; Sir George Cayley; Firefighting aircraft; Gyros; Leonardo da Vinci; Hanna Reitsch; Rescue aircraft; Rotorcraft; Igor Sikorsky; Vertical takeoff and landing

High-altitude flight

Definition: Flight at altitudes higher than most flights but lower than orbital flight; roughly between 50,000 feet (9 miles) and 100 miles.

Significance: High-altitude flight has often been the frontier of aviation technology, meteorology, astronomy, and aerial reconnaissance. Many tasks can still be done more cheaply, or can only be done, in high-altitude flight.

High-Altitude Characteristics

The meaning of the term "high altitude" has changed over the years. Balloonists struggled to reach altitudes between 20,000 and 30,000 feet, yet by the last third of the twentieth century these altitudes were routine for commercial and military jet transports. The only constant is that the frontier always lies at the current definition of high altitude.

Decreasing pressure is the most important feature of high altitude. Most of the earth's atmosphere is in the troposphere, roughly the first 40,000 feet from the surface, and 99 percent of the atmosphere is below 127,000 feet. This has many implications. For high-speed jet aircraft, lesser air density allows greater speed, reduces heating problems, and allows greater engine efficiency until the available oxygen is too dilute to support combustion. For rockets, which require no external oxidizers, there is no limit except available fuel and oxidizer.

For slower aircraft utilizing maximum lift for minimum energy, progressively less air density requires progressively wider wingspans, bigger control surfaces, cleaner aerodynamics, or more power to lift the same payload. For lighter-than-air (LTA) craft, such as balloons and dirigibles, decreasing air density with increasing altitude means there is less lift available per unit volume, so LTA craft must be larger to carry a given payload to higher altitudes.

For living creatures, such as human crewmembers, a low-pressure (hypobaric) environment can be deadly. For instance, at about 18,000 feet the total air pressure is halved from that at sea level, and the amount of oxygen available to the body is similarly halved. The result is hypoxia (low oxygen) with progressively more severe symptoms as pressure declines: euphoria, headache, nausea, irritability, confusion, unconsciousness, and death. Aircraft crews can compensate for low pressure by breathing a greater percentage of oxygen. However, above 49,000 feet even pure oxygen does not have sufficient pressure to sustain life, so crews must have either pressurized cabins or pressure suits.

Flying above much of the atmosphere means that much of the radiation usually stopped by the atmosphere will impact the craft. The lack of atmosphere allows clearer astronomical observations at light wavelengths stopped by the atmosphere, such as infrared. However, increased radiation in ultraviolet and shorter wavelength bands can attack a number of plastics that might be used in aircraft structures, and flight crews are subject to higher doses of ionizing radiation than people on the ground.

Cold is another feature of high altitude. A rough formula is that in temperate zones every thousand feet of altitude is equivalent to traveling 75 miles farther from the equator. Temperatures drop steadily with altitude in the troposphere, stay the same or even rise slightly in the lower stratosphere, and then become somewhat irrelevant as declining air density begins to approach vacuum. Cold is not a serious problem for supersonic craft, for which avoidance of overheating is the prime concern. However, it can be life-threatening for slower craft.

Lastly, every mile of altitude yields roughly 33 miles of line-of-sight to the horizon. This has great importance for airborne radars and communications platforms. A radar plane flying at 40,000 feet has a range 260 miles, compared to 520 miles for a craft at 80,000 feet. In communications, an aircraft holding position or flying in tight circles to stay nearly in the same place can replace satellite communications service at lower cost and allow for ground stations that use much less power. They can also be put in place or upgraded more quickly than can satellite launches.

There are three types of high-altitude craft: highly efficient propeller and jet craft, supersonic jets and rockets, and lighter-than-air craft, such as balloons and dirigibles.

The U-2 and Its Competitors

The Lockheed U-2, sometimes called the Dragon Lady, is the most famous formerly secret high-altitude aircraft. In the early 1950's, during the most intense part of the Cold War, the U.S. intelligence community wanted a spy aircraft that could fly higher than any interceptors in the Soviet Union. Kelly Johnson at Lockheed proposed radically reconfiguring an F-104 Starfighter as a glider body with an 82-foot wingspan and a jet engine so it could fly at 70,000 feet. Johnson and his "Skunk Works" flew the first craft in August, 1955. On July 5, 1956, a U-2 flew over Moscow, the Soviet capital. Although the Soviets protested, they could do nothing about the overflights, and the United States denied its existence.

However, the U-2 flew slowly, turned slowly, had not been designed for stealth by minimizing its radar and infrared signature, and Soviet antiaircraft missiles improved. On May 1, 1960, the Soviets downed a U-2 one thousand miles inside their border, and captured the pilot, precipitating a major diplomatic incident. Another U-2 was shot down during the Cuban Missile Crisis in 1962, and the U-2's were pulled back from well-defended areas. However, they continued to be used into the twenty-first century as high-flying signal-intelligence craft, obtaining data without crossing into hostile territory, and as conventional reconnaissance craft once air superiority was achieved, as in the Gulf War of 1991.

This long life required a series of upgrades. The most important was the U-2R, beginning in 1967, which was a larger, stealthier aircraft that accomodated a two-person crew, a fourteen-hour maximum mission operations time, and a ferrying range of 8,000 miles. The civilian U-2 is the ER-2, which has done mapping and atmospheric sensing for several decades.

The most recent U-2 competition has come from two planes from the company Scaled Composites: the *Raptor* and the *Proteus*. Both use lightweight composite materials and advanced aerodynamics pioneered by Burt Rutan, designer of the nonstop world-circling *Voyager*. The remotely controlled *Raptor* is a propeller-driven slower competitor, but it is stealthier than the U-2, and it can linger over an area for forty-eight hours. It demonstrated an 8,000-mile flight range in 2001.

The *Proteus* is a direct, cheaper competitor to the U-2, with jet propulsion, a 2,000-pound payload, a fourteen-hour operations length, and an operational altitude of nearly 70,000 feet. As with its shape-changing namesake in Greek mythology, the *Proteus* can be configured for several other missions. Most important, it is a telecommunications repeater station, and for this mission, the *Proteus* demonstrated stable flight at 55,000 feet in late 2000.

A new altitude record of 96,500 feet was set on August 13, 2001, by the *Helios*, a robotic flying wing designed by Paul MacCready of AeroVironment. (MacCready had also designed the human-powered *Gossamer Condor.*) Although its payload is only 220 pounds, the *Helios* is direct competition for the Scaled Composites' *Proteus* repeater stations. *Helios* has solar cells for daylight power and for electrolyzing water into hydrogen and oxygen for nighttime fuel-cell power. Consequently, *Helios* can fly for six months at a time.

Lighter-Than-Air Craft at High Altitudes

Balloons were the first craft capable of reaching high altitude. On December 1, 1783, Jacques-Alexander-César Charles made the first flight in a hydrogen balloon and also made the first high-altitude flight, limited only by the uncomfortable cold he encountered. For the next 120 years, balloons were the only means of observing the atmosphere.

Swiss balloonist Auguste Piccard demonstrated the first pressurized cabin on May 27, 1931, when he and an assistant reached 51,793 feet, making them the first fliers ever to reach the stratosphere. More importantly, they discovered that cosmic rays increased with altitude, proving that they came from somewhere in space rather than the other suggested source, radioactivity within the earth.

American and Soviet flights from the 1930's through the 1960's carried personnel and instruments to steadily greater heights and developed many technologies later used in the space race. In fact, on May 4, 1961, the American *Stratolab V* reached an altitude of 113,700 feet with an open gondola, testing space suits in near-space conditions for the Mercury orbital-flight program.

After the 1960's, improved robotic instrumentation allowed LTA craft to shed the weight of the balloonists and their life support gear. By the late twentieth century, the National Aeronautics and Space Administration (NASA) began using super-pressure balloons for relatively small payloads in balloons weighing several tens of pounds. These balloons are different from zero-pressure balloons that expand when warmed by the sun and contract at night. When warmed at high altitude, zero-pressure balloons must vent excess helium to prevent bursting. This gas loss limits mission duration to only several days. With stronger materials, super-pressure balloons keep the same maximum shape even when warmed. Because no gas is lost such balloons can operate for months, and some of these balloons have circled the globe several times. By the early twenty-first century, NASA began flying large super-pressure balloons in a program called the Ultra Long Duration Balloon (ULDB), with balloons carrying several tons of instrument payload. These balloons compete with spacecraft for carrying astronomic payloads because they are cheaper, turnaround time is shorter, and awkward payloads can be accommodated that might not fit in a rocket or aircraft fuselage.

Dirigibles have greater difficulty reaching high altitudes because the volume of buoyant gas needed to lift the payload as well as a body structure, engines, and control surfaces can become truly immense compared to the weight of payload being carried. Yet, dirigibles can fly slowly enough into the wind to remain stationary over one spot for weeks, ideal for communications repeating stations. Thus, by the early twenty-first century, Sky Station International was building a dirigible to compete against those of AeroVironment and Scaled Composites.

Supersonic High-Altitude Craft

The most important supersonic high-altitude craft was the North American X-15 rocket-propelled research airplane, used from 1959 through 1968 to test materials and aerodynamics at speeds as great as 6.7 times the speed of sound (Mach 6.7, or 4,520 miles per hour) and altitudes as high as 354,000 feet. Lessons learned from these tests were later applied to the space shuttle and many supersonic airplanes.

High-altitude supersonic flight development reached a peak in the early 1960's and then languished until the beginning of the twenty-first century. As noted, supersonic craft operate best in high-altitude regimes because thinner air causes less heat through friction and allows greater efficiency. Higher altitudes had also been a general direction of military flight since World War I (1914-1918).

These two trends led to the North American XB-70, planned as a heavy bomber flying at Mach 3 and a flight ceiling of 70,000 feet. The XB-70 flew in the early 1960's. By 1964, the Soviet Union responded with the Mach-2.8 Mikoyan MiG-25 interceptor.

After the 1960's, other developments intervened. First, intercontinental ballistic missiles (ICBMs) were widely deployed. ICBMs could deliver bombs much faster than could aircraft. Furthermore, they did not require the expensive high-temperature alloys and vast amounts of fuel in operational training. Second, increasingly effective surface-to-air missiles caused large military aircraft to switch from high-altitude flight to flying low while ducking around missile sites. The XB-70 was never produced in volume, and the F-25 became largely a high-speed reconnaissance craft. The Lockheed SR-71 Blackbird was the best high-speed reconnaissance craft, with a maximum speed of more than Mach 3 (2,200 miles per hour and a maximum altitude of 90,000 feet).

The XB-70 also demonstrated that no matter how high supersonic transports flew, sonic booms were a major irritant to people on the ground. The booms and the cost of heavy fuel use both limited the market for commercial supersonic transports, such as the Concorde and the similar Tupolev Tu-144.

However, research has continued to develop better supersonic craft as the first stages for launch into orbit because oxygen carried by rockets weighs eight times as much as hydrogen fuel whereas jets get their oxygen from the atmosphere. Also, there have been reports of secret military craft with speeds of Mach 5 through Mach 10 and flight ceilings of 148,000 feet.

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See also: Balloons; Dirigibles; Experimental aircraft; Jet engines; Lighter-than-air craft; Military flight; Auguste Piccard; Propellers; Reconnaissance; Rockets; Burt Rutan; Spaceflight; Supersonic aircraft; Andrei Nikolayevich Tupolev; X planes

High-speed flight

Definition: Flight airspeeds greater than the average, especially speeds close to the maximum attainable speed for the era.

Significance: The utility of civilian or military aircraft is always enhanced by increases in practical flight airspeeds. Much of the historic progress in aviation has revolved around solving the aerodynamic, structural, power, and heat problems associated with ever increasing speeds. Races and speed records, with their promise of prize money or prestige, have often stimulated individuals and governments to advance the art and science of high-speed flight.

As the first humans to make a controlled, powered flight in 1903, Orville and Wilbur Wright held the first unofficial speed record, at 30 miles per hour. Official speed records, though, are those that have been authenticated by the rules of the Fédération Aeronautique Internationale (FAI), formed in Paris in 1906, and these speed records begin with Alberto Santos-Dumont's 26 miles per hour in 1906, increasing to 83 miles per hour by 1911, 119 miles per hour in 1913, 192 miles per hour in 1920, 469 miles per hour on the eve of World War II in 1939, 606 miles per hour with the first jets in 1945, 1,526 miles per hour with second-generation fighter aircraft in 1959, and 2,194 miles per hour by the SR-71A in 1976.

Early High-Speed Flight

Initially, flight speeds were limited primarily by the lack of lightweight power plants, not surprising in view of the fact that development of the gasoline engine was still in its infancy. Thus, the first airplanes required a very large wing area and the most efficient structure was the bridge-based biplane, but its large size and attendant struts and wires generated a great deal of drag. By 1909, Glenn H. Curtiss was able to take his draggy biplane to first place in the first Gordon Bennett closed-circuit race at Rheims, France, with a speed of 47 miles per hour, mostly due to his development of a 50-horsepower V-8 engine that bettered the Wright brothers' original 12-horsepower engine.

Invention of the relatively lightweight, reliable, air-cooled rotary engine, in which the crankshaft is bolted to the aircraft and the cylinders and propeller rotate, led to the next great increment in high speed, culminating in a winning 124.5 miles per hour by a special Deperdussin monoplane racer in the last prewar Gordon Bennett race in 1913.

World War I led to improvements in structures and power plants but negligible increases in speed because of the emphasis on climb rate and maneuverability, which favored biplanes.

After World War I, the Schneider Trophy race for seaplanes inspired great advances in engines. The liquid-cooled engine assumed prominence because of its low frontal area. By 1927, Reginald Mitchell's 900-horsepower Supermarine S.5 had established an absolute speed record of 282 miles per hour; it was the last time a biplane would win the race. The Supermarine S.6 retired the Schneider Trophy with an uncontested win at a speed of 340 miles per hour in 1930, with 2,300 horsepower available from its supercharged, liquid-cooled Rolls-Royce V-12. These racers, however, were impractical aircraft because they used low-drag skin radiators to dissipate the tremendous heat from their liquid-cooled engines.

The winning Rolls-Royce V-12 engine in the S.6 had been inspired by the Curtiss V-12 engine that had powered the Curtiss CR-2 biplane to first place in the Pulitzer race of 1921 (and later to an absolute speed record of 198 miles per hour) and by the CR-3 that won the Schneider Trophy in 1923 at 178 miles per hour. In the United States, however, by the mid-1920's, water-cooled engines were taking second place to newly developed, reliable, air-cooled radial engines that were much lighter and much more suited to commercial applications, but presented a great deal more frontal area and accompanying drag. Charles A. Lindbergh's historic New York-to-Paris flight in 1927 was made possible by a 220-horsepower Wright Whirlwind radial engine, for example.

The monoplane route to higher speeds, now that brute power had accomplished about all it could do, was shown by the features of the unheralded, trouble-prone Dayton-Wright RB-1 racer of 1921: a small unbraced (cantilevered) wing that used flaps to yield acceptable takeoff and landing speeds, a closed cockpit for less drag, and a retractable landing gear. With a low-drag NACA cowling for its radial engine (developed by the National Advisory Committee for Aeronautics or NACA, the predecessor of NASA), the 450-horsepower TravelAir Mystery Ship won the 1929 National Air Races in Cleveland, besting all the military biplanes. James H. "Jimmy" Doolittle set a land plane record of 294 miles per hour in 1932 in the small-winged, bottle-shaped GeeBee R-1, using an 800-horsepower Pratt & Whitney radial engine. By 1939, however, Lockheed had flown the aerodynamically clean prototype of its P-38 twin-engined Lightning to a top speed of 413 miles per hour, and civilian aircraft were forever out of the race for the highest speeds.

In World War II, piston-engined fighters reached speeds of around 500 miles per hour, but only at altitudes above about 20,000 feet, where their supercharged or turbocharged engines could take advantage of the less dense air. The liquid-cooled P-51H Mustang reached 487 miles per hour at 25,000 feet using water/methanol injection and high-octane fuel. An experimental version of the Republic P-47 Thunderbolt, using an 18-cylinder, air-cooled radial engine, reached a speed of 504 miles per hour at 34,450 feet. The Goodyear F-2G, developed from the Chance Vought F-4U Corsair, could reach speeds close to 500 miles per hour. Nonetheless, two facts threatened to forever prevent higher speeds: propeller and wing compressibility (Mach) effects.

The Sound Barrier

Propellers were becoming less and less efficient as their tips approached the speed of sound; the air would break away from the tips and form ear-splitting shock waves. Worse, planes and pilots were being lost when the airflow over the wing approached the speed of sound. Because air is speeded up over the top surface of a wing to produce a lower air pressure there and thereby generate lift, the speed of sound is reached at that point before (sometimes well before) aircraft speed reaches sonic speed (Mach 1). Shortly after a local airspeed of Mach 1 is exceeded, a shock wave is formed where the air suddenly has to be slowed back to subsonic speeds; because the pressure waves that inform the air that it must change its speed or direction cannot propagate into the region ahead of this point, the shock wave represents an extremely narrow region perpendicular to the wing surface where the pressure and density and temperature of the air greatly increase. Shock wave formation not only greatly increases the power requirement, it also causes the airflow to break away from the wing at that point, producing effects very similar to the low-speed stall created when the wing is at a high angle relative to the oncoming air.

At less than 70 percent of the speed of sound (Mach 0.675), a speed easily reached in a dive, the P-38 became uncontrollably nose-heavy as the wing lost lift and the horizontal tail surface lost its downward force; dive flaps were added to the sides of nacelles to save future pilots. Of U.S. fighters, the P-51 Mustang suffered the least from compressibility, thanks to its laminar-flow wing with the thickest point well back from the leading edge, but its pilots were warned that in high-speed dives, uncontrollable violent porpoising preceded a loss of altitude of 10,000 feet or more, at which point a recovery might be possible, because the Mach number decreased as the air temperature increased. The British Spitfire, with its very thin wing section, was eventually dived successfully to Mach 0.9, but it still was not at all clear that controlled supersonic flight would ever be possible.

The propulsion problem was solved by the invention of the turbojet engine by the British and Germans, an engine which obtains thrust by taking in air and using it to burn fuel, with the byproducts exiting to the rear at a much higher speed. The thrust generated is equal to the rate of change in momentum (the product of mass and speed) generated by the engine. The jet engine is most efficient in the less dense air at altitudes above 20,000 feet.

Rocket engines produce even more short-term thrust than jet engines, for their weight, and were used for the earliest transonic and supersonic flights. (Transonic flight is flight for which there is mixed subsonic and supersonic flow, approximately Mach 0.8 to Mach 1.2.) By 1944, the German rocket-powered Messerschmitt Me-263B had reached a speed of 703 miles per hour and the much more practical, jet-powered Messerschmitt Me-262 had reached 624 miles per hour.

Higher speeds required better aerodynamics, including a recognition of the advantages of the swept-back wing and solutions for its disadvantages. Adolf Busemann, in 1935, first published the finding that a swept wing permits a wing to be effectively thinner because the chord (width) of the wing is greater than for a similar unswept wing. It spreads the lift and the cross-section of the wing over a greater percentage of the fuselage, reducing the suddenness of the drag rise and the pitch-down tendency. However, the spanwise flow on a swept wing also tends to cause the wingtips to stall first at low speeds or when maneuvering, making the ailerons ineffective and producing a violent pitch-up tendency. The swept wing also suffers from a Dutch roll (coupled yaw and roll) tendency, which can be serious enough to destroy the aircraft. The stall problem can be treated by using high-lift devices (slats) on the leading edge of the outer wing panels and by chordwise plates (fences). The Dutch roll tendency can be treated by a gyroscopic-based yaw damper, as well as aerodynamically. In May, 1948, the swept-wing, jet-powered North American F-86A Sabre jet achieved an official world speed record of 670 miles per hour.

Supersonic Flight

The sound barrier, however, was still to be breached. The United States chose the bullet-shaped, rocket-propelled Bell X-1 to make the attempt. (Bullets were known to reach supersonic speeds in flight, but they had to spiral for stability and they did not try to use lift to stay in the air.) With only 2.5 minutes worth of rocket fuel, the only available route was to use an air launch from a modified B-29 bomber and glide to a landing afterward. This was possible only because the United States had California's clear skies and vast Muroc Dry Lake (the present Edwards Air Force Base) for landing. On October 14, 1947, test pilot Charles E. "Chuck" Yeager reached Mach 1.06 at 43,000 feet and the first human-generated sonic boom was heard. He glided back at 250 miles per hour, approached at 220 miles per hour, and landed at 190 miles per hour.

The Russian MiG-19 was the first fighter capable of supersonic flight in level flight, followed shortly by the Republic XP-91 and North American's F-100 Super Sabre. The secret was obtaining a short burst of extra thrust by dumping raw fuel directly into the exhaust (after the turbine), a practice called afterburning in the United States and reheat in Great Britain. However, the Super Sabre also had to be cured of a new disease: inertia coupling. With a long, heavy fuselage supported by short, light wings, an aircraft has roll inertia (resistance to changes in roll around the nose-to-tail axis) that is much less than its pitch and yaw inertia, and rolling motion can induce a pitching moment that sends an aircraft into a disastrous tumble. Additional tail and wing area solved the problem for the Super Sabre.

The FAI set new rules for speed records at high altitudes and Great Britain quickly claimed an absolute speed record in March, 1956, when its Fairey Delta 2 (FD.2) flew at 1,132 miles per hour. The official speed record as of 2001 was held by Lockheed's SR-71 Blackbird (a reconnaissance aircraft capable of over Mach 3 at 100,000 feet altitude); in 1976 it averaged 2,194 miles per hour, but probably could have gone even faster.

Transport aircraft have followed in the path blazed by research and fighter aircraft. The Douglas DC-2 almost won the London to Melbourne race in 1933 against specialized racing aircraft. The Boeing 707 was the first successful jet transport, going into service in the late 1950's. The French/British Concorde began Mach 2 airline service in 1976; it uses a highly swept delta planeform with sharp leading edges generating vortices that greatly enhance lift at low speeds (vortex lift).

Hypersonic Flight

Hypersonic flight (greater than Mach 4 or 5) is the new frontier and in this flight realm, heat is the primary foe. Even on the Concorde, skin temperatures of 260 degrees Fahrenheit are reached and the fuselage lengthens by 9 or 10 inches in flight. On the titanium SR-71, temperatures reach 600 degrees Fahrenheit.

The North American X-15 showed that a rocket-powered research aircraft could reach hypersonic speeds; by 1967 the X-15 had flown to 354,000 feet and Mach 6.7, but it had also been seared by 3,000-degree-Fahrenheit temperatures. Ablative (sacrificial) coatings were used; they melt away at high temperatures while absorbing and dissipating the heat.

After the Soviet Union sent Yuri Gagarin into Earth orbit in 1961, beginning the race to the Moon, spaceflight, rather than higher-speed atmospheric flight, became the next U.S. challenge. It was followed by space stations and the space shuttle, the latter of which must attain just the right speed for its orbital height and then, with braking rockets, reenter the atmosphere at about 140,000 feet and Mach 6.7.

The X-43, making its first flight in 2001, is an uninhabited hypersonic research aircraft. It remains to be seen whether it will make hypersonic flight a regular occurrence.

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See also: Concorde; Glenn H. Curtiss; Jimmy Doolittle; Hypersonic aircraft; Jet engines; Mach number; Military flight; Propellers; Rocket propulsion; Alberto Santos-Dumont; Sound barrier; Supersonic aircraft; Wing designs; Wright brothers; X planes; Chuck Yeager

Hijacking

Definition: The act of commandeering an aircraft in flight by means of force or violence.

Significance: Beginning in the late 1960's, air piracy became a major technique of world terrorism. The rise in hijacking incidents led to increases in airport security and air traffic control.

Scope

Aviation security is a major concern, even though hijackings and terrorist acts against civil aviation declined from their height in 1969. Hijacking first became a serious problem for the United States in the late 1960's and early 1970's, when the majority of forcibly diverted flights were directed to Cuba. Air piracy events initiated stricter airport security provisions in the United States with the passage of 14 CFR Part 107, amended in December, 1972. The number of U.S.-registered aircraft hijacked per year fell dramatically from a peak of forty in 1969 to one in 1973. After initiating regulations increasing airport security in the early 1970's, the United States passed Public Law 93-366, the Air Transportation Security Act of 1974. At the international level, the International Civil Aviation Organization (ICAO) adopted Annex 17, Safeguarding International Civil Aviation Against Acts of Unlawful Interference, which became applicable in February, 1975. The number of hijackings briefly remained low, with two in 1976, but subsequently increased.

From January, 1977, to July, 1979, there were seventy-eight air carrier hijackings worldwide, twenty-four of which were of U.S. aircraft. The United States' share steadily increased from 16.6 percent of all hijackings in 1977, to 32 percent of those in 1978, to 47.8 percent of those in the first half of 1979; this two-and-one-half-year period saw more hijackings than the total occurring between 1972 and 1977. All these occurred while a record of more than 18,000 firearms confiscated at airport screening points and 6,400 related arrests showed the effectiveness of new airline passenger screening procedures. In the twenty-four U.S. hijackings that occurred during this period where the hijackers were processed through passenger screening, none actually had a real weapon or high explosive.

In 1980, twenty-one U.S.-registered airplanes were hijacked. In 1981 and 1982, there were fewer than ten hijackings each year, but in a sharp increase, eighteen occurred in 1983. Additional security measures were taken, followed once again by the steady decline. From 1984 to 1987, there were fewer than five hijackings per year, and only two in 1988.

At the end of the twentieth century, the vulnerability of civil aviation to the different forms of terrorist hijacking action was still a major concern. The geographic areas of

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greatest danger were Europe, the Middle East, and Central America. Within the United States, the anti-Castro and the Croatian and Serbian groups were most active. Although hijacking posed a serious threat to civil aviation throughout the world, terrorist activity was curtailed greatly in South America (the location of the first hijacking in aviation history), primarily due to successful paramilitary security, albeit at the expense of significant civil liberties.

On the morning of September 11, 2001, in what was immediately termed the worst act of terrorism in U.S. history, four commercial jetliners were hijacked by teams of terrorists and crashed into significant American buildings. Two airplanes were flown into New York City's World Trade Center, collapsing both of the center's towers. Another was crashed into the Pentagon, in Washington, D.C., collapsing part of that building. A fourth airplane crashed outside of Pittsburgh, Pennsylvania when passengers confronted the hijackers. In all, more than three thousand people died. Although no terrorist group immediately claimed responsibility for the crashes, all evidence pointed to the al-Qaeda terrorist network headed by Saudi billionaire and Islamic fundamentalist Osama bin Laden.

Who Hijacks and Why

Developing a profile of the typical hijacker and understanding the motivation for such an act provides the basis for trained observation to identify and deal with potential hijackers. One set of classifications identifies rational, psychological, or cultural hijackers. Another set of classifications determines whether hijackers are motivated by money, politics, or religion. A rational but dishonest thief with a financial motivation may be swayed by patient discussion, leading to a nonviolent conclusion to the extortion attempt. Both political and religious fanatics hold the greatest threat for an unsatisfactory outcome.

Criminal motives were a factor in 68 percent of the hijackings of U.S. airplanes from 1984 to 1988. Thirteen of the nineteen involved simple extortion, demands for the release of certain incarcerated prisoners, political asylum or repatriation, or flight from criminal prosecution. Of these thirteen, seven activists demanded to be repatriated back to Cuba. The next largest group, four of the nineteen, were determined by judicial authority to be mentally incompetent. Political terrorism accounted for 11 percent of the events between 1984 and 1988.

The hijackers were almost uniformly male; only one of them was a female. Three of the nineteen cases involved more than one hijacker. It was worrying that 47 percent of the hijackers had undergone preboard screening. Although the hijackers claimed to have knives, guns, explosives, incendiary devices, or a combination of these weapons in their possession, the claimed items were verified in only three of the nineteen instances.

The incidents of September 11, 2001, demonstrated the deadly evolution of hijackings. The nineteen terrorists, all men, were willing to die for their cause and to kill thousands in the process. No political demands were made.

Hijackings Outside the United States

Cases of foreign registry hijackings had the same decreasing frequency from a high in 1970. A total of seventy-four foreign-registered aircraft were hijacked from 1984 through 1988. One notable difference, however, was the prolonged duration of threat in terrorist hijackings. A significant example occurred in 1988. On April 5, Kuwaiti Airways Flight 422, en route from Bangkok to Kuwait, was seized. At least seven Middle Eastern men were involved, although the exact number was not verified. They demanded that the Kuwaiti government release seventeen other terrorists incarcerated for the 1983 bombing of government facilities as well as the U.S. and French embassies in Kuwait. The aircraft was diverted to Mashad, Iran, then to Larnaca, Cyprus, and Algiers, Algeria, over a sixteen-day period. Two Kuwaiti passengers were killed. It is believed that the hijackers were well-trained, organized individuals, conscious of the value of manipulating media coverage of the event.

Other motives in foreign cases vary from individuals fleeing authoritarian regimes or law enforcement agencies, to the mentally unstable, to people searching for better economic conditions. One person even sought the reunification of China through hijacking. The most popular area in the world for hijack activity was the Middle East (twenty-six of seventy-four hijackings), followed by Europe (twelve), and Latin America (nine).

With the outbreak of the Gulf War, many individuals feared there would be a widespread outbreak of terrorist crimes. For the first time ever, the entire U.S. National Airspace System was elevated to a Level 4 security status. Previously, the National Contingency Plan was not in effect, nor had its different security levels been established. Tightened security under the plan includes increasing law enforcement officer patrols, allowing only ticketed passengers and employees into boarding areas, eliminating curbside check-in, and denying passenger access to checked luggage. At O'Hare and Dallas/Fort Worth airports, all newspaper vending machines, trash receptacles, and ashtrays were even removed from the terminals. Companies warned their employees to take extra precautions, advising people to take nonstop flights from origin to destination and to avoid certain destinations altogether. Certain airlines known to be the focus of terrorists were to be avoided. Some companies canceled all but the most essential travel. Corporate and private business jets in the United States became popular as companies searched for travel options. Unfortunately, most airports had no budget for extended periods of sustained, high-level security measures and personnel.

Terrorism by definition is "the systematic use of terror, especially as a means of coercion." Unfortunately, effective terrorists want to make big headlines, which can be quickly accomplished when many people are killed or injured or held on an airplane for days. No matter how strict the security measures, it is probable that any terrorist could get a weapon into any airport, anywhere. There are no X-ray machines or any other means of detecting weapons at the entrances to the public areas of airports. Roving police officers have their attention focused on illegally parked vehicles at the curb, on vehicles trying to get to the curb, or on other distractions. Most people around the world share an unspoken but common assumption that hijacking cannot happen to them. This assumption may be unduly optimistic, but in the meantime, cautious security checks continue in an attempt to protect air travelers from hijackings and other acts of terrorism.

Although incidents of terrorism and bomb threats in aviation are few and far between, at the turn of the twenty-first century, threats of terrorism in the muslim world placed airlines and airports on a high state of alert from the Middle East to Europe as well as North America. The events of 2001 showed that the U.S. mainland was a very credible target as well. Iraq and Afghanistan became new breeding grounds for terrorist groups from the Middle East, who have often found hijacking to be an effective terrorist tool.

In December, 1999, Kashmiri hijackers commandeered a plane en route from Kathmandu, Nepal, to New Delhi, India, flying the plane to Amritsar, India; Lahore, Pakistan; Dubai, United Arab Emirates; and finally to Kandahar, Afghanistan. They demanded the release of political prisoners held in India, and killed one passenger who did not comply with their orders quickly enough. The other 154 passengers were eventually released after negotiation, but the hijackers' difficulty in finding a location where they could stop to negotiate illustrates the effectiveness of international treaties against hijacking and the reason why hijacking has become a less effective terrorist tool. Unfortunately, since it is no longer easy to hold a planeload of passengers hostage in order to make a political point, terrorists have turned their energies simply to bombing planes out of the sky or to crashing them, resulting in much higher death rates for passengers caught up in political turmoil.

Security Measures

On December 21, 1988, Pan American Flight 103 exploded over Lockerbie, Scotland, killing 270 people on the plane and 11 others on the ground. Investigation revealed that a plastic explosive, hidden in a portable radio in baggage in the cargo hold, had ripped the jet apart. The placement of the plastic explosive was linked to activities of the Abu Nidal group.

In response to findings of lax airport security leading up to the bombing of Pan American Flight 103, the General Accounting Office (GAO) testified in front of the Presidential Commission on Aviation Security. Four areas of major deficiency were outlined during testimony: passenger screening, airport security controls, security inspections, and airline training requirements for security personal, especially better training standards for overseas security personal. Furthermore, it was suggested that accountability for and oversight of airport security were made especially difficult by the division of responsibility among different organizations. The Federal Aviation Administration (FAA), despite its regulatory role, is not responsible for airport security in any direct way. This contrasts with the state of affairs in Europe, where even though security standards differ among countries, it is a common practice for governments, in their role of overseeing all aspects of aviation, to hire, staff, and operate airport security programs and equipment.

Firearms and other prohibited items continue to be found in large numbers at screening checkpoints. Of thirty-one attempts to hijack scheduled air carriers, none resulted from real firearms or explosive devices passing undetected through screening. In eleven cases, the hijackers either forced their way aboard or in another fashion avoided the normal passenger screening. In fifteen cases, the hijackers said that they had deadly weapons when in fact they had no weapons at all. However, the events of September 11, 2001, showed that knives can be equally dangerous. The hijackers killed crew and passengers with box cutters smuggled on board. As a result, knives of any length were banned on flights.

One security problem is unauthorized access to sensitive areas. Following the crash of a Pacific Southwest Airlines (PSA) flight in California on December 7, 1987, investigators found that there had been a breach of security screening when a former employee used one of six invalid airline photo-identity cards to bypass the passenger screening station at Los Angeles International Airport. He showed the ID card, smuggled a pistol aboard the plane, and shot the flight crew in an act of murder-suicide.

The incident pointed out some of the shortcomings of existing security procedures: poor accounting of identification badges, the need for increased security over points of access to aircraft, and lack of any method to identify and track personnel moving into and out of secured areas. A number of measures, including computer-based electronic card access control systems, eye retina scanners, digitized images or fingerprints, “voiceprints” and closed-circuit television cameras have been implemented to prevent unauthorized persons, including potential hijackers, from gaining access to aircraft. However, the FAA has made slow progress toward certification and installation of the advanced bomb detection equipment at U.S. airports.

In general, efforts to enhance security systems only occur after some specific incident attributable to lax security has occurred. One such reactive response to the Lockerbie tragedy was the FAA’s research into and employment of thermal neutron analysis (TNA) explosive detection systems at air terminals. The FAA is also interested in the X-ray computed tomography (CT) scanner as a second sensor to back up the TNA system. Another system receiving the attention of the FAA is the high-speed backscatter X-ray system, with automatic explosives screening capability, that can search for plastic explosives concealed in luggage. The system has been installed at Honolulu International, Los Angeles International, San Francisco International, and John F. Kennedy airports by Japan Airline Company.

The implementation of the March, 1979, revised federal aviation regulation (FAR) Part 107 governing airport security included the training of law enforcement officers in support of airport security programs and gathering explosives-detection K9 teams. The revision also provided that in certain instances, law enforcement officers supporting the passenger screening system can patrol in the public areas of terminals away from the screening checkpoints, thereby enabling them to provide broader deterrence to criminal acts of violence, while maintaining the capability of responding quickly to any need at the passenger screening points.

The revised rule also contained a total prohibition against unauthorized carriage of a firearm, explosive or incendiary device by persons when entering sterile areas or presenting themselves for inspection at established passenger-screening points. Prior to the revision, only the actual carriage of unauthorized weapons aboard an aircraft was prohibited by the FARs. The revised rule provides for a civil penalty of up to $1,000 and is intended to complement existing federal or local criminal sanctions. This revision strengthens the ability to deter hijackings by keeping weapons off airplanes. Security measures cost money, however, and airport operators are critical of the FAA mandating new programs without providing any funding mechanism for them. The costs of anti-hijacking measures must be passed along to consumers in the form of taxes added to the price of air travel tickets.

International Cooperation

The Bonn Declaration on Hijacking (1978) brought together seven heads of state who jointly committed to intensifying efforts to combat terrorism. The Declaration announced that when a country refuses to extradite or prosecute those who have hijacked an aircraft or if the country does not return the aircraft, the seven nations would initiate action to cease all flights to that country, to halt all incoming flights from that country or any country by airlines of the country concerned. Seven hijackings met the criteria that are covered by the Bonn Declaration.

ICAO, at its first European regional security seminar in Paris, contributed to the enhancement of civil aviation security and improved cooperation between states on a regional basis, including extensive programs to provide technical aid and training to African states.

At a meeting in Quito, Ecuador, in 1979, representatives from all North, Central, and South American states dedicated themselves to ensuring that civil aviation security requirements were diligently carried out. They all supported the International Criminal Police Organization (INTERPOL) General Assembly's resolution to encourage governments to prevent the use of their territories for criminal activity related to interference with civil aviation or as a refuge to avoid criminal prosecution for such acts.

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See also: Air carriers; Airport security; Commercial flight; Emergency procedures; Federal Aviation Administration; Gulf War; Safety issues; Terrorism

Hindenburg

Also known as: *Luftschiff* Zeppelin 129 (LZ-129)
Date: From March 4, 1936, to May 6, 1937
Definition: The largest rigid lighter-than-air passenger transport vehicle ever constructed.
Significance: Dirigibles were becoming an important means of overseas transportation when the *Hindenburg* exploded while docking at Lakehurst, New Jersey, eliminating any hope that this means of transoceanic travel might become widespread.

Germany and the Development of Dirigibles

Lighter-than-air flight began in Europe as early as 1783, when a cloth balloon filled with hot air carried several animals aloft in France. By 1898, European aviation pioneer Alberto Santos-Dumont had fashioned a cylindrical balloon that flew over Paris and the surrounding countryside powered by a motorcycle engine and steered by a rudder. This vehicle, however, carried only one person. By 1900, Count Ferdinand von Zeppelin had built a huge oblong aircraft with a cloth-covered steel frame inside of which were large bags of hydrogen that lifted the vehicle into the air. Several such aircraft, built by Zeppelin's company, Luftschiffbau Zeppelin, were built and were used to carry passengers on sightseeing trips across Germany.

In 1909, the world's first passenger airline, Deutsche Luftschiffahrts Aktien-Gesellschaft (Delag), was established. Its lighter-than-air fleet, consisting of the *Schwaben*, the *Victoria-Luise*, and the *Sachsen*, carried 37,250 passengers on sixteen hundred flights. During their 3,200 hours aloft, the airships covered more than 100,000 accident-free miles.

During World War I (1914-1918), the Germans used dirigibles for reconnaissance and for bombing missions over London. During the following decade, many civilian uses were found for dirigibles. Arctic explorer Roald Amundsen bought a dirigible, in which he flew over the North Pole, traveling the 3,180 miles from Spitsbergen, Norway, to Teller, Alaska, in about 71 hours.

By 1929, Germany had built the *Graf Zeppelin*, which carried twenty passengers on the first nonstop flight around the world. This feat marked the beginning of regular overseas passenger travel in lighter-than-air craft. At this time, it took at least five days to cross the Atlantic Ocean by steamship, and crossings were often rough during storms. In contrast, a dirigible, averaging 80 miles per hour, could make the transatlantic crossing in two and one-half days, floating like a cloud above turbulent seas.

When Adolf Hitler came to power in Germany during the mid-1930's, political storm clouds gathered over Europe. Hitler accomplished a tactical victory by luring the 1936 Olympic Games to Berlin. He conceived the idea of building the largest dirigible in the world, to be flown over the Olympic stadium during the games.

The project, referred to simply as *LZ-129*, was completed quickly. An 804-foot rigid frame of steel was covered with a superstrong, hand-stitched cotton fabric, and the ship's interior amenities were refined to the point that it unquestionably offered the most luxurious means of crossing the Atlantic. On March 4, 1936, German aeronaut Hugo Eckener took *LZ-129* on its maiden flight.

As Eckener hovered over Munich, the city's mayor radioed to ask him the name of the ship. He unhesitatingly responded with the name *Hindenburg*, after German field marshal and former president of Germany's Weimar Republic Paul von Hindenburg, who had died two years earlier. Joseph Goebbels, Germany's minister of propaganda, reprimanded Eckener severely for presuming to name the ship without authorization, telling him that the Reich had been planning to call it the *Adolf Hitler*. A change could not be made gracefully after Eckener's public statement, so the ship continued to be called the *Hindenburg*.

The *Hindenburg*'s Amenities

The luxurious *Hindenburg* was three and one-half times the length of a Boeing 747 and about the same length as the steamship *Titanic*. It was outfitted with extremely lightweight furniture, including a 397-pound aluminum piano. It had a lounge, a writing room, a smoking room, and a dining room, whose tables were set with exquisite floral arrangements, silver, and china. Lavish meals prepared by superb chefs issued forth from its kitchens. Banks of windows along the bottom portion of the aircraft provided dramatic vantage points from which to view the scene below.

The *Hindenburg*'s staterooms were small but efficient, with bunk beds and foldout tables and sinks. Originally the ship could accommodate fifty passengers, but with the success of the 1936 season, during which every stateroom was usually filled, the ship was modified to serve seventy-five passengers. The new staterooms, unlike the old ones, had windows that offered spectacular views.

The May 3, 1937, flight of the *Hindenburg* carried thirty-six passengers and a crew of sixty-one. Those who were traveling alone had staterooms to themselves. Above the passenger-crew areas of the ship were cavernous spaces that could carry up to 100 tons of cargo. These spaces contained bags of hydrogen, required to lift the craft, and water, used for ballast.

Because hydrogen is a highly explosive substance, every precaution was taken to prevent the hydrogen on board from being ignited accidentally. Crew and passengers wore slippers with felt soles. Matches and cigarette lighters were confiscated and later returned to debarking passengers. The smoking room contained only one lighter, secured by a chain, and the room was tightly sealed so that no sparks could escape.

Helium, another gas, which is not explosive, would have lifted the craft as well as hydrogen. Hydrogen, however, took up less space, permitting the *Hindenburg* to carry a larger payload. In addition, the United States, a major supplier of helium, was reluctant to sell this substance to Germany as it moved increasingly toward fascism.

The *Hindenburg*'s Fateful Landing

On Monday, May 3, 1937, the *Hindenburg* drifted from its moorings in Frankfurt at 7:30 P.M. to begin its first flight of the season from Germany to the United States. Although it had made ten trips to New York in 1936, in winter, when the North Atlantic was stormy, the *Hindenburg* flew the Frankfurt-to-Rio de Janiero route instead, resuming its North Atlantic flights when the weather improved. Eighteen flights to the United States were scheduled for 1937.

The *Hindenburg*'s May 3 flight was to have taken about thirty-six hours, with touchdown at Lakehurst, New Jersey, outside New York City, scheduled for the morning of Thursday, May 6. Headwinds across the Atlantic delayed the ship's arrival. By the time it flew over New York City, it was nearly twelve hours late.

The weather was bad, so even though the aircraft flew over Lakehurst, it did not land immediately. Rather, it flew down the coast toward Atlantic City, New Jersey, before circling back for its landing at Lakehurst, where it was awaited by a ground crew and people who had come to meet arriving family and friends.

As the ship inched toward its metal mooring at about 7:30 P.M., it dumped some of its water ballast to slow its descent, dousing some of the ground crew below. Those on the ground looked up at the gleaming ship with rapt expressions. Suddenly a thunderous noise shook the area, and the observers' expressions turned from joy to horror, as the ship trembled violently with reverberating explosions. As the hydrogen quickly ignited, fireballs engulfed the ship.

Chaos ruled as people on board, many with their clothing and hair on fire, jumped from the craft to the ground 100 feet below. Others, such as cabin boy Werner Franz, who, two weeks short of his fifteenth birthday, was the *Hindenburg*'s youngest crew member, were trapped. As

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fire rolled toward Franz from two directions, his situation seemed hopeless. Suddenly a ballast tank ruptured, immersing him in 2 tons of water. Soaking wet, Franz jumped from the inferno onto the ground, emerging with only minor injuries. He arrived home in Germany on May 22, his birthday.

In all, twenty-two of the *Hindenburg*'s crew of sixty-one died in the disaster, including Captain Ernst Lehmann who, although badly burned, had returned to the inferno in an attempt to rescue trapped passengers and crew. Twenty-three of the thirty-six passengers survived, although a number of them were severely injured.

Possible Causes of the Disaster

Following the *Hindenburg*'s destruction, speculation about its causes was widespread. Certainly the hydrogen used to lift the craft, once ignited, exploded to create a fire of great intensity. However, what caused the hydrogen to ignite remained a mystery.

Some experts believed that as the aircraft had flown through the electrical storms that had raged along its course, static electricity had collected on its exterior, so that when it made contact with its metal mooring, sparks flew and ignited the hydrogen, small quantities of which could already have been leaking. The U.S. Department of Commerce established a commission to probe into the cause of the explosion, but no firm conclusion was forthcoming from that commission. Among the possible causes mentioned were a ball of lightning, demon protons, static electricity, and St. Elmo's fire, a discharge of atmospheric electricity that commonly collects on aircraft flying in thunderstorms. However, eyewitnesses verified that the fire started inside the ship; if any of these possibilities been valid, the fire would have begun on the outside.

Given the strained relations between the United States and Hitler's Germany, the U.S. government wanted to prevent the disaster from escalating into an international incident. The official finding of the committee identified the disaster's cause as St. Elmo's fire, although in all of aviation history, no similar incident had ever been recorded.

In Germany, General Hermann Göring ordered the German commission investigating the explosion to "discover nothing." He officially declared the event an act of God, foreclosing further investigation.

Conspiracy Theories

Accidents such as the explosion of the *Hindenburg* often spawn conspiracy theories, which are sometimes given serious consideration. One cannot forget that Adolf Hitler, in promoting the development of the *Hindenburg*, sought to bring favorable attention both to Germany and to his despotic regime, in only its second year when the airship was conceived.

Germany had already planned to build other transoceanic dirigibles, and those opposed to Hitler did not want Germany to fulfill this dream. The destruction of the largest dirigible in the world would thwart plans for expanding Germany's lighter-than-air passenger service and would be a great personal blow to the country's dictator. Further, one must remember that threats had been made against the *Hindenburg*. Not long before its ill-fated trip, a bomb had been found in the dining salon of the *Graf Zeppelin* and was removed before it exploded.

Some conspiracy theorists noted that one of the passengers on board the *Hindenburg* had been Joseph Spah, a German who had fled the country as Hilter was coming to power, and who was an outspoken opponent of the Nazi government. Spah had been observed in restricted areas and explained his presence there by saying that he had wanted to visit his dog, who was being carried in the ship's hold.

Those doubting the conspiracy theories pointed out that if a passenger or crew member had sought to destroy the *Hindenburg* by planting a bomb somewhere aboard, that person would have had to die in the explosion. The counterargument to this objection is that a time bomb might have been hidden somewhere in the craft's vast superstructure with the intention of destroying the ship after it had landed. Because the *Hindenburg* arrived twelve hours behind schedule, such a bomb might have detonated just as the dirigible was landing.

R. Baird Shuman

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See also: Dirigibles; Lighter-than-air craft; Transatlantic flight; Ferdinand von Zeppelin

History of human flight

Definition: A series of developments that have allowed people to travel through the air in manufactured aircraft.

Significance: Since the earliest recorded history, people dreamed of flying, often ascribing the power to mythical gods. The airplane changed the world as has no other invention before or since by conquering the problem of distance.

Early Scientific Theories

Seventeenth century English physicist Sir Issac Newton postulated that heavier-than-air flight was impossible. Newtonian physics concluded that the resistance encountered by a wing would require an even heavier engine, which in turn would require an even larger wing, which would require an even heavier engine, and so on, in a circuitous conundrum.

The history of the science of human flight arguably began in 1680, when Italian physicist Giovanni Alfonso Borelli definitively proved that humans could not fly under their own power, because their pectoral muscles were simply too weak to support flight, regardless of the wing structures one might employ. That evidence should have ended tower jumping and flapping wing contraptions, but it did not. Some persisted, even into the twentieth century, in their preoccupation with the impossible. Others searched for less fatal alternatives, turning from flapping to floating.

Hot-Air and Hydrogen Balloons

An artist captured the supposed earliest recorded hot-air balloon demonstration, which was a small model, sent briefly aloft in 1709. Scientifically studying and documenting their efforts with pubic demonstrations, French brothers Joseph-Michel and Jacques-Étienne Montgolfier achieved the first true hot-air balloon ascents. On June 4, 1783, near Lyon, France, they demonstrated for the public their uncrewed aerostat, a huge linen bag lined with paper, 100 feet in circumference, which rose 6,000 feet aloft when a straw-fed fire heated the air inside the bag.

The Montgolfiers were not alone, however, in their quest for the sky. A series of scientific discoveries followed, and in 1766, hydrogen was discovered to be one-fourteenth the weight of air. French physicist Jacques-Alexander-César Charles created his own version of the aerostat, crafting a rubber-coated silk balloon filled with hydrogen, which he publicly demonstrated on August 24, 1783, before a large crowd which included the American diplomat and inventor Benjamin Franklin.

During this period, the field of aviation experienced many pioneering firsts. In a demonstration before French king Louis XVI and his wife Marie-Antoinette at Versailles in September, 1783, the Montgolfiers sent aloft aviation's first living voyagers: a rooster, a sheep, and a duck. The first crewed balloon flight came on October 15, 1783, with volunteer Jean-François Pilâtre de Rozier, a young doctor, on board. The original plan had been to send aloft two criminals from prison, in case they did not come down alive. However, Pilâtre de Rozier insisted on taking the place of the prisoners. On November 21, 1783, he and the marquis François d'Arlandes flew untethered across Paris. On December 1, 1783, the first crewed hydrogen balloon ascended with Charles and a passenger. After a lengthy two-hour, 27-mile flight, Charles set down, left off his passenger, and made a second flight, at sunset. With one less person aboard, the balloon rose to 9,000 feet, and Charles became the first person to see the sun set twice in one day.

With these first successes also came tragedy. The first to fly was also the first to die. Pilâtre de Rozier, in attempting to cross the English Channel on June 15, 1785, combined the hot-air-and-hydrogen balloon technology, putting a fire under a hydrogen balloon. The flight lasted only four minutes before exploding and killing its pilot.

Military use for the balloon was not far behind, starting a familiar sequence which would be repeated throughout history. In June, 1793, the French Republican government put observers in tethered balloons to report on enemy movements. In April, 1794, the French formed the first balloon corps, used in several European campaigns but disbanded by Napoleon in 1802.

Powered Flight

The matter of balloon steering remained unresolved until the twentieth century, when the elongated steerable dirigible was developed. At about the same time, the first powered airplane was invented. These near-simultaneous achievements were not serendipitous. Both enterprises depended on the same thing to succeed: a suitable engine to power the aircraft.

Although early engines were problematic, they held great promise. In 1876, German engineer Nikolaus August Otto designed and built the world's first practical internal combustion engine to use liquid petrol as fuel. In 1885, simultaneously and independently, German engineers Gottleib Daimler and Carl Benz built the first lightweight, high-speed petrol engines.

Gliders and Winged Flight

Although Orville and Wilbur Wright's secret to success in achieving the first powered flight was the engine they designed and built themselves, the two brothers researched, designed, tested, and built the plane, propellers, and control surfaces and structures that ultimately helped them to succeed. They systematically and scientifically studied the work of early glider pioneers, most notably that of the British Sir George Cayley, known as the father of aeronautics.

In 1804, Cayley had built the first known heavier-than-air flying model. Over the next fifty years, he built three full-scale gliders capable of flight with a passenger on board. In 1871, the wind tunnel was invented to enable the aerodynamic study of scale models. The Wrights perfected their own wind tunnel and used it systematically to study and perfect their wing and propeller designs. Their scientific approach enabled them to succeed where others had failed.

Another glider great, the German aviation pioneer Otto Lilienthal, developed and flew controllable gliders, working from 1891 until his death in 1896 while attempting a powered glide. He tested his gliders by leaping from an enormous hill he had built near Berlin. The Wrights, too, began by experimenting with gliders.

Still others would play a role in the Wright's story by disseminating information. Octave Chanute was a French-American engineer credited with building the first bridge across the Missouri River and the stockyards in Chicago and Kansas City. Bored with engineering for trains and livestock, he turned his attention to aeronautics. In 1894 he published *Progress in Flying Machines*, which collected and summarized the information humans had learned to date about heavier-than-air flying machines. On May 13, 1900, Wilbur Wright wrote to Chanute to introduce himself and inquire about available information that would assist the Wrights' experimentation.

The Wrights had learned of Chanute after having written the Smithsonian Institution seeking information on flying. They learned that Samuel Pierpont Langley, the director of the Smithsonian, was experimenting with heavier-than-air flight. Langley had received the first federal government contracts to build a powered human-carrying plane, but both his attempts, with planes launched from atop a houseboat in the Potomac River, were failures. He gave up in disappointment, most of his calculations proven embarrassingly incorrect when, one week later, he was beaten by the Wrights in the race to fly.

The Wright Brothers' Achievement

It is almost impossible to overstate the significance of the Wrights' accomplishment. Through careful study and diligent testing, they unlocked the secret to controlled flight. By wing warping, or twisting, they could cause the plane to turn. This mechanism was the forerunner of the aileron on modern planes. The Wrights systematically studied aspect ratios, comparing the wing's length to its width, and devising tables to decide on the most suitable wing sizes and shapes. They researched propellers in their wind tunnels, understanding that the propeller was a rotary wing with forward lift. They defeated torque by using two propellers rotating in opposite directions, connected to sprockets by a bicycle chain. When they could find no satisfactory engine, they designed and built their own.

At their testing grounds at Kitty Hawk, North Carolina, on December 17, 1903, at 10:35 A.M., the Wright brothers made their first flight, with Orville at the controls, and Wilbur running alongside him. Orville had positioned a camera before the flight, and John T. Daniels, a volunteer helper who had run up from the Kill Devil Hill Life Saving Station, snapped the picture of the first powered, sustained flight by humankind. The Wrights made four flights that day. The longest, with Wilbur at the controls, lasted 59 seconds and covered 852 feet.

In many ways the most important part of the history of flight was over on the day it began. The scant one hundred years in the history of human flight show astonishing discovery and achievement, but in reality, much remains exactly as it was researched and recorded in the Wrights' early records. In the next two years, the Wrights built more airplanes and made more discoveries about piloting them: how to control, turn, and avoid stalls. In January, 1906, the Wrights offered to sell their plane to the U.S. War Department, which declined. In 1907, they took their plane to Europe, seeking in vain to find a buyer overseas. The Wrights left their airplane stored in a shed in Europe and returned, dejected, to Dayton.

In 1908, however, the British Army acquired the Wrights' aeroplane number 1 and the U.S. Army agreed to pay the Wrights $25,000 for one of their airplanes. A French group agreed to pay $100,000. Wilbur went to France, got the plane out of the shed and upgraded it with some recent advancements.

To fulfill the U.S. government contract, Orville went to Fort Myer to test-fly the airplanes. Tragedy struck on the last day of the test flights, and a twenty-six-year-old lieutenant, Thomas Selfridge, became the first person to lose his life in an airplane accident.

Thereafter, the aviation firsts came in rapid succession. In 1909, French aviator Louis Blériot flew across the English Channel in a self-built monoplane. The public's fascination with aviation was fueled by air meets that occurred on both sides of the Atlantic Ocean. By 1910, there were nighttime takeoffs, makeshift lighted beacons and runways, stunt flying, and the first takeoff from a ship deck. The next few years brought ship-deck landings, the first U.S. transcontinental flights, the crossing of the Mediterranean and the establishment of the British Royal Flying Corps. With heavy initial losses and little early success, the U.S. Signal Corps was also established.

Airplanes as Warplanes

On June 28, 1914, Europe was thrown into World War I. At the start of the war, there were 1,200 German planes, and 1,000 French and British planes. On April 6, 1917, the United States entered World War I, and a U.S. military aviation section was established. Although 1,000 men enlisted, fewer than 250 planes were amassed.

Fighter planes and their pilots would earn fame and affection during World War I. Eddie Rickenbacker of Columbus, Ohio, who later helped found Eastern Air Lines, was the top U.S. ace, and also flew for France with the U.S. volunteer group, the Lafayette Escadrille. General William "Billy" Mitchell, returned home in 1919 from his European service advocating an independent U.S. air power. He predicted the attack on Pearl Harbor decades before its occurrence and forced the U.S. government to examine what had happened to money appropriated by Congress for World War I fighter planes that were never delivered. Justice Department investigations and Congressional hearings were held, but eventually Congress tired of the issue and agreed not to pursue the matter further.

Aviation in the Interwar Years

After the war was over, airplane travel offered a way around the war's destruction and devastation, and, in combination with ground transportation, allowed access to far-flung colonial outposts. European governments directly subsidized the development of commercial air carriers, such as KLM, Lufthansa, British Airways, and Air France.

The U.S. government, in contrast, opposed direct subsidies for the development of commercial air carriers, but instead used U.S. airmail contracts to establish and subsidize the aviation industry. In 1925, air mail was privatized, and wealthy American industrialists snapped up the first contracts. As aircraft improvements were made and more reliable engines were developed, navigational aids helped to make flying a more certain venture. In 1926, government regulation and certification of pilots, aircraft, air traffic rules, maps, weather reports, and accident investigation aided the private air carriers by improving the safety, efficiency, economics, and reputation of flying.

American fliers and planes soon established their worldwide dominance in the field of aviation. The first around-the-world flight was accomplished by Douglas Aircraft World Cruisers, manufactured in Santa Monica, California. Four Cruisers departed Seattle, Washington, on April 6, 1924, and two Cruisers returned to the same spot 27,553 miles and 175 days later, on September 28. Seven years later, a similar feat was accomplished in just eight days, when American aviator Wiley Post circumnavigated the globe.

In May, 1927, Charles A. Lindbergh, flying from New York to Paris, became the first pilot to make a solo transatlantic crossing. He was immediately lauded as a hero and remains among the most famous fliers in history. Lindbergh would go on to devote his life to the promotion of both civil and military aviation. In 1932, Amelia Earhart crossed the Atlantic solo, and fame followed her flight. She was lost in 1937, attempting to circumnavigate the globe via the 27,000-mile equator route.

The record-setting flights of the 1920's and 1930's bear witness to the fact that during this period, planes were undergoing dramatic technical improvements. No airplane before or since has captivated the world, or its aircraft sales, as did the Douglas DC-3. Still the most successful transport plane ever, with 10,926 manufactured in the United States, and perhaps as many as 5,000 more manufactured overseas by other countries, the twin-engine DC-3, also known as the Gooney Bird, Dakota, or Skytrain, along with the DC-4, also known as the Skymaster, with double the DC-3's engines, passenger capacity, and range, revolutionized air transportation.

Alternate Methods of Flight

Other methods of human flight rose, or fell, in the 1920's and 1930's. In 1926, American physicist Robert H. Goddard demonstrated the liquid fuel rocket. In 1936, the first truly successful helicopter, the Focke-Wulf, was developed in Germany. In 1937, British engineer Sir Frank Whittle established the world's first turbojet engine development program. Zeppelin airships, two and one-half times the length of a football field, were first launched in 1909 and began commercial service in 1911. Zeppelins provided the world's first passenger airline service. On May 6, 1937, the world's largest airship, the hydrogen-filled *Hindenberg*, exploded while approaching moorings in New Jersey, after completing a trip from Germany. Although lives had been lost in zeppelin travel until the *Hindenberg* disaster, the loss of the airship, captured on film and rebroadcast worldwide, ended the era of the airship, a scant thirty years into its history. Today, the sight of a helium-filled blimp overhead is a rare occurrence usually confined to the airspace over sporting events.

World War II

As the 1930's drew to a close, war again loomed in Europe and Asia. In 1932, Japan employed aircraft carriers in conflicts with China. In 1935, Italy used air forces to invade Ethiopia. In 1936, the nation sent air forces to aid General Francisco Franco in the Spanish Civil War, as did Germany, which had sent troops to Italy for secret pilot training. By 1938, Germany had reached wartime levels of airplane production. The Soviet Union sent planes to Spain to help defend against Franco's forces. In 1939, the Soviet Union aided China against Japan, as did the United States, with its American Volunteer Group, also known as the Flying Tigers.

On September 1, 1939, German chancellor Adolf Hitler invaded Poland. The Luftwaffe, the German air force, struck the Polish airfields, taking out most of Poland's planes. In 1940, Denmark, the Netherlands, Belgium, and France fell to the Germans. Beginning on September 7, 1940, Hitler's Luftwaffe commenced nightly bombing of London. Aided in part by radar warning stations, London and Britain held, and Hitler turned his attention elsewhere when he failed to achieve control of the air in the Battle of Britain. In 1941, Hitler invaded the Soviet Union. Although the Soviets suffered significant casualties and the loss of 8,000 planes, the German planes could not reach the Soviet aircraft factories, and the Soviets kept building.

In the United States, airplane production had been dramatically increasing throughout the late 1930's. In 1938, airplane production was increased to 10,000 units per year.

On December 7, 1941, the Japanese attacked Pearl Harbor, Hawaii, much as Billy Mitchell had predicted. In rapid succession, the Philippines, Hong Kong, Singapore, Malaya, the Dutch East Indies, Borneo, and Burma fell to the Japanese. In 1942, American bomber groups were deployed over Tokyo, Europe, and Africa. In 1943, the Eighth Air Force began attacks on Germany, and the Fifteenth Air Force began attacks on Italy. By 1944, U.S. aircraft manufacturers had produced 96,318 planes in one year. On May 7, 1945, Germany surrendered, even though it had developed formidable new weapons in the V-1 pilotless bomber jet and the V-2 missile, with a 2,000-pound warhead, a range of 220 miles, and a speed of up to 3,600 miles per hour.

Meanwhile, the air war raged on in the Pacific. The United States continued its strategic bombing of Japan with B-29 aircraft. The threat posed by Japanese kamikaze suicide bombers increased, as it surfaced that Japan intended to use the majority of its remaining planes as kamikazes. The decision was made to use the atomic bomb on Japan. On August 6, 1945, the first bomb was dropped on the city of Hiroshima, and a second was dropped on Nagasaki on August 9. Within six days, Japan had surrendered.

Berlin Airlift

After World War II, Germany was literally divided in two. East Germany was walled off by the Soviet Union and placed under a Communist government. West Germany was free and protected by U.S. forces. Landlocked within East Germany was the city of Berlin, half of which was not under Communist control and was protected by the U.S. and its allies. In 1948 and 1949, the United States airlifted food and supplies into Berlin, using Douglas C-47 and C-54 aircraft, in what was at the time the largest humanitarian effort in history.

An Independent U.S. Air Force

Following World War II, the United States altered its development and use of military aircraft. In 1947, the Army Air Corps became the newest branch of the armed forces, and the U.S. Air Force and the Central Intelligence Agency (CIA) were created. These two acts were not independent. The CIA, the Air Force, and private aerospace contractors worked together to develop new aircraft and intelligence technologies. One such facility, Lockheed Corporation's secret development division was dubbed the "Skunk Works," and its projects were so classified that they did not appear even in federal budgets. In 1947, a military plane broke the sound barrier.

The Cold War

Although World War II had ended, the Cold War took its place. A handful of the world's most powerful nations possessed the capability to make and deploy nuclear weapons. The United States and the Soviet Union, former World War II allies, both developed intercontinental ballistic missiles (ICBMs) capable of attacking the other nation when launched from home soil. The deterrent effect of these weapons was called mutual assured destruction (MAD). The destructive capabilities and the distrust between the two superpowers spurred the space race, as well as military actions in other parts of the world.

The Korean War

On June 25, 1950, Communist North Korea crossed the thirty-eighth parallel, invading free South Korea. The Soviet Union aided North Korea, and the United States helped to defend South Korea. November, 1950, saw the world's first all-jet air battle between a Soviet MiG and a U.S. F-80 Shooting Star. Later, the U.S. F-86 Sabre jet would prove an even tougher opponent against the MiGs. On July 27, 1953, an uneasy armistice was signed, but difficulties persisted, and U.S. forces continued to help defend the peace.

The Jet Age

In the 1950's civil aviation also entered the jet age. In May, 1952, the British De Havilland Comet commenced passenger service. Soon after entering service, three such planes seemingly came apart in midflight. By April, 1954, the plane was grounded, and the American Douglas DC-8 and the Boeing 707 came to dominate the world's jet passenger airline market, giving their manufacturers the lead in the industry for years, until a European consortium was formed in 1970 to manufacture the Airbus aircraft.

The Space Age

The Soviet Union led the early space race, with a series of firsts. In 1957, the Soviet Union sent Sputnik, the world's first Earth-orbiting satellite, into space. In 1961, the Soviet cosmonaut Yuri Gagarin became the first human in space with his Earth-orbiting mission Vostok 1. The United States followed shortly thereafter with Alan Shepard, Virgil "Gus" Grissom, and John Glenn.

In the early 1960's international attention and tensions were also riveted by the work of American spy planes when the Soviets shot down an American U-2 plane and captured its pilot, Gary Powers, and spy plane photographs revealed Soviet movement to put missiles on Cuba, within range of the United States.

The Vietnam War

Events in Southeast Asia during the 1950's and 1960's involved the United States in another war and again tested the nation's air power. While trying to stabilize a tenuous political situation between North and South Vietnam, the United States was drawn into a police action that would occupy two presidents and divide the American people. The Vietnam War was called the first television war, with fighting broadcast on the nightly news.

Memorable Events in Flight

Many people claim there are events in history that are so important that every person who was alive and sentient can remember exactly where they were and what they were doing when it happened. One such event was the assassination of President John F. Kennedy on November 22, 1963. Another three involve human flight. On July 20, 1969, the *Eagle* lunar landing craft set down on the surface of Moon, where U.S. astronauts Neil Armstrong and Edwin "Buzz" Aldrin left footprints and an American flag. Another such event is the January 28, 1986, explosion of the space shuttle *Challenger*, which killed seven astronauts, including Christa McAuliffe, the first teacher in space. The third day is September 11, 2001, when four hijackings resulted in the deaths of almost five thousand people at the World Trade Center and the Pentagon.

Operation Desert Storm

By 1991, when Americans would watch another war on television, aviation had evolved significantly from the time of the Vietnam War. During the Gulf War, missile-mounted cameras delivered photographic images while delivering bombs with exactitude measurable in inches, without risking American fliers. Global Positioning System (GPS) satellites had been placed in orbit and delivered with inexpensive handheld units target exactitude. One-half million American military personnel and the armament and equipment to support them were delivered to the other side of the world. The war was over within days. For the first time since the invention of the airplane, there was a war with no aces.

Highway in the Sky

The technology revealed in Operation Desert Storm helped to revolutionize the world of civilian aviation throughout the late twentieth century. The U.S. air traffic control (ATC) system had been pinning its hopes on a new microwave landing system, which was scrapped in favor of the astonishingly accurate GPS system. Computer flight control and navigation technology was adapted for affordable installation in small general aviation and personal aircraft, delivering military precision and failsafe computer systems for private pilots.

The ability to wage war without legions of pilots convinced the U.S. Joint Chiefs of Staff that the military should develop uninhabited aerial vehicles (UAVs) for both intelligence and weapons delivery. Lightweight and quiet jet engines and lightweight but strong composite flight structures were developed for the job. The military was not alone in realizing the value to human flight of such engines and materials.

In 1977, one of the oldest obstacles to human flight was finally overcome, when *Gossamer Condor*, powered by pedals, made the first human-powered flight. Its designer had worked with extremely lightweight but strong materials, as had Jeana Yeager and Dick Rutan in piloting the *Voyager*, which in 1986 became the first plane to make a nonstop transglobal flight without refueling. The 1903 Wright *Flyer* and the 1988 *Voyager* sit side by side at the National Air and Space Museum, awaiting the next addition in the history of human flight.

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See also: Air carriers; Apollo Program; Balloons; Commercial flight; Gulf War; *Hindenburg*; Human-powered flight; Korean War; Lighter-than-air craft; Manufacturers; Military flight; Billy Mitchell; Montgolfier brothers; Propellers; Burt Rutan; Space shuttle; Spaceflight; Uninhabited Aerial Vehicles; Vietnam War; Wing designs; World War I; World War II; Wright brothers; Wright *Flyer*

Hornet

Also known as: F/A-18, XF-17 Cobra

Date: First flight of XF-17 Cobra, 1974; first flight of F/A-18A, 1983; first flight of F/A-18C, 1987; first flight of F/A-18E, 1995

Definition: A fighter and attack aircraft that represents one of the first truly multirole military aircraft.

Significance: The Hornet represents the cornerstone of current and future U.S. Navy and Marine Corps air power.

Development

One of the most successful combat aircraft in history, the F/A-18 Hornet finds its orgins in the failure of another aircraft, its precursor, the Cobra. Designed by the Northrop Corporation in the late 1960's, the Cobra was a lightweight, multimission aircraft offered to the air forces of smaller nations that could not afford large numbers of separately dedicated fighter and attack aircraft.

Although the Cobra was a capable aircraft, it found no takers. However, an opportunity emerged in the early 1970's, when the U.S. Air Force solicited proposals for a lightweight fighter design. Air Force fighters of the early 1960's, such as the F-4 Phantom II, relied on long-range missiles as their primary armament. During the Vietnam War, however, the Air Force found itself engaging smaller, more agile Soviet-built fighters in close-combat situations, in which the pilots of the U.S. aircraft could not use their missiles and had difficulty outmaneuvering their smaller adversaries.

The purpose of the new aircraft design search was to reverse the trend of increasingly larger and more expensive aircraft. The Air Force planned to build hundreds of the lightweight fighters to counter the Soviet threat to Western Europe at the height of the Cold War. In January, 1972, the Air Force opened the Lightweight Fighter Program (LFP) by soliciting design bids from various aircraft producers. Northrop responded with an updated version of the Cobra, labeled the YF-17. A year later, the Air Force selected the YF-17 and an offering from General Dynamics, the YF-16, for prototype production, and both aircraft flew in 1974.

The two designs had significant differences. The Northrop aircraft featured two smaller engines with twin vertical tails, whereas the General Dynamics craft had a single large engine and a single tail fin. The YF-16 carried a limited armament of short-range air-to-air missiles and an internal 20-millimeter cannon. In comparison, the YF-17 carried the same weaponry, but also featured advanced radar capable of guiding medium-range air-to-air missiles. Despite meeting all of the flight requirements and possessing a greater range of weapons, the YF-17 lost the competition to the less expensive YF-16 in 1975.

This defeat was not the end of the Cobra, however. By 1975, the U.S. Navy had opened its Carrier Fighter and Attack, Experimental (VFAX) competition to find a new strike fighter for its aircraft carriers. The new Navy aircraft, in replacing two different aircraft, would have to perform multiple tasks in limited carrier deck space. The Navy wanted the new airplane to replace the F-4 Phantom II, an air-defense fighter with a secondary attack capability, and the A-7 Corsair II, a dedicated light attack aircraft. Northrop gained the upper hand in the VFAX competition by teaming with McDonnell Douglas Corporation, a company with a long history of building carrier aircraft for the Navy. Northrop and McDonnell Douglas adapted the original land-based Cobra design into a that of a carrier-based strike fighter, adopting the new designation XF-18 Hornet to signify the emergence of a new plane from the XF-17 Cobra. With McDonnell Douglas now acting as the lead company in the aircraft's development, the Navy selected the XF-18 Hornet as its VFAX winner in 1976. Final design work proceeded, and the single-seat F/A-18A and two-seat F/A-18B became operational in 1983.

The redesigned Hornet immediately proved its worth. The Navy had originally intended to produce separate versions of the Hornet in F-18 fighter and A-18 attack models. The advanced radar originally installed for the LFP, however, proved capable of handling both missions, and separate variants never emerged. As a multimission aircraft, the Hornet became the only airplane with the F/A designation, symbolizing its dual role of air defense and attack.

In 1987, the Navy took delivery of its first improved Hornets, the single-seat F/A-18C and the two-seat F/A-18D, with provisions for Maverick air-to-surface missiles, AMRAAM air-to-air missiles, and advanced avionics for night flying. The popularity of the Hornet eventually led the Navy's precision-flying team, the Blue Angels, to adopt the agile aircraft in 1986. The Hornet's multimission capability attracted several other buyers; the U.S. Marine Corps replaced its F-4 Phantoms, A-4 Skyhawks, and A-6 Intruders with the Hornet. The Hornet is also employed by the air forces of Australia, Canada, Finland, Kuwait, Malaysia, Spain, and Switzerland.

Use

The Hornet F/A-18 boasts an excellent combat record. It first entered combat in 1986, when the United States

F/A-18 Hornet Characteristics

	F/A-18C, F/A-18D	*F/A-18E, F/A-18F*
Primary Function	Multirole attack and fighter aircraft	Multirole attack and fighter aircraft
Builder	McDonnell Douglas (prime), Northrop (major subcontractor)	McDonnell Douglas
Unit Cost	$24 million	$35 million
Propulsion	Two F404-GE-402 enhanced performance turbofan engines	Two F414-GE-400 turbofan engines
Thrust per Engine (pounds static thrust)	17,700	22,000
Length (feet)	56	60.3
Height (feet)	15.3	16
Maximum Takeoff Gross Weight (pounds)	51,900	66,000
Wingspan (feet)	40.4	44.9
Ceiling (feet)	50,000+	50,000+
Speed	Mach 1.7+	Mach 1.8+
Crew	C model, 1; D model, 2	E model, 1; F model, 2
Armament	One M61A1/A2 Vulcan 20-millimeter cannon	One M61A1/A2 Vulcan 20-millimeter cannon
External Payload	AIM 9 Sidewinder, AIM 7 Sparrow, AIM-120 AMRAAM, Harpoon, HARM, Shrike, SLAM, SLAM-ER, Walleye, and Maverick missiles; Joint Stand-Off Weapon; Joint Direct Attack Munition; various general-purpose bombs, mines, and rockets	AIM 9 Sidewinder, AIM 7 Sparrow, AIM-120 AMRAAM, Harpoon, HARM, Shrike, SLAM, SLAM-ER, Walleye, and Maverick missiles; Joint Stand-Off Weapon; Joint Direct Attack Munition; various general-purpose bombs, mines, and rockets
Date Deployed	November, 1978 (first flight)	December, 1995 (first flight)

Source: Data taken from (www.chinfo.navy.mil/navpalib/factfile/aircraft/air-fa18.html), November 6, 2001.

bombed the North African country of Libya in retaliation for that nation's support of terrorist organizations and the bombing deaths of U.S. citizens. In support of the air raids, Hornets from the USS *Coral Sea* destroyed Libyan air defense sites with HARM antiradar missiles.

Hornets also participated in Operation Desert Storm, the 1990-1991 military campaing to end Iraqi occupation of its neighboring nation, Kuwait. In this conflict, the Hornet's flexibility proved to be its biggest asset. F/A-18's destroyed Iraqi patrol boats that threatened Allied ships with antiship missiles, provided air defense for coalition forces, and bombed Iraqi targets in support of the ground offensive. The best example of the F/A-18's flexibility during the Gulf War happened when two Hornets on a bombing mission came under attack from two Iraqi fighters. Without dropping their bombs, the Hornet pilots switched their radars to air defense mode, shot down the Iraqi aircraft, switched their radars back to ground attack, and finished their bombing run.

The Hornet continues to receive upgrades that will keep it in service for years to come. In 1995, the prototype F/A-18E Super Hornet made its first flight. Designed to replace U.S. Navy A-6 Intruders and F-14 Tomcats, the Super Hornet is 25 percent larger than earlier F/A-18's, with a corresponding increase in capability.

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See also: Air force, U.S.; Aircraft carriers; Eagle; Fighter pilots; Gulf War; Marine pilots, U.S.; McDonnell Douglas; Navy pilots, U.S.; Tomcat; Vietnam War

Hot-air balloons

Date: First crewed free flight on November 21, 1783

Definition: Large round inflatable sacks filled with hot air that rise above the ground, towing compartments for passengers or cargo.

Significance: The hot-air balloon ushered in the age of human flight by providing a means for people to leave the earth and rise to significant heights for sustained periods. This lighter-than-air craft also proved that air was still breathable and life sustaining at higher altitudes.

Early History

Hot-air balloons inaugurated the concept of human flight. The hot-air balloon proved for the first time that a human being could survive at some height above the earth. This was a notable scientific achievement, since prior to the advent of balloons many people had no clear understanding of how high the breathable atmosphere extended. With the advent of the balloon, the dream of leaving the confines of the earth was realized. This was the dawn of a new era, the preamble to the space age.

Two French brothers, Joseph-Michel and Jacques-Étienne Montgolfier, invented the hot-air balloon in 1783. Their inspiration was the observation that a paper bag placed over an indoor smoking fire rose in the air. As a test, they lined a large cloth bag with paper and caused it to rise by filling it with black smoke and hot air from an outdoor straw fire. Later, the Montgolfiers sent animals aloft first on tethered balloons and then on a free flight in order to prove that the animals could survive above the earth. They succeeded: The animals lived. After the free flight, King Louis XVI of France was persuaded to allow the required permission for humans to attempt a test flight. With approval, two other Frenchmen, Jean-François Pilâtre de Rozier and the Marquis François-Laurent d'Arlandes, made the first human free-flight balloon ascent on November 21, 1783. In a 70-foot-high, 46-foot-diameter Montgolfier balloon, they flew for 25 minutes, traveling for several miles over the city of Paris. The balloon carried its own grated fire pot, to which the pilots frequently added straw. Although the pilots had to extinguish small fires when parts of the balloon's flimsy material ignited from sparks, they landed safely. This flight was witnessed by thousands of Parisians. The second human free-flight balloon ascension was made by Professor Jacques Alexandre César Charles and a passenger on December 1, 1783, in a hydrogen-filled balloon.

Hydrogen-filled balloons, filled with dangerously combustible gas, nevertheless had the advantage of requiring only one-third the gas volume of hot-air balloons for the same buoyancy. The larger hot-air balloons were more difficult to handle and transport. The risk of balloon material igniting from the sparks of open fires made them hazardous, and smoke from the fire choked the riders. Flight time was limited by the fuel supply. In contrast, the hydrogen balloon was well suited to long-term scientific and military observation. Its gas was not expelled until a descent was desired. For these reasons, hot-air balloons became rare during the years between 1800 and 1960, while hydrogen types flourished.

Twentieth Century

A rebirth of hot-air ballooning occurred on October 10, 1960, in Bruning, Nebraska, when an American, Ed Yost, performed a free-flight test in his prototype balloon. His new design featured a polyurethane-coated nylon envelope and a propane-powered burner. This system was much safer and more rugged than that of the previous era. In 1963, Yost and a partner, Don Piccard, traveled to Britain and made the first English Channel crossing by hot-air balloon.

By the 1970's, hot-air balloon manufacturers had flourished in the United States, Britain, and France. A hot-air balloon could be obtained for the price of an expensive motorcycle, thus bringing it within the budget of many sports enthusiasts. Many balloonists started businesses offering one-hour chartered flights for one hundred dollars.

High cost and adventurous record-breaking attempts also continued in the twentieth century. Bertrand Piccard and Brian Jones achieved the first nonstop circumnavigation of the globe in March, 1999, in a combination hot-air-and-helium balloon. They launched their *Breitling Orbiter 3* from Switzerland, traveled around the world in twenty days, and landed in Egypt.

Construction

The main parts of a modern hot-air balloon are the envelope, the burner-fuel system, and the basket. The envelope is the bag, or air sack, containing hot air. It is constructed of pieces of fabric, usually nylon. Each slice of fabric, called a gore, consists of panels and stretches from the top to the bottom of the balloon. Forming the gores in specific dimensions determines the overall shape of the balloon. Round, oblong, and special shapes such as those of a piggy bank, a soda can, and even Mickey Mouse have been constructed, often for advertising.

The envelope top, or crown, is constructed with a parachute valve, a piece of fabric in the shape of a parachute. It is attached in such a manner that a section can be pulled away when a pilot pulls a connected cord. This action releases some of the hot air through the top of the balloon, reduces the overall inside air temperature, and causes the balloon to descend. At the base, which is open, there is usually a short, cylindrical fabric section called the skirt. It is coated with fire-resistant material, because it is close to the flame. The burner is mounted in a frame attached between the basket and the skirt.

Propane from a tank is ignited by the burner's pilot light. An on-off valve allows the pilot to control fuel flow. The amount of fuel available determines the amount of time the balloon can stay aloft. Baskets, which usually hold from two to five people in addition to propane fuel tanks, are still made of wicker because the shock-absorbent material helps provide a soft landing for passengers and pilots.

Use

In the United States, hot-air balloons must be registered with the Federal Aviation Administration (FAA). Pilots are certified in one of three classes: student, private, or commercial. Hot-air balloons lift off by inflating their containing envelope with heated air. Because hot air expands, the heated air becomes lighter than the ambient, cooler surrounding air, which pushes upward against the air bag and provides the lift necessary for flight. Within the envelope, the heated, lighter air rises and displaces the cooler, heavier air, which descends.

Prior to launch, the pilot checks weather conditions for local winds and any possible storm indications. Storms are hazardous for several reasons: Lightning strikes can electrocute people and damage the balloon; rain, hail, or snow can cause damage, present visibility problems, and make the balloon heavier; and high wind makes launching and landing dangerous. To check the weather conditions, a pilot can either consult a weather service or go to the launch site and send up a small party-size helium balloon. From the balloon's changing position as it ascends, the pilot can gauge both the speed and the direction of the wind.

Because the air inside the envelope of a hot-air balloon is lighter than the air outside, the relative pressure is upward, and air does not pour out of the open-ended base. To prepare for launching, the deflated envelope is laid out on the ground, then the gas-fired burner is posi-

Milestones in Hot-Air Ballooning

November 21, 1783: De Rozier and d'Arlandes make the first crewed free flight, in Paris, France, in a Montgolfier hot-air balloon.

June 15, 1785: De Rozier and a companion fall to their deaths after a hybrid hot-air-and-hydrogen balloon ignites over the English Channel, becoming hot-air ballooning's first fatalities.

1800-1960: Hot-air ballooning experiences a low-activity period as hydrogren-filled balloons increase in popularity.

October 10, 1960: Ed Yost, of Bruning, Nebraska, reintroduces a newly designed hot-air balloon, initiating a renaissance in hot-air ballooning.

January 17, 1991: Richard Branson and Per Lindstrand make the first hot-air transpacific flight, in the largest hot-air balloon flown.

March 20, 1999: Bertrand Piccard and Brian Jones make the first nonstop global circumnavigation, in a hybrid hot-air and helium balloon.

tioned to force heated air into the envelope opening. Another method uses a powerful fan to initially provide a partial cold-air inflation. The balloon, as it inflates, gradually rises from horizontal to vertical. The balloon basket is anchored to prevent a gust of wind from blowing the balloon away prior to launch. The ground crew also holds the basket down until pilot and passengers are ready to launch.

Once the balloon is fully inflated, more lift can be generated by continuing to heat the air within it. When the lift of the heated air is greater than the total weight of the balloon, basket, equipment, and occupants, the balloon rises. Just prior to this point, all tie-lines are released, and the crew releases the basket. The pilot fires the burner again, and the balloon lifts off. Whenever the burner is turned off, the air in the bag gradually cools, and the balloon slowly descends. Neither the heating nor the cooling causes an instant effect. There is a thermal time lag, usually of a half-minute or more, due to the large amount of air to heat or cool. To maintain one particular altitude, the pilot periodically turns the burner on and off. If the pilot is skilled, the balloon will neither rise nor fall to any appreciable degree during this operation. In addition to keeping the burner off, the pilot can also cause a descent by momentarily opening the parachute valve and allowing some of the hot air to escape.

Because a hot-air balloon has no propulsion system, the horizontal direction and speed of the balloon are determined by the prevailing winds. Riding with the wind, passengers feel no wind except for gusts. Winds generally blow in different directions at different altitudes. The pilot seeks out the desired wind to carry the balloon in the desired direction.

There is an upper limit to balloon ascension, even if the burner is left on continuously. As elevation above the ground increases, the air becomes thinner. Eventually, the air becomes so thin that it provides no further lift. The pilot uses an onboard altimeter to determine the balloon's altitude and a variometer to indicate the rate of ascent or descent. A Global Positioning System (GPS) device can be used to obtain a readout on the balloon's latitude, longitude, and elevation.

Normally, the pilot tries to land in a large, flat, open area, such as a field, meadow, flatland, or desert, with no nearby obstructions, such as power lines, telephone poles, trees, or fences. In the case of a no-wind landing, the touchdown can be very gentle. If there is wind, the basket will drag along the ground until stopped by friction. After the basket has stopped, the pilot can fully open the parachute valve, causing the balloon to collapse completely. The ground crew tracks the balloon's path in a recovery vehicle and meets it at the landing site.

Festivals

There are thousands of hot-air balloon pilots worldwide, and periodic balloon festivals are held in many countries. These festivals usually feature competitions and mass ascensions, in which as many as five hundred balloons float in the air at the same time. The annual October festival in Albuquerque, New Mexico, is one of the largest festivals, with more than 850 balloons aloft in cooperative weather.

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See also: Balloons; Blimps; Buoyant aircraft; Dirigibles; History of human flight; Lighter-than-air craft; Montgolfier brothers

Hovercraft

Also known as: Air cushion vehicles, Surface effect ships

Definition: Vessels that float above the surface of the water on a cushion of air.

Significance: Hovercraft have allowed aircraft vessels to operate at very high speeds and become fully amphibious.

Background

Humans have sailed ships since the beginning of recorded history. These ships have always been designed and built based on the ancient mathematician Archimedes's principle of displacement. More recently, using eighteenth century Swiss mathematician Daniel Bernoulli's principle of dynamic lift, humans learned to build vessels that lift out of the water and fly above it.

A vessel that flies over the surface of the water is interesting for a number of reasons, the first of which is the concept of displacement. A ship floating in water displaces, or pushes aside, a weight of water equal to its own weight. This is Archimedes's principle. If the displacement is reduced by flying the vessel above the water, the drag, or the friction acting against the vessel's hull to slow it down, is reduced. Secondly, if the drag is reduced by reducing displacement, the speed can be increased dramatically using the same horsepower. Most conventional floating vessels have a top speed of 35 to 40 miles per hour. Hovercraft have a top speed of 100 to 150 miles per hour. A final advantage to flying over water is that hovercraft can be fully amphibious. That is, they can travel over land as easily as they travel over water.

History

The earliest experiments with hovercraft were undertaken in 1716 by Emanuel Swedenborg, a Swedish designer and philosopher. Swedenborg designed and built a vessel that looked somewhat like an upside-down dinghy. It had a cockpit in the center with air scoop openings on either side. These scoops were rotated by the operator, and air forced under the vessel lifted it above the water's surface. The problem with the design was that the horsepower required to maintain the lift was greater than the operator could create.

The first successful operation of a hovercraft was made by another Swede, Hans Dineson. Dineson built a vessel with rigid sidewalls and a flexible skirt both fore and aft, or front and back. By 1916, Austrian engineer Dagobert Müller von Thomamuhl had built another rigid sidewall hovercraft torpedo boat that was capable of a speed of 40 miles per hour.

Over the next half-century, many other designers and builders experimented with hovercraft and other types of "flying" vessels. In 1959, Christopher Cockerell tested his vessel. This vessel not only floated on a cushion of air, as many others had done, but it also used air jets, rather than fans, to maintain this air cushion. These air jets reduced the leakage from the vessel and increased the height of clearance from the sea. The first full-scale hovercraft was built by Saunders-Roe in England and christened the *SR.N1*. The vessel made its maiden voyage from Calais, France, to Dover, England, on the morning of July 25, 1959. This date was chosen to commemorate French aeronautics pioneer Louis Blériot's epic cross-Channel flight in a heavier-than-air craft fifty years earlier.

Another Englishman, C. H. Latimer-Needham, added skirts to Cockerell's invention in 1961. This adjustment dramatically increased the height of the vessel above the water. The increase in the depth of the vessel's air cushion allowed it to function in much rougher waters.

Hovercraft Design

Vehicles that either ride above the surface of the water or are partially lifted above the water's surface by a cushion of air have been called by many names by their various designers and builders. Although "hovercraft" is certainly one of the most familiar of these names, the vehicles are also known as air-cushion vehicles (ACVs), trapped-air-cushion vehicles (TACs), captured-air-bubble vehicles (CABs), ground-effect machines (GEMs), surface-effect vessels (SEVs), and surface-effect ships (SESs). In all cases, the design of the hovercraft follows a few basic principles. First, since air is 815 times less dense than water, it is easier to push something through the air than through the water. Second, increasing the amount of the hull that is lifted out of the water decreases the amount of drag the vehicle experiences and increases the speed of the vessel.

Hovercraft, or ACVs, are lifted out of the water in one of two ways: by either static or dynamic lift. Hovercraft are said to be aerostatic or aerodynamic. "Aerostatic" means they can be lifted, generally by fans, even when they are not moving. "Aerodynamic" means that the hovercraft's forward motion creates the lift. These vessels settle back to the surface when their forward motion is stopped.

Aerostatic vessels have developed in two different ways. The first of these is through use of the plenum chamber. The plenum chamber is the large area under the hovercraft that contains the air cushion. Fans push large volumes of air down into this area. Skirting around the edge of the vessel helps contain the cushion of air under the vessel. These vessels are designed so that a large amount of air escapes around the bottom of the skirt and helps to lift the vessel clear of the water.

The second type of aerostatic hovercraft is the annular jet type, such as that designed and built by Cockerell in 1959. In the annular jet type hovercraft, the inner skirt and the outer skirt are pinched together at the base, and this pinching creates a jet of air. These jets are focused inward

Image Not Available

and downward around the edges of the vessel. In this way, less air from the cushion is lost and greater lift can be generated with the same power.

Aerodynamic hovercraft depend on their forward motion to create enough lift for the vessel to rise clear of the water's surface. There are two types of aerodynamic vessels. The first of these is the ram-wing design. As the name implies, the speed of the vessel forces, or rams, air under the hull, lifting the vessel clear of the water's surface. At slow speed or when stopped, the vessels float in the water, only lifting as they accelerate. Many of these vessels use rigid sidewalls to contain or focus the airflow under the hull when moving.

The second type of aerodynamic vessel is the wing-in-ground type, also sometimes called ground-effect vessels. The Soviets built a class of this type of vessel, called Ekranoplan, for their military. In ground-effect vessels, the surface of the sea and the underside of the vessel create a tunnel in which air is trapped, lifting the vessel clear of the water's surface. These vessels also usually have rigid sidewalls to support the air cushion.

Skirting

In 1961, when skirts began to be added to hovercraft, a number of things occurred. First, the skirt deepened the air cushion, so the vessels rose higher out of the water. Second, drag was reduced by lifting the vessel, so speeds increased using the same amount of horsepower. Finally, the skirt reduced the size of vessel required to operate in rough water by 75 percent, because the skirt effectively lifted the vessel above the waves rather than running through them.

Skirts are of two types. The first is the flexible skirt, resembling large rubber inner tubes that extend down from the sides and ends of the vessel. Even though this skirt extends all the way around the vessel, it is usually made up of more than one piece and contains the cushion of air. Side sections and front and rear sections are placed very close together to appear as one piece. The skirt on a vessel is designed so that its depth is twice the significant, or average, wave height for the area in which the hovercraft is to be used. In this way, the waves do not wash over the vessel when it is moving. Some vessel designs contain not only a flexible outer skirt, but also smaller skirts within the larger one. These inner skirts are called petticoats. In this way, the air cushion can be maintained even in rough sea conditions.

The second type of skirting is rigid. These are often called sidewalls. Vessels with this type of skirting generally have flexible "finger" skirts at the front and back of the vessel and along the vessel's rigid sidewalls. The sidewalls are constructed of the same metals as the hull of the vessels, whereas the fingers are of the same rubber as the flexible skirts.

Propulsion and Lifting Systems

Hovercraft are different than other types of seaborne vessels in that they need two different types of power systems. One system creates the lift required to form the cushion of air under the vessel. The other system is used to develop the thrust to drive the vessel through or over the water.

Propulsion systems for most types of hovercraft involve propellers driving the vessel over the water. These propellers are driven by gas-turbine or diesel engines. A small percentage (10 percent) of hovercraft, mainly surface-effect ships (SESs), are driven by water jets that extend down from the rigid sidewalls. Such vessels can be problematic in very rough seas, although water jets control the steering of the vessel better than do the propellers.

Lifting systems involve pushing a very large volume of air under the vessel to create a cushion. The simplest type are the axial fans, in which the air moves in the same direction as the axis of the fan. This system works well for smaller vessels and vessels that do not require a high-pressure air cushion. The other type of fan is a centrifugal fan, in which the air is thrown out at 90-degree right angles to the axis of the fan. Centrifugal fans appear to work better in larger vessels, in which higher pressures are needed and fans may be spaced along the length of the vessel.

On some types of vessels, side thrusters are used for maneuvering at slower speeds. At speeds of less than 15 miles per hour, the cushion fans can release small amounts of air out of the side of the vessel, causing it to turn. These are called "puff ports" or "thrust ports." At higher speeds, however, these ports are ineffective.

Application of Design

Hovercraft, or ACV, designs have been adapted by a variety of users in different areas over the years. One of the first groups to exploit the application of hovercraft design was the military. Hovercraft were fast, maneuverable, and completely amphibious. They could be made small in size and armed as patrol boats or gun boats. They could be used in coastal areas, swamps, and even over open ground. They could be adapted and made larger to carry people and equipment ashore from naval vessels lying offshore.

The civilian adaptation of the hovercraft concept was no less effective or diverse. The most widely advertised uses of hovercraft were as passenger and vehicle ferries in congested urban areas. The ferries that cross the English Channel, large vessels carrying both passengers and vehicles, have for a number of years been successful on several routes.

An interesting use of hovercraft is in areas of sensitive terrain. Hovercraft are used in the Arctic over frozen tundra, over frozen ocean surface, or on frozen rivers. They are also used in swamp or marsh areas or on beachfronts where sand may be too soft for other types of vehicles. Recently, they have been used for heavy lifting of industrial equipment such as oil-field or mining equipment. Of course, no vehicle that travels at great speeds can escape the sporting enthusiast. Groups have developed that race different types of hovercraft depending on size, horsepower, and the skill of the driver.

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See also: Forces of flight; Jet engines; Military flight; Propellers; Propulsion

Howard R. Hughes

Date: Born on December 24, 1905, in Houston, Texas; died on April 5, 1976, in an airplane en route from Acapulco, Mexico, to Houston, Texas

Definition: Pioneer aviator, aircraft designer, builder, and multimillionaire.

Significance: A world-class pilot and aircraft designer, Hughes is known, in aviation, for building and flying the *Spruce Goose*, by far the largest aircraft of its day and for founding the Hughes Aircraft Corporation.

Howard R. Hughes was born into wealth in 1905, attended private schools in his youth, and later studied at both Rice University and the California Institute of Technology. He first flew in an airplane when he was fourteen years old. Upon the death of both of his parents in his late teens, he inherited $871,000 and the Hughes Tool Company, which held the patent on the most widely used well-drilling bit in the world. Hughes left school to operate the company, but his interests were not limited by that business.

From 1926 through 1932, Hughes was active in the production of motion pictures, became a pilot, and founded the Hughes Aircraft Company, where he designed, built, and flew airplanes. In 1935, in a plane of his own design, he set a world speed record of 352.39 miles per hour and followed that with transcontinental records in 1936 and 1937. Following his record-breaking around-the-world flight in 1938, he was treated to a ticker-tape parade in New York City. By 1938, he held nearly every major aviation award. For his flying accomplishments he won the Harmon Trophy in 1938, the Collier Trophy in 1939, the Octave Chanute Award in 1940, and a Congressional Medal in 1941.

By 1939, Hughes had placed the Hughes Aircraft Company at the forefront of design in experimental military airplanes. During World War II, his company was a major defense contractor. Hughes designed the eight-engine *Spruce Goose*, a large plywood seaplane contracted as a troop carrier in 1942. Its only flight was piloted by Hughes in 1947. Hughes's successes placed him among the top three most wealthy Americans.

At the war's end, Hughes reentered the Hollywood scene and controlled RKO Studios from 1948 through 1955. Throughout the 1950's, he concentrated on expanding his business empire, and by the 1960's, he was a billionaire. He owned the controlling stock in Trans World Airlines until he was forced to sell out in 1966. Hughes had suffered a nervous breakdown in 1944 and had been critically injured in a 1946 air crash, after which he developed an addiction to morphine that led to other dependencies. Always an eccentric, he went into seclusion in 1950, becoming a reclusive shell of a person living in a rented hotel room in Las Vegas, Nevada. Almost nothing is known of this period of his life. Hughes was elected into the Aviation Hall of Fame in 1973. He died in 1976 on board a plane traveling from Acapulco, Mexico, to Houston, Texas, where he was to receive medical treatment.

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See also: Manufacturers; Military flight; Record flights; *Spruce Goose*; Trans World Airlines; Transcontinental flight

Human-powered flight

Definition: Sustained, level flight powered solely through the use of human muscle.

Significance: The earliest attempts at human flight were powered by the pilot's own activity. Although nonhuman engines proved to be the key to viable aircraft, experimental human-powered craft continued to be built into the twenty-first century. These craft were often the products of university students and professors or enthusiastic amateurs, spurred on as much by the intellectual challenge as by the stimulus of monetary prizes.

Although it will never be an efficient mode of transportation, human-powered flight satisfies an innate human desire to emulate the freedom of birds. Unfortunately, using arms to flap attached wings cannot generate adequate lift and propulsion, as bird wings do, but well-conditioned athletes can maintain fractional horsepower outputs for long periods of time using their legs, and this, in the late twentieth century, led to a series of remarkably long, controlled flights over both land and water. The earliest truly successful flights were made by entrepreneurs in response to monetary prizes. Unfortunately, it does not appear that the resulting aircraft are practical flying machines for the vast majority of fliers and homebuilders, requiring too much muscle power and being far too large, too fragile, too expensive and too vulnerable to being upset by atmospheric turbulence.

The earliest seekers of human-powered flight were the tower and bridge jumpers, dating from at least 1000 C.E. Stability and control, as well as wing-flapping propulsion, were always in question, although some glides were at least partially successful. The key insight, as it was for motor-powered human flight, was to separate lift and propulsion: use fixed wings for lift and an engine and a propeller for propulsion. Monetary prizes eventually stimulated gifted teams of designers and enthusiasts and they have transformed the almost universal dreams of human-powered flight into reality.

The first prize offered for human-powered flight, the Prix Peugeot of 1912, was won in Paris in 1921 by bicycling champion Gabriel Poulain and his *Aviette* when he flew 40 feet in a straight line, using biplane wings attached to a bicycle to glide forward after he abruptly increased his wing angle to lift him into the air. By 1937, a 154-pound German bicycle racer, who was able to generate a momentary power output of 1.3 horsepower, had upped the straight-line distance to almost 0.5 miles using a 75-pound sailplanelike airplane, called *Mufli*, with a pedal-powered propeller.

The Kremer Prize

Late-blooming enthusiasm for human-powered flight in England resulted in seven men forming the Cranfield Man-Powered Aircraft Committee in 1957. Industrialist and philanthropist Henry Kremer was then inspired, in 1959, to offer a £5,000 prize for the first British human-powered aircraft that could take off and fly a figure-eight course between two turning points not less than 0.5 miles apart and fly over a 10-foot height marker at the beginning and end of the flight. In response, three postgraduate students of Southampton University formed SUMPAC (for Southampton University Man-Powered Air Craft) and made the first British human-powered flight of 50 feet in 1961. But SUMPAC was unable to exceed 2,000 feet in flight length and could not turn more than about 80 degrees.

A second effort, backed by the famous De Havilland Aircraft Company, flew about 3,000 feet at an average height of over 6 feet in 1962 in *Puffin*, creating a world record that was to stand for ten years, but the craft could not be turned more than about 80 degrees. The distance record, still a British record, was made in 1972 by John Potter with a 3,513-foot flight in *Jupiter.* Meanwhile, Professor Hidemasa Kimura of Nihon University was working with his students, and in 1966 their *Linnet* made Japan's first human-powered flight; the flight was only 49 feet in length but this began a long-term commitment to human-powered aircraft. By 1977 their *Stork B* had established a new world record of 6,869.75 feet in a flight of over four minutes and was a strong contender for the Kremer Prize.

By 1967, the Kremer Prize for a figure-eight human-powered flight had been doubled and opened to entrants from any country. Then, in 1973, with still no winner in sight, Henry Kremer raised the award to £50,000 (about $129,000 at that time), the largest prize in the history of aviation.

The human-powered movement was very slow to reach the United States. Finally, in 1973, Professor Eugene Covert and students at the Massachusetts Institute of Technology (MIT) built a two-person biplane named *Burd*, which apparently never even left the ground under its own power. Credit for the first human-powered flight in the United States is therefore given to Joseph Zinno, retired from the U.S. Air Force, for his 77-foot flight in 1976 in *Olympian ZB-1*, which he had designed, built, and flown.

MacCready's Success

It was in that same year of 1976 that fifty-one-year-old Californian Paul MacCready decided that he knew how to design a human-powered aircraft that could win the Kremer Prize. He had impressive credentials for the challenge. As a teenager, MacCready was a Junior National Champion in model airplanes; at the age of sixteen, he soloed a Piper Cub; in 1947, he graduated from Yale with a degree in physics; in 1948 and 1949, he was the National Soaring Champion; in 1952, he received a doctorate in aeronautics from California Institute of Technology; in 1957, he decided to go into business for himself, eventually forming AeroVironment in 1971 to solve energy and environmental problems.

MacCready's initial design was inspired by observations of soaring birds and the Rogallo hang glider. He realized that the low power output from a human meant that the airplane had to have a very large wing area (around 1,000 square feet) and have a very high aspect ratio (a large span of about 100 feet with a chord of only about 10 feet) in order to minimize lift-induced drag. The drag of the required bracing wires for an extremely light, fragile aircraft with these huge dimensions would be acceptable if flight speeds and flight altitudes were very low. The structure would have to be designed to be easily repaired, the same rule practiced by the Wright brothers. Aerodynamicist Peter Lissaman convinced MacCready that a canard surface had to be added to his wing for pitch stability. Turning the aircraft was a major hurdle, because the outer wing always wanted to stall; wing warping and a rolling front (canard) surface eventually solved this problem.

MacCready thought it would take six weeks to win the prize; it took a year. Flight control, weather, power, and structural problems kept cropping up. Finally, on August 23, 1997, the Kremer Prize was won by MacCready's team with an official flight time of 6 minutes, 22.5 seconds. Their huge airplane, the *Gossamer Condor*, weighed 70 pounds and the pilot and engine, bicycle racer Bryan Allen, weighed 137 pounds. On September 22 of that year, Maude Oldershaw piloted the *Gossamer Condor*. It is interesting to note that all of the principal members of the team were model aircraft builders; many were also hang-glider enthusiasts. The *Gossamer Condor* is now the property of the National Air and Space Museum in Washington, D.C.

Crossing the English Channel

Retired British Rear Admiral Nicholas Goodhart had developed a huge (138-foot wingspan) twin-powered airplane, *Manflier*, for the Kremer Prize and, beaten to the prize, he suggested that the next great project should be a human-powered flight across the English Channel. Henry Kremer responded with a doubled award of £100,000 for the first such successful human-powered flight. It would require remaining in the air for more than one hour.

MacCready quickly rose to the new challenge with a new, lighter, stronger, more streamlined design, the *Gossamer Albatross*, using high-technology materials (carbon fiber-reinforced plastic, DuPont Kevlar, and a new, superthin DuPont Mylar for the covering), a new cruise prop designed by aerodynamicist Eugene Larabee of MIT, and new cockpit instrumentation, including a Polaroid sonar altimeter. By June, 1978, guided in his rigorous physical training by physiologist Joseph Mastropaolo, Allen was able to generate 0.31 horsepower for 2.5 hours, enough time, MacCready thought, to make a successful flight. However, two months later, the warp control jammed and *Gossamer Albatross* suffered the worst crash of the program, although the pilot was only bruised. Some eight months later, on April 25, 1979, Allen flew a record flight of over one hour and the decision was made to go to England and try for the prize. After weeks of waiting on the English coast for suitable weather, at 5:51 A.M. on June 12, 1979, pilot/power plant Allen lifted off from England. Slowed by a headwind, out of his crucial water supply, and cockpit instrumentation out of battery power, Allen felt at four different times that he would have to give up the effort. Somehow, fighting cramping legs and nearing exhaustion, he struggled on and, at 7:40 A.M., touched down lightly in France, winning the second large Kremer Prize for the team. He had flown *Gossamer Albatross* 22.25 miles in 2 hours, 49 minutes (an average speed over the water of less than 8 miles per hour).

The Langford Group

Meanwhile, in 1978, the MIT Model Rocket Society, led by student John Langford, decided to see if they could get the hangar-evicted MIT *Burd* to fly with the addition of two 1.5-horsepower model airplane engines. The attempt failed, but the society pledged to build something that would fly by springtime, a craft that would compete for Kremer's Channel prize. The society's *Chrysalis* made its first flight on June 5, 1979, just one week before Allen won the English Channel prize. They had built a real flying machine, however, one that ended up being flown by more than forty-five pilots before the end of the summer.

Two years later, Langford had returned to MIT as a graduate student and led an effort to win a new Kremer prize, this one for flying around a 1,500 meter (4,185 feet) course in less than three minutes, requiring a speed of 21 miles per hour. Energy storage before takeoff was allowed. The group's *Monarch* won the $33,000 prize on May 11, 1984, narrowly beating MacCready's latest effort. Inspired, the Langford team vowed to pursue the "ultimate" human flight challenge: to emulate the fabled flight of the exiled Daedalus and son Icarus from the island of Crete to Greece. Thus began a four-year effort that ended up requiring more than $1 million worth of corporate and institutional sponsorship.

Key members of the team included builder Juan Cruz, Mark Drela (completing a thesis on low-speed aerodynamics), physiologist Ethan Nadel, and a group of highly trained and conditioned superathletes, as well as leader Langford. The result was a plane that weighed 70 pounds without pilot, power plant, or fuel, 29 feet in length, with a wingspan of 112 feet, and with a cruising airspeed of 15 miles per hour. On April 23, 1988, piloted and powered by a Greek bicycle champion racer, Kanellos Kanellopoulos, they flew their *Daedalus* the more than 70 miles from Crete over the sea to Santorini in about four hours, breaking up just 90 feet off shore when the craft encountered a strong headwind with turbulent air.

The next frontier in human-powered flight appears to be the helicopter. In 1980, a prize of $25,000 was offered by the American Helicopter Society for the first human-powered helicopter that could hover for a full minute, rising to at least 10 feet above the ground at some point during that period. Successful hovers have so far not exceeded about 24 seconds and the height requirement appears to be even more difficult.

W. N. Hubin

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See also: Aerodynamics; Airplanes; Experimental aircraft; Forces of flight; Helicopters; Ultralight aircraft; Wing designs

Hypersonic aircraft

Definition: Aircraft capable of flying at speeds greater than five times the speed of sound.

Significance: Flight at hypersonic speeds is required to efficiently reach space and return from it. Aircraft flying at hypersonic speeds encounter several problems in addition to those encountered at lower speeds, including extremely high temperatures and pressures, as well as the need for control systems which react to disturbances extremely quickly.

Applications

Although they are advertised as being able to circle the globe in less than four hours, hypersonic aircraft do not offer much promise to weary airline passengers in the near future. Most applications of hypersonic aircraft are either in the context of warfare or spaceflight. With the exception of the terminal stage of certain missiles, hypersonic flight is conducted exclusively at very high altitudes, where the air density and pressure are a fraction of their values at sea level.

In space, any controlled maneuver requires the expenditure of fuel, whereas inside the atmosphere, aerodynamic forces can be used by deflecting control surfaces. Because the speed required for Earth orbit at low altitudes is approximately 18,000 miles per hour, spacecraft reenter the atmosphere at extremely high Mach numbers, ranging typically from 25 on the space shuttle to over 36 on the Apollo capsules. In reentry flight, the craft spends only a few minutes at hypersonic speed before decelerating to supersonic speeds, which allow more controlled maneuvering and gliding to selected landing sites.

During ascent into space, modern hypersonic aircraft ride on rocket boosters, spending the shortest possible time in the dense lower regions of the atmosphere. This situation will have to change when aircraft use air-breathing engines for propulsion at hypersonic speeds. Air-breathing engines take the oxygen needed for combustion from the atmosphere, reducing the amount lifted from the ground. The advantage of mastering this technology may be easily seen. In a hydrogen-oxygen propulsion system, which is the most efficient known means of chemical propulsion, 89 percent of the total weight of fuel and oxidizer is oxygen. However, air-breathing hypersonic flight poses several difficult problems.

Features of Hypersonic Flows

The air flowing around a vehicle moving at hypersonic speeds has several interesting features. In front of the vehicle nose stands an extremely strong shock wave. This shock is like the blast wave from an explosion, heating the air enough to make oxygen and nitrogen molecules vibrate at high frequencies, dissociate into atoms, radiate large amounts of heat, and even ionize. The air becomes compressed to values as high as ten to one hundred times its normal density, and the extremely high pressure imposes very high loads on the vehicle. Over the upper surface of the vehicle, the air accelerates to supersonic speeds, and the density and temperature fall so quickly that the dissociated air does not have time to recombine. Around the vehicle, shock waves lie very close to the surface. Air friction heats the surface and increases the drag on the vehicle. Within a thin layer, the flow changes properties through a very large range. The reliable design of such vehicles is extremely difficult, because accurate, full-scale aerodynamic prediction is difficult and expensive, and approximate methods do not provide enough accuracy.

Refining the prediction methods through experimentation is also not easy because of the sheer difficulty of conducting flow experiments under hypersonic conditions. Hypersonic wind tunnels require extreme pressures, temperatures, and flow rates and can operate under steady conditions only for milliseconds. In the early 1990's, when President Ronald Reagan's National AeroSpace Plane initiative resumed the development of technology for hypersonic flight, the total experience of wind-tunnel testing at hypersonic speeds from all tests conducted to that date was estimated to be less than one second.

Early Hypersonic Flights

The inherent difficulties of hypersonic travel have not prevented the development of hypersonic vehicles. In 1933, German rocket expert Eugen Sänger published his concept for an "antipodal bomber" (antipodes are two points on opposite sides of the earth), a crewed hypersonic glider launched on a large rocket that would deliver bombs to distant targets across the globe, by skipping in and out of the atmosphere. This project was canceled in 1942.

In February, 1949, the U.S. Army launched the V-2 WAC Corporal rocket from the White Sands Missile Range in New Mexico. The rocket reached a speed of 3,500 miles per hour and an altitude of 100 miles before the WAC Corporal stage ignited and reached an altitude of 244 miles. The vehicle reentered the atmosphere at a speed of more than 5,000 miles per hour.

On April 12, 1961, Soviet flight major Yuri Gagarin returned to Earth after an orbital flight during which he traveled at hypersonic speeds that charred the surface of his spherical space capsule. Since then, rockets with or without human crew have routinely flown in the hypersonic regime.

The X-15 Program

The first hypersonic research airplane, which used aerodynamic lift to stay aloft, was the North American X-15, developed by the National Aeronautics and Space Administration (NASA). Air-launched from a B-52 bomber, the X-15 first flew on June 8, 1959. It was 50.75 feet long with a wingspan of 22.25 feet. Its Thiokol XLR-99 throttleable rocket engine burned a mixture of anhydrous ammonia and liquid oxygen to reach Mach 6. By the end of August, 1963, the X-15 piloted by NASA's Joseph A. Walker had reached a record altitude of 354,200 feet.

X-15 flight tests revealed a number of interesting facts about hypersonic flight, including the existence of turbulent hypersonic boundary layers, and that turbulent heating rates were lower than predicted by theory, but that hot spots developed on the surface, causing material failures. The flights demonstrated piloted transition from aerodynamic to reaction controls and back again, including hypersonic/supersonic reentry at angles of attack up to 26 degrees and glide to precise landings.

The third X-15, which set a number of records, was lost, along with its pilot, Michael J. Adams, on November 15, 1967. The program was canceled after this fatal accident.

Air-Breathing Propulsion

The X-15A-2 vehicle was designed to pursue the idea of hypersonic flight using an air-breathing engine instead of a rocket. The plan was to test a ramjet engine using supersonic combustion, although it was never flight-tested. The challenges of hypersonic air-breathing propulsion were numerous, but two fundamental problems dominated.

First, theoretical research showed that drag is incurred when a supersonic flow is slowed down to subsonic speeds, as through a shock, and when heat is added to a flow at a high Mach number. At low supersonic speeds, the drag due to the shock is less than the drag that would be incurred if heat were added to a supersonic flow. Thus, ramjet engines for flight at less than Mach 4 use shocks to slow the flow to subsonic speeds before adding heat by burning fuel in the combustion chamber of the ramjet engine. At speeds above Mach 4, it is more efficient to add heat at supersonic speeds than it is to slow down the flow to subsonic conditions.

Second, in supersonic combustion there is an extremely short time available in which to add fuel, mix it with the air moving at supersonic speed, and complete the combustion before the flow exits the engine. The X-30, dubbed the National AeroSpace Plane, was built to develop supersonic combustion ramjets, or scramjets. In the 1990's, this program was canceled without any test flights.

NASA's Langley Research Center at the turn of the millennium described a program called Hyper X to study hypersonics technology at speeds from Mach 5 to Mach 10. The NASA/Boeing X-43 was designed to study scramjet-powered flight at speeds from Mach 6 to Mach 10, following launch using a Pegasus booster rocket from a

The X-15, shown here with pilot Neil Armstrong, was the first hypersonic aircraft developed by the United States. (NASA)

B-52 over the Pacific Ocean. Released at 20,000 feet, the 12-foot-long X-43 was designed to be accelerated by the rocket to a speed of Mach 6 and an altitude of 90,000 feet. The scramjet engine was designed to operate for seven to ten seconds, accelerating the X-43 to a speed of Mach 10. The engine had an oval-shaped air intake and burned hydrogen with air in a copper combustion chamber at supersonic speeds. Lacking landing gear, the vehicle was designed to transmit data before expending its energy and falling into the ocean.

Lifting Bodies

The U.S. Air Force and NASA have continued to study hypersonic lifting bodies for hypersonic reentry. The X-20 Dyna-Soar hypersonic boost glide vehicle was designed to launch into orbit on a Titan III solid-fuel rocket, reenter the atmosphere, and glide at hypersonic speeds to deliver a nuclear weapon. However, the Dyna-Soar was shelved without ever flying.

The X-23 lifting body flew in 1966, demonstrating maneuvering during reentry. The X-24A and X-24B craft investigated low-speed characteristics of lifting bodies. The NASA/Boeing X-37, part of NASA's Hyper X program, investigates technologies for orbit-on-demand, including hypersonic glide reentry. The vehicle, built by Boeing Phantom Works, is 27.5 feet long, with a wingspan of 15 feet, a weight of about 6 tons, and a payload bay 7 feet long and 4 feet in diameter. The Boeing X-40 maneuverable spaceplane integrated technology demonstrator is a predecessor to planned vehicles for flight at Mach 16 up to 300,000 feet, sending 1,000 to 3,000 pounds of payload into orbit for military missions.

In the 1990's, the X-38 crew return vehicle (CRV) extended the work on the X-23 and X-24, in the development of a lifting body that would be attached to the International Space Station (ISS) as an emergency escape system. Separated from the ISS using rocket thrusters and able to carry an incapacitated crew of up to seven, the X-38 was to navigate using the Global Positioning System (GPS) and glide through hypersonic reentry at angles of attack of up to 38 degrees, with the heating taken by thermal tiles on the vehicle. Following supersonic maneuvering using flaperons, the X-38 would deploy first parachutes and then a large parafoil. An on-board automatic control system would guide the parafoil-suspended X-38 to a soft landing into the wind. In 2001, the X-38 project was canceled, but a parallel project conducted by the French and the European Space Agency aimed to develop a reusable crew taxi or crew rescue vehicle.

NASA's space shuttle uses aerodynamic lift at high angles of attack and hypersonic speeds of up to Mach 25 during its reentry and descent into the atmosphere. It uses heat-shield tiles to protect critical parts of the fuselage and the wings during reentry. By using aerodynamic lift in the upper atmosphere, the shuttle stays at high altitudes, where the air is much thinner, until much of its orbital kinetic energy has been dissipated before sinking into the denser parts of the atmosphere and gliding to a runway landing.

Other Reusable Hypersonic Spaceplanes

The NASA/Lockheed Martin X-33 reusable launch vehicle, a smaller predecessor of the Lockheed VentureStar concept, tested the idea of achieving single-stage boost to low-Earth orbit using ultra-lightweight composite fuel and oxidizer tanks and a rocket engine that used an "aerospike" external expansion nozzle. The X-33 was canceled in 2001, along with the launch-on-demand, glide-to-landing NASA/Orbital Sciences X-34 vehicle.

The Buran (Snowstorm) Soviet space shuttle had its first orbital flight in November, 1988, on an Energia booster. It circled Earth twice between 247 and 256 kilometers above the surface before reentering and landing at Tyuratum. The French-European Hermes spaceplane project was conceived as a mini-shuttle, carrying four to six crew members and 4,500 kilograms of cargo into orbit atop an Ariane-5 booster. The project was canceled in 1992 but may have been replaced by the continuing European Space Agency (ESA) crew rescue vehicle project.

Hypersonic air-breathing vehicle designs including a scramjet engine were reported to have been tested in the 1990's by Russia on top of a surface-to-air missile and by the Indian Space Research Organization using a solid rocket booster. The Japanese Hope-X space shuttle and the British horizontal takeoff and landing (HOTOL) concepts do not appear to have progressed beyond small-scale wind-tunnel models. As of mid-2001, there was no reusable hypersonic aerodynamic vehicle in operation other than NASA's space shuttle.

Wave-Rider Concepts

Aircraft configurations optimized for aerodynamic flight at hypersonic speeds are generally thin and flat, with a highly swept fuselage and short wings. At hypersonic cruise, the upper surface of the vehicle stays essentially parallel to the flight direction, minimizing the disturbance to the flow there. The oblique shock formed under the vehicle stays very close to the slanted surface, providing a lifting cushion of high pressure. Such vehicles are called hypersonic waveriders. Waverider configurations generally exhibit rudders and elevator-aileron combinations (elevons) as primary control surfaces. Tip flaps improve lift-to-drag ratio and rudder effectiveness. Such vehicles are unstable in pitch, like many modern fighter planes, and require fly-by-wire, stability-augmented computer control. Concepts for reducing the shock drag and heating at the nose include the Russian idea of injecting ionized gas jets into the shock, and the American idea of ionizing the gas ahead using plasma or laser beams.

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See also: Air Force, U.S.; Forces of flight; Yuri Gagarin; High-speed flight; Mach number; Military flight; National Aeronautics and Space Administration; Rocket propulsion; Sound barrier; Spaceflight; Supersonic aircraft; X planes

I

Iberia Airlines

Also known as: Iberia, Compania Mercantil Anonima Iberia

Definition: Spain's largest international carrier and one of the world's major carriers.

Significance: A large global carrier with a consolidated position in its domestic and regional market as well as the Europe-Latin America market.

History

Iberia, in full Compania Mercantil Anonima Iberia, or Iberia Commercial Limited-liability Company, is a major airline headquartered in Madrid, Spain. In its current incarnation, Iberia was originally state-owned and created by law on June 7, 1940. As such, it was given rights to the air transport of persons and cargo within Spain. It took control of a privately owned airline established in 1937, which in turn had revived the name of a company called Iberia Compania Aerea de Tranportes, founded June 28, 1927. As of December 14, 1927, that airline began a regular service between Madrid and Barcelona. King Alfonso XIII was a passenger on the inaugural flight, made in one of the new company's three Rohrbach-Roland aircraft. The current name of the airline was adopted September 5, 1941. Based on its original date of operations (1927), Iberia is one of the world's oldest scheduled airlines. Between 1927 and 1939, Iberia's service was entirely within Spain (including Majorca). Its longest route, established in 1937, was from Vitoria in northern Spain to Tetuán in Spanish Morocco, with stops in Burgos, Salamanca, Cáceres, and Seville. It also provided services linking Santiago de Compostela with Salamanca and Valladolid. Madrid-Seville flights were added in 1939.

Iberia became an international airline in 1939 when it began regular services between Madrid and Lisbon. In 1946, Iberia began a service connecting Madrid with London and Rome. That same year, it became the first airline to fly between Europe and South America, using a DC-4 to cover the Madrid-Buenos Aires route. Shortly afterward it added regular flights to Havana, Caracas, Puerto Rico, Mexico City, Rio de Janeiro, and New York. In the 1960's, Iberia joined the jet age, replacing its Super Constellations with DC-8's on the Madrid-New York route. This both shortened the duration of the flights and added seat capacity and passenger comfort. The arrival in 1970 of the first wide-bodied aircraft, the Boeing 747, consolidated Iberia's competitive position. Iberia also acquired Boeing 727's for its domestic routes, including the busy Madrid-Barcelona shuttle launched in 1974, as well as new DC-10's to replace its turboprop fleet.

New maintenance facilities were built at the La Muñoza site near Madrid's Barajas Airport and the company joined the international aircraft maintenance consortium, Atlas. Iberia's technicians were trained to maintain the latest aircraft in its own fleet and those of other airlines. Iberia's fleet includes the Boeing 747, Boeing 767, Boeing 757, Boeing 727, Boeing 737, McDonnell Douglas (Boeing) DC-9, McDonnell Douglas (Boeing) MD-87 and MD-88, McDonnell Douglas (Boeing) DC-8 Cargo, Airbus A340, A300, A321, A320, and A319, Canadair CRJ 200, Aerospatiale ATR72, and Fokker F-50. On the company's fiftieth anniversary in 1977, the Iberia corporate logotype was changed and its fleet was given the new look. Iberia became a founding partner of the computerized European ticket reservations system Amadeus, embarked on a major fleet replacement program, and set up a new air freight company and the regional airlines that now make up the Iberia Group.

Organization and Network

Iberia is the head of a group that encompasses three other carriers. Two of these airlines are subsidiaries (Binter Canarias and Binter Mediterráneo) and one a franchise (Iberia Regional/Air Nostrum). The trend toward market globalization in the airline industry led Iberia to join the oneworld Alliance on September 1, 1999. Along with the Star Alliance, oneworld Alliance is one of the two major international alliances with a global scope. Iberia's partnership with American Airlines and British Airways, along with its membership in the oneworld Alliance, enhanced its competitive position in the global market. In addition to American Airlines, British Airways, and Iberia, oneworld members include Aer Lingus, Cathay Pacific, Finnair, Lan Chile, and Qantas. Alliance members cooperate in schedules and routes to create a seamless global network. As its membership attests, oneworld covers the entire globe.

In 2001, the Iberia Group flew to ninety-nine destinations in forty-two countries. With a fleet of more than two

Events in Iberia History

1927: Iberia is formed and begins regular service between Madrid and Barcelona, Spain.
1939: Iberia makes its first international flight, from Madrid and Lisbon, Portugal.
1944: The airline is nationalized and expands its route network.
1946: Iberia begins service to London and Rome and becomes the first airline to fly between Europe and South America, establishing a route from Madrid to Buenos Aires.
1960's: The airline takes delivery of its first jet-powered aircraft, the DC-8, which flies the Madrid-to-New York route.
1970: The airline takes delivery of its first wide-body aircraft, a Boeing 747 jumbojet.
1980's: Iberia is a founding partner of Amadeus, a computerized ticket reservations system.
1999: Iberia joins the oneworld Alliance, a global network of cooperating airlines.

hundred aircraft, it offers an average of nine hundred daily flights. In 1999, Iberia carried 26 million passengers and 220,000 tons of freight. The number of its destinations, the frequency of its flights, and its market share make Iberia the leader of the Spanish market and the airline with the most comprehensive network for travel between Europe and Latin America.

Iberia has an experienced air-maintenance operation, servicing not only its own fleet but also those of other airlines. Iberia is also Spain's leading handling company, supplying ground services to aircraft and passengers in all of Spain's domestic airports on behalf of some 220 airlines and charter companies. In 1999, it provided such services to a total of 428,000 aircraft and 79 million passengers. Iberia is a founder and 18.28 percent partner in Amadeus, one of the world's major computerized air ticket reservation systems. With Gate Gourmet, a leading in-flight catering company, it is the co-owner of Iberswiss, which prepares almost 11 million meal trays per year. As a partner in the tour operator companies Viva Tours and Tiempo Libre, Iberia is actively involved in the holiday travel package business, and through its Cacesa subsidiary it provides urgent freight and courier services.

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See also: Air carriers; American Airlines; British Airways

Icing

Definition: Accumulation of frozen moisture on an aircraft.

Significance: The buildup of ice on an aircraft poses a serious hazard by interfering with the aircraft's lift and causing additional drag and weight.

Dangers

When an aircraft encounters freezing temperatures and visible moisture, icing, the accumulation of frozen moisture, is possible. Although icing is a serious hazard to the safety of any flight, light aircraft are particularly susceptible to aircraft icing, as such craft have few, if any, anti-icing or deicing systems. Icing can destroy an aircraft's ability to create lift and engine power when ice builds up on the structure and within the engine-induction system.

Types of Icing

There are two types of aircraft icing, structural and induction. Structural ice may form on aircraft lifting surfaces, such as the wing and horizontal stabilizer, and on the windshield and protruding devices, such as the propellers, engine air intakes, antennas, struts, and landing gear. Ice adds additional weight to the aircraft. More critical, though, is the additional drag that the ice causes by disrupting the smooth flow of air over the lift-producing surfaces. Moderate to severe accumulations of structural ice can greatly affect aircraft controllability. Both wind-tunnel and flight tests have proven that ice accumulations no thicker or rougher than a piece of coarse sandpaper can reduce lift by 30 percent and increase drag by as much as 40 percent.

Structural icing may be present as rime, clear, or mixed ice. Rime ice has a rough, milky-white appearance. Rime ice forms when relatively small drops of moisture strike freezing aircraft surfaces and adhere to the surface rapidly.

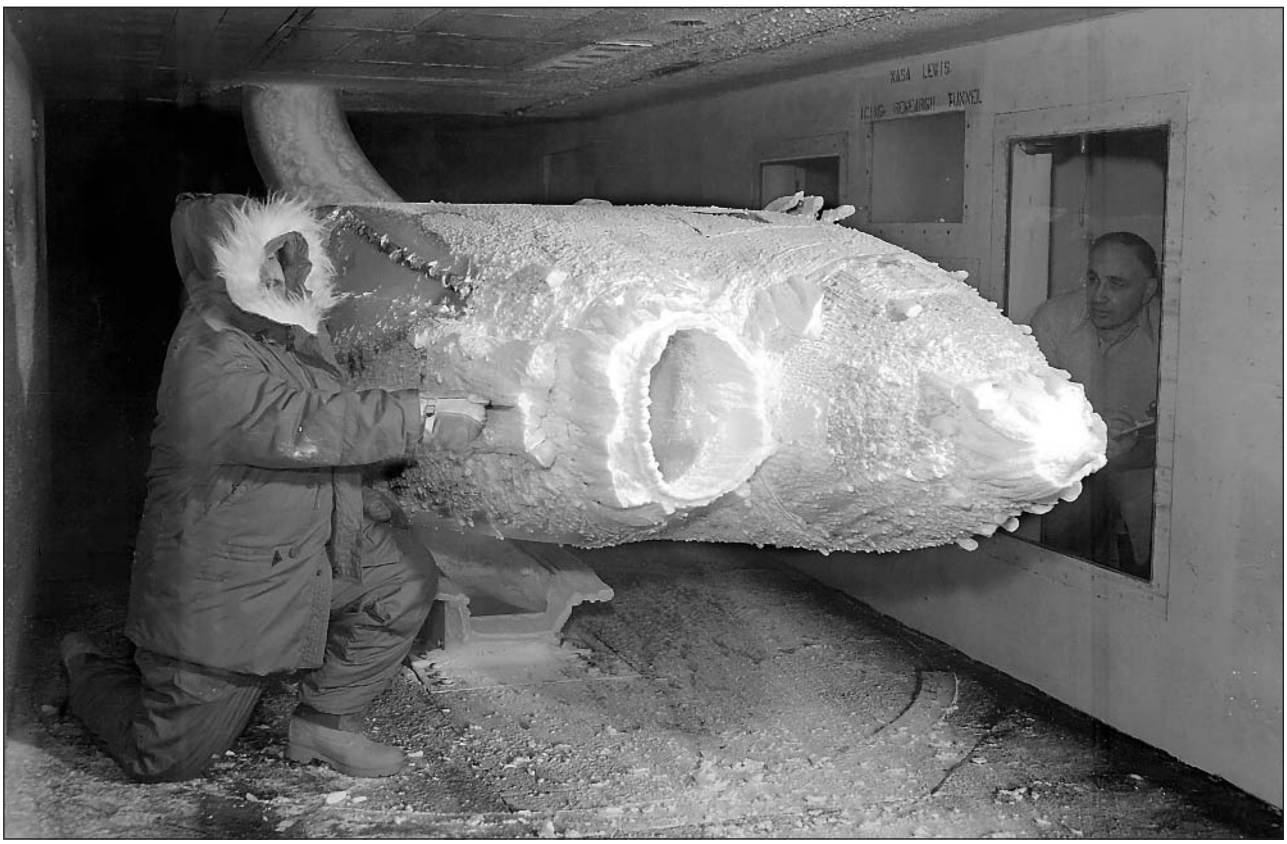
The milky white appearance is caused by the presence of air trapped in the rapidly freezing ice. Deicing systems are generally effective in removing rime ice, because rime ice is less tenacious than other forms of ice.

Clear ice forms when large drops of moisture strike aircraft surfaces and freeze at a slower rate. The slower freezing process displaces air from the accreting ice, allowing the formation of a clear, very tenacious coating of ice on the aircraft's surfaces. Because of the lack of aeration in the ice, clear ice is difficult to remove and quite heavy. Mixed ice is a combination of rime and clear ice and exhibits characteristics of both.

Induction icing can reduce engine performance and may result in complete engine stoppage. Aircraft equipped with carburetors may experience ice buildup in a restricted air passage, called a venturi, that is located in the carburetor. An increase in air velocity and a resultant decrease in pressure within the venturi results in a reduction in air temperature. This lowering of air temperature creates the potential for moisture within the air to freeze and create ice accumulations along the sides of the venturi. The ice buildup reduces the flow of air and fuel through the venturi, resulting in decreased engine performance. In severe instances, ice may completely occlude the venturi, resulting in complete loss of engine power. In the case of aircraft equipped with fuel-injection systems, ice can accumulate in air intakes, reducing the flow of air to the engine. Ice occluding engine air intakes can cause reductions in available engine power as well as complete engine failure.

Formation of Ice

Although all clouds are the manifestation of water in its gaseous state, the moisture content of clouds can vary greatly. Very-cold-winter states such as Montana, North Dakota, and Minnesota often have relatively dry clouds. In contrast, states such as Pennsylvania and New York often produce very wet winter clouds that, when temperatures drop below freezing, have a high potential for icing. Clouds with temperatures at or just below the freezing point, 32 degrees Fahrenheit, or 0 degrees Celsius, are the



The accumulation of ice on the exterior structures of an aircraft can affect a plane's lift and drag. NASA has conducted extensive research on icing in its icing research tunnel at the Glenn Research Center. (NASA) most likely to result in aircraft icing. Moisture in air that is well below the freezing point is already frozen and therefore will not adhere to aircraft. Wind can move moisture-laden air between regions. Wind moving across large bodies of water, such as oceans or the Great Lakes, will result in greater moisture content within the air. Mountains can cause a lifting phenomenon that may force moisture-laden air upward in the atmosphere where the natural temperature lapse rate cools the surrounding air to the freezing point.

Areas of low-pressure and fronts are the greatest producers of ice. Although in some instances, isolated air-mass instabilities may also produce sufficient moisture and temperatures capable of producing ice-generating conditions.

Freezing rain and drizzle are the most hazardous ice-producing conditions. Freezing rain occurs when temperature inversions exist. Rain falling from clouds in warmer air aloft begins to freeze as it enters freezing air at lower altitudes. Freezing rain and drizzle can produce severe ice accumulations that rapidly overwhelm the ice-shedding capabilities of even the best anti-icing and deicing equipment.

Predicting Ice

In the United States, the U.S. National Weather Service (NWS) is the government agency responsible for weather forecasting. Utilizing NWS and other weather forecasting sources, the Federal Aviation Administration (FAA) disseminates weather information to the aviation community through a network of Flight Service Stations (FSS). FSS specialists provide comprehensive weather briefings to pilots. These briefings are usually conducted over the telephone but may also be accomplished in person at the Flight Service Station. Pilots may also obtain icing and other weather information on the Direct User Access Terminal System (DUATS), utilizing a personal computer and Internet connection. Graphic weather charts available to FSS specialists and DUATS users include predictions of areas of potential icing. In addition, special meteorological notices called AIRMETS and SIGMETS are issued when potentially hazardous icing conditions exist. These notices provide pilots with an additional warning of potential icing. Pilots experiencing icing conditions report these conditions to the nearest FSS. Pilot reports (PIREPS) are usually conveyed directly to FSS specialists via the aircraft radio. PIREPS are an important component of the weather reporting system, because they describe actual conditions and not merely forecasts.

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See also: Accident investigation; Airplanes; Federal Aviation Authority; National Transportation Safety Board; Safety issues; Weather conditions

Insects

Definition: A small invertebrate animal that has a segmented body, six legs, and two or four wings.

Significance: Due to their unique flight environment and small size, insects have evolved ingenious flight mechanisms to generate lift.

Background

A popular anecdote relates that in the 1930's a student of German aerodynamicist Ludwig Prandtl was asked by a biologist at a dinner party to estimate the lift of a bumblebee. To make this estimate, techniques similar to those commonly used to predict the lift of aircraft wings were used. To the surprise of the dinner guests, the results suggested that bumblebees should not be able to fly, although this is obviously not the case.

Insects are, in fact, the most accomplished of flying animals, with unsurpassed flying abilities. Insects can hover, fly backward, and even perform somersaults. Because insects are small in size and their wings typically move at relatively low speeds, the air through which an insect flies has the same relative feel as syrup to a human.

An important parameter in aerodynamics is the Reynolds number, which relates the motion of the air to its viscosity, where the viscosity is a measure of the stickiness of the air. Thus, for air, a low Reynolds number flow generally indicates that the airspeed is low, and the effects of viscosity are significant. As insects move their wings at comparatively low speed, they fly at very low Reynolds numbers. Few airfoils, or shapes of wings in profile, are capable of creating lift efficiently at the Reynolds numbers of an insect wing in flight or hover.

To circumvent the problem of flying at very low Reynolds numbers, insects have developed sophisticated flight mechanisms for developing lift, mechanisms of which engineers in the 1930's were unaware. This is one of the reasons for the problems with the analysis by Prandtl's student. From the 1970's to the 1990's, a clearer picture of insect flight techniques developed, based on the data from numerous comprehensive experimental studies and some computer-based numerical analysis.

Flight Basics

A wing in steady flight, such that its speed and angle of attack, or the angle of the wing to the oncoming airstream, are unchanging, develops lift due to the air flowing smoothly over its surfaces, and being deflected downward. This type of lift is called attached flow lift. An aircraft wing can also develop lift from the formation of a tornado-like vortex above the wing surface. Such leading edge vortices can clearly be seen above the wings of aircraft, such as the Concorde, at takeoff or landing on humid days. The vortex tends to pull up the wing, thereby increasing its lift. This type of lift is called vortex lift. An aircraft can use both attached flow lift and vortex lift, such that the two lift values can be added together.

Due to viscosity on the wing's surface, the speed of the air is zero. This represents a condition referred to as the no-slip condition. However, at some distance above the wing's surface, the airspeed reaches that which would occur if the flow had no viscosity. The region between the surface and this point is referred to as the boundary layer. The nature and behavior of this boundary layer has a significant impact on the ability of a wing to develop lift at very low Reynolds numbers. The boundary layer can either be laminar, turbulent, or transitional from laminar to turbulent. A laminar boundary layer is composed of air moving in orderly lines. A turbulent boundary layer is composed of air moving close to the airfoil surface in swirling motions. A laminar boundary layer is prone to separate from the airfoil surface far more easily than a turbulent boundary layer. At the very low Reynolds numbers at which insects fly, the boundary layer over their wings is always laminar. This causes the air to separate very easily over their wings, with the result that it is difficult for insects to develop enough attached flow lift to support their weight. However, for some insects, even if the boundary layer did not separate, the attached flow lift developed by the insect wing would still not be sufficient to support the insect's weight. It is thus necessary for insects to use other lift mechanisms, such as vortex lift, to create enough lift to stay aloft and maneuver.

Insect Flight Apparatus

An insect wing is composed of a thin membrane, which uses veins to provide strength. The wings of insects reflect the largest differences between the different insect orders. Some insects have two wings, and others four, but they all use similar flying techniques. Several insects, such as houseflies, originally had four wings. However, evolutionary development modified the two hind wings into small stumps, or halteres, which stabilize the housefly. Some insects with four wings, such as the dragonfly, beat their front and rear wings out of phase, meaning that the two sets of wings do not move forward and backward simultaneously. Other insects that also have four wings, such as butterflies, beat the front and back wings in phase, so both sets of wings flap effectively as a single set of wings.

To create the flapping motion, insects can use either of two muscle systems, direct or indirect. Direct muscles are attached to the wings and the bottom of the insect's thorax. Separate muscles are used to raise and lower the wings. To use a flapping system with direct muscles, the insect's brain must continually tell the flight muscles to relax and contract. Generally, insects that use direct muscles for flight cannot beat their wings very quickly because the brain has to coordinate the two sets of flight muscles for the insect to fly successfully. Indirect muscles are not directly attached to the wings. The indirect muscles consist of dorsoventral muscles, which connect to the top and bottom of the thorax, and the longitudinal muscles that run from the front to the back of the insect's thorax. The insect's wings are connected to the thorax by hinges. By alternating the contraction of the two muscle sets, the thorax of the insect begins to vibrate. The wings, attached to the thorax, begin to flap, with a contraction of the dorsoventricular muscles moving the wings upward. Contraction of the longitudinal muscles pulls the wings down.

One advantage of an indirect muscle system is that the insect's wings can beat at very high frequencies, up to 1,000 times per second for a gnat. Flies typically beat their wings approximately two hundred times per second, whereas beetles may beat them about eighty times per second, and butterflies about thirty times per second. The major advantage of indirect muscles, though, is that they require fewer instructions from the insect's brain than do direct muscles. Once the muscles are rhythmically contracting, they no longer need instructions from the brain. Houseflies use an indirect muscle system, whereas locusts use a direct muscle system. Insects using an indirect muscle system are far better fliers than those using a direct muscle system; the latter often appear clumsy in flight.

Insect Flight Techniques

Meticulous experiments performed in the 1990's clarified the methods that insects use to develop lift in the potentially unfavorable environment in which they fly. Experiments by Cambridge University zoologist Charles Ellington and colleagues showed that insects use attached flow lift as well as vortex lift, similar to the lift developed over highly swept wings such as those of the Concorde or numerous fighter aircraft. Computer simulation of the flow over a large moth, the hawkmoth, showed similar results.

Insects generally move their wings in a pattern that may resemble a figure eight or some variant of it. The plane in which the wings are moved backward and forward is the so-called stroke plane. A wing stroke begins with the wings almost touching above the insect's body. The front of the wing is rotated down rapidly, and the wing is accelerated downward; this is the downstroke. For most insects, the wings are rotated through approximately 120 degrees in the stroke plane. The boundary layer, the thin layer of air adjacent to the wing surface that is affected by viscosity, separates from the wing surface at the front of the wing, and no longer conforms smoothly to the wing's surface. Due to the motion of the insect wing, this boundary layer forms a tornado-like vortex above the wing. The vortex has the effect of increasing the lift of the insect's wing by causing vortex lift to develop.

At the beginning and end of the insect's wing stroke, the wing is rotated or flipped rapidly. Through careful timing of the point at which the wing is flipped, the insect is able to develop extra lift by causing the air over its upper surface to effectively speed up and that on the lower surface to slow down. This lift is similar to that developed by a spinning tennis ball. Some insects may also move their wings in such a fashion that they move through the wake, or energized air left behind by the previous wing cycle. As the insect wing moves through the air, air that comes into contact with the wing is set in motion and may begin to rotate. This air can then increase the lift of the wing if the motion of the wing is correct. For many insects, the angle of the stroke plane to the insect's body is essentially fixed. Thus, for the insect to change from hovering to forward flight, it rotates its body, so that the force from the wings will generate both some lift to support its weight as well as some thrust to propel it forward. Generally, insects generate most of the lift to support their weight on the downstroke, where the wings are moved from above to below the insect's body. The duration of the downstroke is also typically twice as long as the upstroke.

Another flight technique, referred to as the clap-and-fling technique by scientist Torkel Weis-Fogh, is used by some smaller insects such as Chalcid wasps. Initially, the insect's wings are positioned above the body with the wings touching, as may be seen when a butterfly is at rest. The insect then rapidly draws the front, or anterior, edges of its wings apart, and then rotates the two wings down. The advantage of such a flight method is that both wings instantly develop maximum lift. Normally, when a stationary wing is initially accelerated, it takes some time for the lift developed by the wing to reach its final steady value. However, the clap and fling represents a brilliant biological adaptation for circumventing the reasons for delay. Presumably, due to wear on the wings from continual colliding, few insects actually use the clap and fling.

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See also: Aerodynamics; Animal flight; Bats; Birds; Forces of flight; Ludwig Prandtl

Instrumentation

Definition: Gages and instruments used by the pilot to monitor the condition of an aircraft and the condition of flight.

Significance: Instrumentation contributes to flight safety and the usability of aircraft. Without instruments, aircraft would be able to fly only for short periods on sunny days.

History

The earliest aircraft had no instruments at all. Pilots controlled the airplane and the engine using their senses of sight, hearing, and touch. As airplanes grew more complex, pilots needed more instruments to control the planes and monitor the engines. In addition, pilots required instruments to help them navigate and to maintain control of the aircraft in fog or clouds.

The first instruments installed in aircraft monitored the crafts' engines and fuel. By World War I (1914-1918), aircraft had compasses, inclinometers, and simple altimeters to help pilots navigate and maintain control.

In 1928, Paul Kollsman invented the first sensitive altimeter. A year later, on September 24, 1929, Army lieutenant James H. "Jimmy" Doolittle, using Kollsman's altimeter and other instruments, demonstrated that an aircraft could be successfully controlled by reference to instruments alone. With a safety pilot in the forward cockpit, Doolittle climbed into the rear cockpit and covered it so he could not see out. Then he took off, flew a 15-mile triangular course, and landed. For the first time, an aircraft had been flown by reference to instruments alone. Although engineers improved instrument accuracy and reliability, the basic design of flight instruments remained the same from the 1930's to the 1960's.

During the 1960's and 1970's, as the transistor and, later, the integrated circuit came into general usage, instruments began to change dramatically. The instrument could be mounted away from the cockpit, and the information could be displayed on a simple indicator. In the 1980's, as microprocessors came into general usage, the indicators could be replaced with cathode ray tubes and liquid crystal displays.

Magnetic Compass

The most basic instrument used for navigation is the magnetic compass. The magnetic compass uses two small magnets attached to a floating compass card inside a container filled with kerosene. These magnets point toward the earth's magnetic north pole. The compass card has letters and numbers printed on it that allow the pilot to determine the direction of flight. The movement of the airplane during flight causes the magnetic compass to swing back and forth. This limits the pilot's ability to determine flight direction with precision.

Pitot-Static Flight Instruments

The static system is designed to measure the ambient air pressure surrounding the aircraft. A static port consisting of small holes drilled through the side of the aircraft is connected to tubing that leads to the pressure-sensing instruments. The pitot tube is usually a cylindrical device with a hole at one end, installed so that the end with the hole faces forward. The other end is connected to a hose that leads to airspeed sensing instruments. With this arrangement, as the aircraft moves forward, it will create a positive air pressure within the pitot tube. Used together, the pitot tube, the static port, and the hoses associated with each are known as the pitot-static system.

Three flight instruments are based on measuring air pressure and are connected to the pitot-static system. These are known as pitot-static instruments and, in general, need no external power source.

Airspeed Indicator. The airspeed indicator is connected through hoses to both the pitot tube and the static port. The basic function of the airspeed indicator is to compare air pressure caused by aircraft movement to ambient air pressure. Within the instrument, a small set of bellows connects to the hose leading to the pitot tube. The bellows are also mechanically connected through gears and springs to a needle on the face of the airspeed indicator. The case of the instrument is connected to the hose leading to the static port. As the aircraft moves through the air, the pressure in the pitot tube inflates the bellows. As the bellows expand, the needle will move to indicate airspeed. Airspeed indicators can be calibrated in nautical miles per hour (knots), miles per hour, or both.

Altimeter. The altimeter is connected through hoses to the static port. The basic function of this instrument is to measure barometric air pressure. If a tube is placed into a mercury reservoir, the atmospheric pressure will force the mercury up into the tube. Measuring the length of tubing filled with mercury will give an indication of the atmospheric pressure. At sea level, the length of tube filled will be approximately 29.92 inches of mercury. At 20,000 feet, the length would only be 13.75 inches of mercury. This pressure is commonly known as barometric pressure.

Inside the altimeter is a sealed pressure capsule connected to needles on a dial calibrated in feet of altitude. As the aircraft climbs skyward, the capsule expands, causing the needles to indicate an altitude above sea level. The altimeter is only accurate when the pilot sets the altimeter for the local barometric pressure. For example, before takeoff, the pilot gets a weather report that indicates the local barometric pressure and then enters the pressure into the altimeter. Once entered, the altimeter will read the field elevation, or altitude above sea level.

Vertical Speed Indicator. The vertical speed indicator is connected through hoses to the static port. The function of this instrument is to measure the rate of altitude change. Inside the vertical speed indicator is a pressure capsule with a calibrated leak. This capsule is connected to a needle on the face of the instrument. As the aircraft increases or decreases in altitude, the capsule will expand or contract, and air will either leak in or out of the capsule, causing the needle to indicate the rate of either climb or descent.

Gyroscopic Flight Instruments

The gyroscopic instruments work on the principle that a spinning wheel will remain rigid in space. The gyroscopic instruments are constructed around a spinning wheel called a gyroscope. Once spinning, the gyroscope will remain rigid; therefore, it is mounted on special devices called gimbals. The gimbals allow the aircraft to move freely around the rigid gyroscope. Gyroscopic instruments are different from pitot-static instruments in that they require a power source. These instruments may be either air or electrically powered.

Directional Gyro. Unlike the magnetic compass, the directional gyro remains stable in spite of aircraft movement. The gimbal of the directional gyro connects to a circular compass card. A number or letter under a lubber line at the top of the instrument indicates the direction in which the aircraft is pointed.

Attitude Gyro. This instrument is also known as the artificial horizon, or attitude indicator. Two gimbals within the attitude gyro are connected to a horizon-reference arm. Using two gimbals allows the aircraft to move freely in all directions around the rigid gyroscope. The reference arm rotates right and left and moves up and down. When the gyroscope is spinning and rigid in space, the horizon reference bar will remain level. As the airplane climbs, descends, or banks, the pilot can compare the position of the reference bar to an airplane symbol and bank index on the face of the instrument. In this manner, the pilot can then determine the attitude of the aircraft relative to the horizon.

Rate Gyros. There are two different types of rate gyros, the turn and slip indicator, and the turn and bank indicator. Both types feature an inclinometer on the face of the instrument that indicates whether or not the aircraft is sliding sideways. A sideways slide is known as either a slip or a skid.

The turn and slip indicator uses a gyroscope in a horizontally mounted gimbal connected to a needle in the face of the instrument. As the aircraft turns, the gimbal rotates and forces the needle to the left or right, depending on the direction of the turn. The faster the turn, the greater the deflection of the needle. In a turn and bank indicator, also known as a turn coordinator, the gimbal is mounted at an angle and connected to a symbolic airplane on the instrument face. This instrument senses both bank rate and turn rate.

Engine Instruments

All aircraft are equipped with a tachometer. A tachometer measures the rotation speed of the engine in revolutions per minute or in percent of maximum. In piston-powered aircraft, the tachometer may also include an hour meter to measure the time that the engine has been running. In helicopters, the tachometer will have two needles, one to measure engine speed and the other to measure rotor speed. Jet-powered aircraft have two tachometers labeled N_1 and N_2. The N_1 tachometer measures the speed of the low-pressure compressor, and the N_2 tachometer measures the speed of the high-pressure compressor.

Oil temperature and pressure gauges are also found on all aircraft. Many piston-powered aircraft are cooled by a combination of air and oil. By monitoring the oil temperature, the pilot can determine if the engine is operating within its proper temperature range. All engines are lubricated with oil, and the oil pressure gauge alerts the pilot to any changes in oil pressure that would indicate an engine problem.

Many aircraft are equipped with an exhaust-gas temperature gauge. This instrument measures the temperature of the exhaust gases, and pilots use this instrument to monitor the efficiency of the engine.

Piston-powered aircraft may be equipped with a manifold pressure gauge. This instrument is similar in construction to, yet less sensitive than, an altimeter. The manifold pressure gauge measures the air pressure within the intake manifold. For aircraft equipped with constant-speed propellers, this instrument is the only reliable way to measure the power output of the engine.

Jet engines will have instruments that measure pressure at both the low and high pressure compressors. These pressure gauges allow the pilot to monitor the performance of the engine.

Systems Instruments

Pilots monitor the condition of the electrical system in the aircraft by using an ammeter. Ammeters measure electrical current flow in amperes. Some aircraft also have a voltmeter. The voltmeter measures electrical potential in volts. By monitoring these instruments, the pilot can determine whether the battery is charging or discharging and whether the generator is working properly.

All aircraft are equipped with fuel quantity indicators, the equivalent of a fuel gauge in an automobile. Since many aircraft have more than one fuel tank, there may be more than one fuel gauge. In some cases, a single gauge can be used with a selector switch so that the pilot must measure fuel quantity one tank at a time.

Some aircraft are equipped with fuel flow gauges. These instruments monitor the rate at which the engine or engines are using fuel. Pilots use these gauges to monitor the condition of the engines and to plan when fuel stops will be necessary.

Electronic Flight Instrumentation System

Electronic flight instrumentation systems (EFIS) can be used in place of every instrument except the magnetic compass. By nature, instruments with no moving parts are more reliable than their mechanical counterparts. Various techniques are used to replace the mechanical components of an instrument. For example, by using accelerometers coupled to microprocessors, engineers can duplicate the operation of the gyroscope. In addition, a laser beam shining through a ring of optic fiber can duplicate the operation of a mechanical accelerometer.

By using technology similar to computers and televisions, information can be displayed on cathode ray tubes or liquid crystal displays. In most EFIS designs, all of the flight instrument information is exhibited on one or two displays, while navigation, engine, and other information will be shown on other displays.

EFIS-equipped aircraft may a have special engine monitoring system called the engine indicating and crew alerting system (EICAS). With EICAS, engine data are not all displayed continuously. During normal operation, only a minimum amount of information is displayed. If a malfunction occurs, important information will appear automatically on the electronic display.

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See also: Airplanes; Avionics; Cockpit; Flight control systems; Guidance systems; Pilots and copilots; Training and education

J

Japan Airlines

Definition: Japan Airlines is part of a privately owned Japanese travel corporation. The airline serves both a large domestic market and a network of international routes.

Significance: Japan Airlines is Asia's largest airline.

History

Japan's major international airline began shortly after World War II, when the country was recovering economically and was beginning to see opportunities to participate in the newly aligned world. In 1951, Japan Air Lines was formed as a privately owned company. Its first flights were domestic, achieved by leasing both aircraft (Martin 202's) and crews from Northwest Airlines, which served Japan from North America.

In the following year, Japan Air Lines had acquired its own aircraft and trained its own crews and had become a major element in Japan's internal transportation system. In 1953, the Japanese government acquired 50 percent of the company and became an owner and controller for the next thirty-four years. During this time the company was considered a government-sponsored air carrier.

Japan Air Lines achieved its ambition of becoming an international carrier in 1954, when it introduced its first foreign destination, San Francisco. As the decade continued, the airline added other international routes, with accelerated growth beginning in 1960 when jet service with DC-8's was introduced. Polar flights to Europe (London, Paris, and Copenhagen) and westward lower-latitude flights to Europe (Rome, Frankfurt, and London via Karāchi and Cairo) constituted a truly global pattern. When the United States finally allowed Japan Air Lines to cross it with flights from the West Coast to New York and on to Europe, it became officially an "around-the-world" airline.

A noteworthy introduction occurred in 1974 when the airline began flights to and from the People's Republic of China. Historians list this event as one of the important opening steps between Communist China and the West. Japan Air Lines flights provided a channel of travel, communication, and commerce where one was greatly needed.

In 1987, the Japanese government divested itself of its share (then 34 percent) in the company, which became again a private corporation. Ownership is traded on the stock exchange and majority stockholders are primarily Japanese banks and insurance companies.

Two years later, the company underwent a reorganization, the most visible aspect being a change in its name from Japan Air Lines to Japan Airlines. During the last decades of the twentieth century, the corporation expanded its business into other travel and related companies, including subsidiary airlines, hotels, and even rapid surface travel concepts. By the year 2000, Japan Airlines was carrying over 30 million passengers and 1 million tons of cargo per year. It had become Asia's largest airline. By that year, revenues of the airline part of the corporation had reached a level of just over $10 billion.

Routes

At the beginning of the twenty-first century, Japan Airlines routes served seventy-eight different cities in a total of twenty-nine countries and territories, and, through code-sharing agreements with other airlines, its routes included eighty additional cities in the United States. The majority of its primary destinations are in Japan, where the schedules include twenty-three cities. It directly serves twelve U.S. airports. Its worldwide routes include polar routes to Europe, around-the-world service via the United States, extensive Asian service especially to China, and one South American city, São Paulo, Brazil.

Within Japan, the airline shows an unusual pattern of service. In most countries, especially physically small countries such as Japan, domestic airlines use small, short-haul aircraft. Japan Airlines, however, serves Japanese cities with wide-body craft, including many Boeing 747's. In fact, Boeing developed the 747SR (short range) and the 747SR-SUD (short range, stretched upper deck) largely because of Japan Airlines' domestic needs. To support these routes, Japan Airlines has eighteen thousand employees and operates 112 offices worldwide.

Fleet

Japan Airlines has an unusually top-heavy fleet, with the largest number of Boeing 747's of any airline in the world. In 2001, it was flying eighty 747's, including seven different versions of that airplane. These made up the bulk of its fleet of 135 planes. Of the remainder, most were also jumbojets (including the 767, which, although smaller than the 747 and the 777, qualifies as a jumbojet because of its intercontinental capability). There were only twelve smaller jets, including Boeing 737's and MD-11's.

Most JAL aircraft are painted in traditional, business-like colors, a white body with the circular JAL logo, formed by the body and wings of a *tsuru* (crane), on the tail and the letters JAL on the fuselage. However, the company introduced fancier colors for special routes in the 1990's. The domestic 737's, for instance, are each named for a different flower and sport pictures of their flower on their sides. The 777's are called "star jets" and the name of a bright star with a picture of its constellation is shown on each plane's fuselage. Planes used for resort destinations, such as Hawaii, Guam, and Saipan, are called *Reso'cha* and are decorated with elaborate pictures of tropical flowers and birds.

Subsidiaries

The airline expanded and diversified in the last decades of the twentieth century and now is connected with approximately three hundred subsidiaries and affiliates, including a hotel chain (Nikko Hotels International), subsidiary airlines (such as Japan Asian Airways) and tour and resort operations. In addition to these attempts to enhance revenue, the company has also engaged in environmental activities, including a program of monitoring the carbon dioxide content in the stratosphere using equipment installed on its intercontinental jet planes on normally scheduled flights. It sponsors international cultural and sports events, such as the Otobutai concerts, remarkable musical events that combine traditional Japanese music performances with music from the West, all performed in one of the historic castles of Kyoto.

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See also: Air carriers; Boeing; Jumbojets; Northwest Airlines; 707 plane family; Transglobal flight

Jennys

Also known as: Curtiss Jennys, JN-2, JN-3, JN-4, JN-4C, JN-4D, JN-4H

Date: First JN design built in 1914; JN-4D introduced in June, 1917

Definition: The most important U.S.-designed and-built airplane of the World War I era.

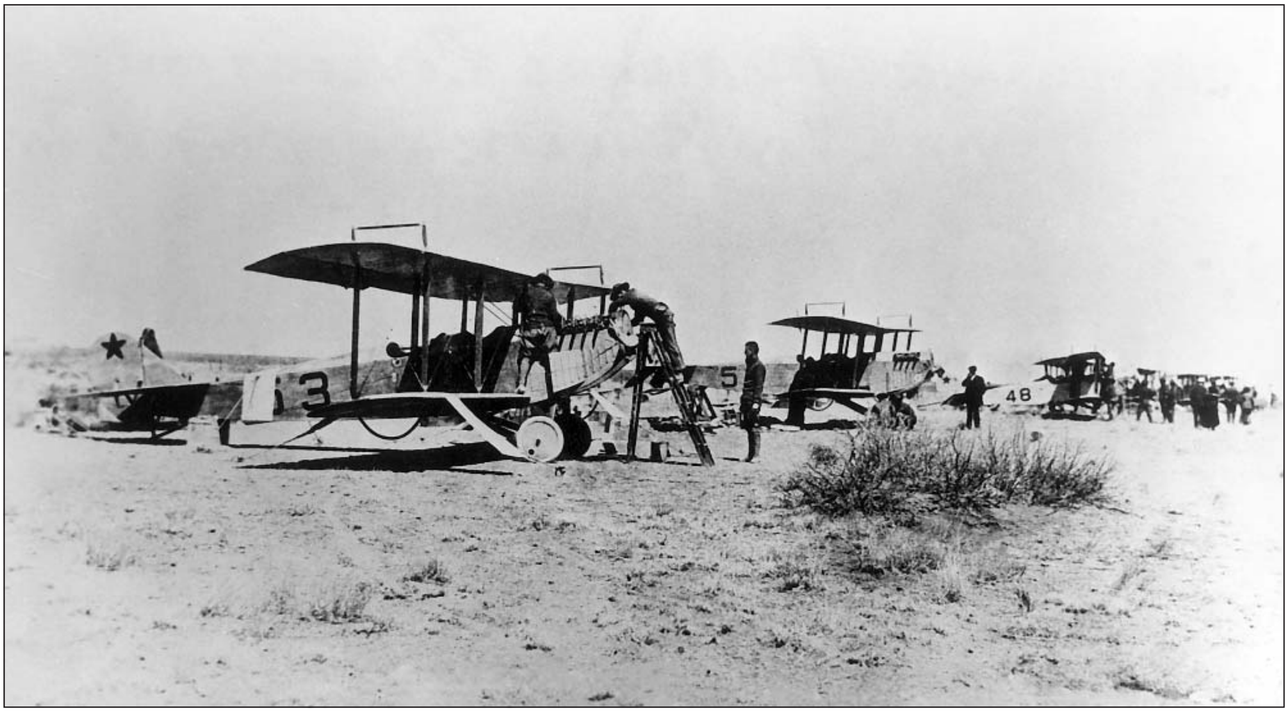
Significance: Thousands of American, British, and Canadian army pilots were trained in Jennys, and after the war, the readily available airplane served in the United States as a trainer and a barnstorming exhibition plane at county fairs and farmers' fields. It was also the first plane officially to carry airmail in the United States.

Evolution of the JN Series

"Jenny" was the affectionate nickname given to any of several models of the Curtiss JN series of aircraft by thousands of U.S. and British flight cadets who learned to fly between 1915 and the early 1920's. The JN aircraft design resulted from a 1914 request from the British government for a trainer aircraft for its army pilots.

By 1914, aeronautical pioneer Glenn H. Curtiss had established the largest aircraft manufacturing company in the United States, although most of his airplanes were sold either to the U.S. Navy or to European governments to avoid entanglement in his patent battles with the Wright brothers. Prior to the JN aircraft, most of Curtiss's land-plane designs had used pusher propellers, which Curtiss believed gave the pilot better visibility, but, in response to an Army request, he developed a tractor design with the propeller in front. The initial design, termed the "J" model aircraft, was developed by B. Douglas Thomas, an engineer whom Curtiss hired from the Sopwith Company of England. The best elements of this design were combined with the best of Curtiss's "N" aircraft designs to give the "JN" designation.

The aircraft evolved from the JN-2, which had two wings of equal span, into the JN-3 and the JN-4, which had slightly staggered (offset front-to-back) wings with the upper wing of greater span than the lower wing. Also departing from earlier Curtiss designs, the Jenny had flaplike ailerons built into the trailing edges of its upper wings rather than small winglike ailerons suspended between the



This squadron of Jennys, based in New Mexico, was used in a campaign against Pancho Villa in 1916. (The Institute of Texas Cultures, courtesy Kirk McManus Collection, Aeroflax Inc.)

wings' tips. To avoid the hotly contested Wright patent on lateral control, `which the Wrights claimed included ailerons, the Curtiss planes were built without ailerons and shipped to England, where ailerons made by another Curtiss company in Canada were added.

World War I

The British loved the Jenny, calling it the perfect trainer, and more orders followed, leading Curtiss to build many in Canada, where the JN-4C became known as the Canuck. When the United States entered World War I, it also chose the JN-4 as its trainer, deciding to use European-designed planes for fighters and bombers. Over eight thousand of these various JN-4 versions were built as trainers, and hundreds more were built for private purchasers. Almost three thousand JN-4D versions, powered by the famed 90-horsepower Curtiss OX-5 engine, were built for the U.S. Army and others. The JN-4D cruised at 60 miles per hour, had a top speed of 75 miles per hour, and had a ceiling altitude of 6,500 feet. The basic JN-4D weighed 1,390 pounds and could carry 530 pounds of fuel, people, and baggage or mail. It had a 43.65-foot wingspan along its upper wing and a total wing area of 352 square feet. It was 27.33 feet long. The JN-4H, with a larger 150-horsepower Hispano-Suiza engine, boasted a slightly higher speed and was purchased in quantity later in the war by the U.S. Army. It was used for training well into the 1920's. Curtiss also built a Navy version of the JN-4 with floats, designated N-9H.

After World War I

The end of the conflict in Europe brought thousands of former Army pilots home with a yearning to keep flying. They were joined by other young men and women who were excited about learning to fly, but opportunities for civilians to fly for a living were very limited. Unlike in Europe, no airlines existed in the United States, and the fledgling U.S. airmail service was being flown by Army pilots in Jennys. However, surplus Jennys were plentiful and inexpensive, and many were purchased by flight schools and groups of pilots who formed exhibition teams traveling the country giving airplane rides and barnstorming.

The absence of any regulations for flying in the United States enabled almost anyone with an airplane, regardless of pilot ability or airplane state of repair, to offer rides for a few dollars or to do stunt flying at county fairs or at farms on the outskirts of small towns. The Aero Club of America did issue pilot's licenses, but neither the U.S. government nor most states required licensure or registration of any kind. Indeed, part of the thrill of going to a barnstorming exhibition was the anticipation of a crash, and it was fortunate that the limited speeds of the Jenny and similar planes enabled pilots to survive many accidents with only broken bones. Many young people of the era earned their flight training by working on the Curtiss OX-5 engine, by repairing the JN-4 airframe, and sometimes even by signing on as wing-walkers, who hung onto a Jenny's wings and struts by their arms and legs as the plane flew over cheering local crowds.

The Jenny truly opened up the world of aviation to Americans, giving many an insatiable taste for flying. It did more to awaken the nation to the thrills and promises of aviation than any other airplane of its time. Many Jennys survive today in private and museum collections, and if one is fortunate, he or she might catch one flying an exhibition of antique aircraft.

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See also: Airmail delivery; Barnstorming; Glenn H. Curtiss; Pilots and copilots; Training and education; Wing-walking; World War I

Jet engines

Definition: An internal combustion engine that converts the chemical energy of fuel into mechanical energy in the form of thrust by the high-speed exhaust gases leaving the engine nozzle.

Significance: Fundamentally, a jet engine is a gas turbine. Gas turbines are used widely to generate electricity in power stations, to power boats, trains, military tanks, and to drive gas pipeline compressors. It is as a jet engine, however, that the gas turbine has had its greatest industrial impact.

Description

The jet engine consists of several components: a compressor, a combustion chamber, a turbine, and an exhaust system. At the front of the jet engine is the compressor, driven by a shaft connected to the turbine. The compressor takes in air from the atmosphere and compresses it to produce high-pressure air. The air then enters the combustion chamber, where jet fuel is injected in fine droplets. Combustion occurs with ignition, and the hot gases exit the combustion chamber and enter the turbine, downstream of the combustion chamber. The hot gases leave the turbine through the exhaust system, exiting at high speed from the jet engine nozzle and propelling forward both the jet engine and the aircraft attached to it. The principle behind this propulsion is described by Newton's third law of motion, which states that for every action there is a reaction equal in magnitude and opposite in direction. Jet propulsion is the movement of a small mass of gas at a very high velocity, whereas in a propeller plane, the propeller moves a large mass of air at low velocity.

History

The first patent for the modern gas turbine was granted in 1930 in England to Sir Frank Whittle, whose design led to the W-l turbojet engine with a centrifugal compressor. Simultaneously yet independently, German engineer Hans P. von Ohain also obtained a patent for a turbojet engine less than five years after Whittle had received his patent. Von Ohain's engine also had a centrifugal compressor, whereas another German design, by Ernst Heinkel, had an axial compressor. A plane with von Ohain's He-S3b engine made its test flight on August 27, 1939. Two years later, on April 12, 1941, a plane with Whittle's turbojet engine was tested.

By the 1940's, German turbojet engine prototypes had adopted the axial compressor, whereas British models all used the centrifugal compressor. By 1943, the two main turbojet engines were Germany's Junkers Jumo 004 and Britain's Rolls-Royce Welland. In the United States, General Electric Company engineers modified the Whittle engine and produced an American version called the I engine. In October, 1942, the I engine had its first test flight in the Bell P-59A.

During World War II, scientists from both Allied and Axis countries worked feverishly to design and test the jet engine. By 1946, several countries had successfully developed turbojet engines. In the United States, General Electric built the I-16 and the I-40. In England, Rolls-Royce built the Welland I, the Derwent I, and the Nene. In Germany, Junkers manufactured the Jumo 004-4.

By the 1950's, the turbojet had been applied to civilian aviation. Early passenger jets included the De Havilland Comet I, which first flew in 1952 but was withdrawn from service two years later because of fatal accidents. By 1954, the United States had successfully tested its Boeing 707 passenger jet, with regular flights commencing four years later. After adopting the jet engine, commercial aviation quickly developed into an international business, with most countries operating their own national airlines. International jet aircraft industries manufacture many types of planes: wide-body models that can carry hundreds of passengers; supersonic planes that can fly at Mach 2; aircraft that are capable of vertical takeoffs and landings (VTOL); and military jet aircraft that can take off and land on the deck of an aircraft carrier.

The gas-turbine engine that powers all jet aircraft is, however, basically the same engine that was designed by Sir Frank Whittle in 1930. It consists of a compressor, combustion chamber, turbine, and exhaust system. There are four major manufacturers of jet engines: Société Nationale de Construction de Moteurs Aeronautiques (SNECMA) in France, Rolls-Royce in the United Kingdom, and Pratt & Whitney and General Electric in the United States.

Components

Compressor. The purpose of the compressor is to increase the pressure of the gas. In the compressor, atmospheric air is pressurized to typically ten to forty times the inlet pressure, and consequently the temperature of the air rises to between 200 and 550 degrees Celsius. The ideal gas law states the proportionality of the pressure and temperature of gases. The two basic types of compressors are the centrifugal-flow compressor and the axial-flow compressor.

The centrifugal-flow compressor, preferred for smaller engines, is a simpler device that uses an impeller, or rotor, to accelerate the intake air and a diffuser to raise the pressure of the air. The axial-flow compressor is favored for most engine designs, because it is capable of increasing the overall pressure ratio. The axial-flow compressor uses rotors fitted to many differently sized discs to accelerate the intake air and stationary blades, known as stators, to diffuse the air until its pressure rises to the correct value.

The type of compressor used in an engine affects the engine's exterior appearance: An engine with a centrifugal compressor usually has a larger front area than an engine with an axial compressor. An engine with an axial compressor is longer and has a smaller diameter than an engine with a centrifugal compressor.

Combustion Chamber. In the combustion chamber, jet fuel, typically kerosene, is injected in fine droplets to allow for fast evaporation and subsequent mixing with the hot, compressed air. The compressed air is used for combustion, which occurs with ignition; the hot pressurized gases then reach temperatures of 1,800 to 2,000 degrees Celsius. To protect the combustion chamber walls from these high temperatures, some of the intake air, routed from the compressor, is used to cool the combustion chamber walls.

The three types of combustion chambers are the multiple chamber, annular chamber, and can-annular chamber. The multiple chamber, with individual chambers, or flame tubes, arranged radially, is used on engines with centrifugal compressors and early axial-flow compressor engines. The annular chamber has one annular flame tube with an inner and outer casing. The can-annular chamber combines characteristics of the multiple chamber and the annular chamber and has several flame tubes in one casing.

Turbine. In an aircraft engine, the sole function of the turbine, which is downstream of the combustion chamber, is to power the compressor. Similar to the compressor, the turbine has several large discs, though typically not as many as the compressor, fitted with many blades. Gases at temperatures between 850 and 17,000 Celsius exit the combustion chamber and enter the turbine. The hot gases impact the turbine blades, causing the discs carrying them to rotate at high speeds, averaging 10,000 revolutions per minute. The discs are mounted on a shaft that is connected at the other end to the compressor discs. The turbine blades are usually made of nickel alloys, because these materials are both strong and able to withstand the high temperatures within the turbine. The blades are fitted with many small holes through which cool air is forced to prevent the blades from melting.

Exhaust System. The jet engine's exhaust system is configured so as to maximize the thrust of the engine. The exhaust system consists of a nozzle and may also include a thrust reverser and an afterburner.

In a basic exhaust system, the hot gases leaving the turbine are discharged through a propelling nozzle at a velocity that provides thrust. In VTOL aircraft, the nozzle swivels vertically so the aircraft can move up and down.

The thrust reverser enables the aircraft to slow down and stop more quickly upon landing, allowing the aircraft to land on shorter runways without relying solely on braking devices. Thrust reversal quite simply reverses the direction of exhaust gases to decelerate the aircraft. The two main thrust reversal methods use either clamshell-type deflector doors or bucket-type deflector doors on a retractable ejector.

Afterburner. An afterburner is used in some aircraft, such as supersonic jets (SSTs), including the Concorde and military aircraft, that need to reach high speeds in a short time. Unburned oxygen from the jet engine's exhaust system flows into an afterburner, where more fuel is injected into the hot gases to augment the thrust of the engine. The temperature of the exhaust gases increases, thereby increasing the gas velocity and the thrust of the engine. This additional thrust allows for acceleration to supersonic speeds or for faster takeoffs to accommodate combat situations or the shorter runways of aircraft carriers.

Types of Jet Engines

The basic types of jet engines are the turbojet, turbofan, turboprop, and turboshaft. Turbojet and turbofan engines are called reaction engines, because they derive their power from the reaction to the momentum of the exhaust gases. The turboprop and turboshaft engines, however, utilize the momentum of the exhaust gases to drive a power turbine that, in turn, drives either a propeller or an output shaft.

Turbojet. The turbojet was the first jet engine type to be invented and flown. In a turbojet, all of the intake air passes through the compressor and is burned in the combustion chamber. The hot gases pass through the turbine and are then expelled through the exhaust nozzle to provide the thrust required to propel the engine and the aircraft attached to it forward. Examples of the turbojet appear in both civilian and military aircraft, including the Olympus 593 in the Concorde SST.

Turbofan. By the end of the twentieth century, the turbofan had become the most popular choice for aircraft propulsion in both civilian and military aircraft. In a turbofan engine, a large fan is placed at the front of the compressor of the jet engine. The amount of intake air is increased up to ten times. Most of this cool intake air either bypasses the compressor, combustion chamber, and turbine and exits the fan nozzle separately, as in separate-flow turbofans, or gets mixed with the turbine exhaust and exits through a common nozzle, as in the mixed-flow turbofan.

Afterburners in turbofan engines are equipped with a mixer to mix the cooler bypass air with the hot exhaust gases, thus allowing an easier burning of the bypassed air. Turbofan engines are characterized by their bypass ratio, which is the mass flow rate, in pounds per second, of air going through the fan divided by the mass flow rate of air going through the compressor. Low-bypass engines have ratios of up to two; medium-bypass engines have ratios from two to four, and high-bypass engines have ratios from five to eight. Ultrahigh-bypass engines have bypass ratios from nine to fifteen or higher. The highest bypass ratios, although providing high propulsion efficiency, likewise involve large, heavy components.

The advantage of the turbofan is its greater thrust on the same amount of fuel, which results in more efficient propulsion, lower noise levels, and an improved fuel consumption. Turbofan jet engines power all modern commercial aircraft, such as the Boeing 747; business jets, such as the Gulfstream IV; and most military airplanes, such as the F-18. Future turbofans may combine various bypass features. For example, the variable-cycle engine (VCE) would have both high-bypass and low-bypass features. Such an engine would be designed for planes that travel at subsonic and supersonic speeds. The VCE would operate by a valve that would control the bypass stream, either increasing it for subsonic speeds or decreasing it for supersonic speeds.

Turboprop. A turboprop engine is a turbojet engine with an extra turbine, called a power turbine, that drives a propeller. In the turboprop engine, the jet exhaust has little or no thrust. Planes powered by turboprop engines typically fly at lower altitudes and reach speeds up to 400 miles per hour (640 kilometers per hour). An example of the turboprop engine is the Rolls-Royce DART in the British Aerospace 748 and the Fokker F-27.

Turboshaft. A turboshaft is a turboprop engine without the propeller. The power turbine is instead attached to a gearbox or to a shaft. One or more turboshaft engines are used on helicopters to power the rotors. The turboshaft engine has industrial applications, such as in power stations, and marine applications, such as in hovercrafts.

Jet Engine Pollution

Because it is an internal combustion engine whose exhaust gases flow directly into the environment, a jet engine is a serious source of air pollution. Because of its high level of noise, its also causes noise pollution.

Air Pollution. Air pollution results from the combustion process of the gas-turbine engine. Jet-engine emissions, including carbon dioxide, carbon monoxide, hydrocarbons, and nitrogen oxide gas, contribute to both the greenhouse effect and atmospheric ozone depletion. They also endanger the health of people especially near airports.

Some regard aircraft transportation as more polluting than any other type of transportation, including the automobile. Generally, older aircraft are greater polluters than newer aircraft. The turbofan and bypass turbofan engines in particular use less fuel and therefore pollute less. A new MD-90 is about 50 percent more economical than a DC-9 or a DC-10, because the newer plane uses less fuel. Nevertheless, studies show that per passenger, an airplane uses twice as much fuel per passenger than does a car with three passengers, when the car drives the distance a jet travels in one hour (770 kilometers).

Airplane fuel consumption could be improved by eliminating various classes of cabins in the aircraft. Business- and first-class cabins seat fewer passengers, thereby reducing the overall fuel efficiency of the aircraft. If a reduction in carbon dioxide aviation emissions is to be realized, older aircraft must be replaced with newer ones that have more fuel-efficient engines. The most environmentally friendly aircraft include the B-777 and B-767. Carbon monoxide is contained in the combustion exhaust fumes. Both carbon monoxide and hydrocarbon emissions occur at the highest rates when airplanes idle their engines on runways, where often twenty planes are lined up waiting for takeoff. Airplanes pollute hundreds of times more when idling than when flying.

Nitrogen dioxide emissions contribute to acid-rain formation. The emission of hydrocarbons, especially radical ones, contribute to ozone formation. In terms of these emissions, the new high-bypass turbofan jet engines pollute much less than older turbofan and turbojet engines. Sulfur dioxide emissions also contribute to acid-rain formation. Nitrogen oxides have a possible role in ozone depletion, and its reduction can only be effected by less air traffic in general.

Noise Pollution. Noise is measured on a logarithmic scale in decibels, a unit of audio power. The decibel range is from zero decibels to about 160 decibels. A normal conversation takes place at about 40 decibels, and a noise level of 90 decibels would make it impossible to hear a normal conversation. The noise from a nearby jet takeoff is about 110 decibels. The main source of jet-engine noise is the propulsion system and the resultant noises generated by both internal and external processes.

In early turbojet engines, the noise occurred behind the exhaust nozzles when the hot exhaust gases mixed with the cool atmospheric gas. The high-bypass turbofan engines alleviated this noise problem.

Nevertheless, noise issues continue with the fan noise and core noise in high-bypass turbofan engines. Fan noise can be either broadband, discrete tone, or multiple tone, depending on whether the tip speed of the fan rotor blades is subsonic or supersonic. Core noise includes the noise from the rotation of the compressor, the noise from the turbulence generated in the combustion chamber, and the noise from the turbine.

Aircraft noise is regulated by federal rules that become increasingly stringent with time. Aircraft are classified as either stage one, for very noisy, 1960's-era jetliners; stage two, for moderately noisy, 1970's-era jetliners; or stage three, for more quiet, modern aircraft. Beginning in the year 2000, only stage-three aircraft may operate in the United States and Europe. Supersonic commercial aircraft, such as the Concorde, operate under different regulations and are only allowed to take off and land at certain airports because of the noise they make during takeoff.

To reduce external noise, the exhaust stream velocity may be decreased by flying jets that have a turbofan engine with a bypass ratio of five or higher. Such engines reduce exhaust noise considerably. With lower levels of external noise, internal noises are more audible.

To reduce internal noise, the fan tip speed can be decreased, although this would result in the necessity of more compressor stages, therefore resulting in a heavier engine. More spacing between the rotor and stator would also lessen the noise, but the larger spaces would require a larger engine.

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See also: Engine designs; Jumbojets; Propulsion; Ramjets; Turbojets and turbofans; Turboprops

Jet packs

Definition: Propellant packs used for individual flight, rather than for aircraft.

Significance: Jet packs, originally conceived for use in terrestrial battle, have become of major importance in providing for the safety of astronauts during space walks.

Rocket Belts

The jet pack is a device to allow a single person to fly without being enclosed in an aircraft. Jet packs first came to public attention during the opening ceremonies of the 1984 Summer Olympic Games in Los Angeles, California. The jet pack itself attaches to a regular backpack.

The inventor of the first practical jet pack, or rocket belt, was Wendell F. Moore. In the early 1950's, Moore was an engineer at Bell Aerosystems and worked on the concept of small, light system mounted on a person's back, that could be worn into battle. The idea had first been proposed by the Germans, who had been working on it at the end of World War II. However, Moore found very few people at Bell willing to fly the jet pack more than once or twice. Fortunately, Moore's nineteen-year-old neighbor, William P. Suitor, had watched him working on the project in his backyard and was eager to fly the rocket belt. Suitor was hired by Bell in 1964 to work with its designers and engineers to learn to fly the new aircraft, at first on tethers, then in free flight. Suitor became known as the "Rocket Man."

The rocket belt or jet pack used a hydrogen peroxide reaction rocket engine. The engine has a tank of compressed liquid nitrogen that pushes hydrogen peroxide out of two other tanks into a reaction chamber, a box with silver screens coated with samarium nitrate. This box reacts to the hydrogen peroxide, in turn creating a high-pressure steam that propels the belt as it flows out of the flight nozzles. The steam is so hot that it renders the jet pack not only quite dangerous but also loud, emitting a screaming sound. Nevertheless, the pack handles amazingly well.

In addition to the original Bell rocket belt, there is the RB2000, designed by Brad Barker, Joe Wright, Larry Stanley, and Doug Malewicki. These men used the basic principle and design of the original Bell model but managed to increase the flight time from 20 to 30 seconds. Various improvements, such as the use of new materials that can withstand higher temperature, have led to a lighter belt. The importance of such a belt is its ability to carry more propellant while still being comfortable for the pilot. Nonetheless, 30 seconds is the most one can expect to fly with the belt. In order for the jet pack to be really practical, it will be necessary to develop tiny jet engines to power it, which can be used in concert with the lightweight hydrogen peroxide rockets for fast takeoff, higher altitude, and longer flights.

Given its early promise, it is surprising that jet-pack technology failed to make an impact on personal transportation during the late twentieth century. There are hopes that the twenty-first century will finally see it achieve its promise as a viable means for personal travel.

Image Not Available

Jet Packs in Space

Jet packs, once purely science fiction, are now part of the standard equipment of astronauts. The pack is a device fitted with pressurized metal containers that let out jets of gas, worn by astronauts on their backs to enable them to move around in space outside a spacecraft. The National Aeronautics and Space Administration (NASA) has introduced a new version of the jet pack called Simplified Aid for Extravehicular Activity Rescue (SAFER). This pack is a backup for the traditional tether that attaches the astronaut to the spacecraft. It is intended as an extra precaution for astronauts working outside space vehicles. The jet pack is also useful as a rescue device for astronauts who work outside spaceships. This pack was first tested in 1994 during a flight of the space shuttle *Discovery.* Astronauts Mark Lee and Carl Meade were the first to test the jet pack in space on September 16, 1994.

The pack weighs 80 pounds and carries 3 pounds of nitrogen propellant. There are twenty-four 1-inch-long thrusters, four to each side of a cube. Astronauts use a joystick fastened to the chest of the spacesuit to control their maneuvers. After astronauts right themselves, the packs enable them to get back to their vehicles at a maximum rate of 10 feet per second, or just over 6 miles per hour. The average speed, however, is closer to 1 mile per hour. There is little time for hesitation, since the packs only hold thirteen minutes of propellant fuel.

SAFER maneuvers much more easily than the previous 340-pound pack last used in 1984, the Manned Maneuvering Unit (MMU). Unlike the MMU, the new jet pack is worn during routine space walks. The astronaut can use various combinations of the jets to control pitches and rolls. The jet pack, which is rather boxy in shape, clips onto the regular backpack. There is a liquid crystal display allowing the astronaut to monitor information about fuel and battery power. There is also a computer in the pack to control the deployment of jets to stabilize the falling astronaut.

The development of SAFER has given greater credibility to the jet pack. Extravehicular activity emergencies are an astronaut's worst nightmare. SAFER provides the astronaut a good chance to get back to the vehicle even in a worst-case emergency scenario. The first test of the jet packs was a success. However, two subsequent trials revealed problems. In 1997, the jet thrusters of Scott Parazynski's pack failed to fire. In 1998, Jerry Ross's pack burned his nitrogen gas at a higher rate than expected. These problems led NASA to conduct rigorous ground tests to locate and solve the problems. Astronauts compare jet packs to parachutes: pieces of equipment that they hope never to use, but that are reassuring to have available.

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See also: Astronauts and cosmonauts; National Aeronautics and Space Administration, Propulsion; Spaceflight

Jet Propulsion Laboratory

Definition: The primary National Aeronautics and Space Administration (NASA) site for control and operations of U.S. lunar and interplanetary missions.

Significance: Almost all U.S. lunar and planetary missions have been controlled from the Jet Propulsion Laboratory (JPL) since it was transferred to NASA's control. Prior to that time, many of the United States' early developments in rocketry and missiles took place at JPL. JPL is also responsible for NASA's Deep Space Network of tracking and telemetry stations.

The Early Years

The Jet Propulsion Laboratory, located in Pasadena, California, evolved from a project in rocket propulsion that began in the early 1930's. During that time, one of the leading organizations in aeronautics study and research was the Guggenheim Aeronautical Laboratory at the California Institute of Technology (GALCIT), directed by Dr. Theodore von Kármán, also in Pasadena. In 1936, graduate student Frank J. Malina successfully approached von Kármán with a proposal to write his doctoral dissertation on rocket propulsion and high-altitude sounding rockets. This early work in rocket propulsion attracted the attention of two local rocket enthusiasts, John Parsons and Ed Forman. Together, the four men worked through the theories of rocket propulsion and designed a rocket engine, with some insights gained from a meeting with rocket pioneer Robert H. Goddard.

Because no safe campus facilities were available at which to test the rocket engine, Malina, Parsons, and Forman drove to an isolated site a few miles from the California Institute of Technology (Caltech) in the Arroyo Seco wilderness area. Although their first few tests were unsuccessful, the men eventually developed a working rocket engine. Their early successes with rocket engines gained the group facilities on the Caltech campus in which to continue their work.

In 1938, GALCIT was awarded a grant to study the possibility of using rockets to assist U.S. Army Air Corps aircraft on takeoff from short runways. A much larger grant from the National Academy of Sciences was awarded in 1939 to continue the jet-assisted takeoff (JATO) rocket work, signaling the beginnings of a significant shift for GALCIT's rocket project, from research for sounding rockets to research for military applications. In 1943, von Kármán produced a report, together with Malina and Qian Xuesen, on rocket research at GALCIT and proposed a significant expansion of rocket research, including a proposal to construct missiles capable of carrying explosive warheads and investigations of ramjet engines. This report contained the first usage of the term Jet Propulsion Laboratory to describe the GALCIT rocket facilities that had been constructed for the JATO work.

Though the laboratory's research was focused primarily on rocket propulsion technology, von Kármán chose the name Jet Propulsion Laboratory over Rocket Propulsion Laboratory. There may have been several reasons for this choice. Because rockets propel themselves through jets of gas, the term "jet propulsion" is more general than "rocket propulsion" and technically more accurate. Furthermore, by not limiting the scope of the laboratory to rocket research, von Kármán was leaving the door open for the laboratory to continue the original GALCIT work in other fields of aeronautical research. In addition, many military minds may have mentally associated the term "rocket" with fireworks. Jet propulsion was a new technical term that would more readily have caught their attention. Finally, due to the preponderance of poorly written science fiction about rockets and rocket ships and the negative publicity many amateur rocket enthusiasts had garnered, the term "rocket" had come to carry an unfavorable connotation, which von Kármán may have been trying to avoid.

The Army Years

In 1944, the Army authorized a $1,600,000 grant to construct a major research and development facility for rocketry and guided missile research operated under contract by Caltech. The new facility was officially named the Jet Propulsion Laboratory, GALCIT. The new JPL was charged with the mission of carrying forth several separate areas of research: rocket engine research, underwater solid-fueled missiles, ramjet research, and long-range heavy missile research, most of which had been mentioned in von Kármán's proposal the year before. At about this time, von Kármán left both Caltech and JPL, and the directorship of the now-official Jet Propulsion Laboratory fell to his former graduate student, Dr. Frank Malina.

To measure performance of their rockets, JPL's engineers and scientists developed radio telemetry techniques to monitor their missiles in flight. Telemetry is data transmitted from a remote location by radio signals. To track its missiles, JPL also developed a series of ground radio and radar stations. By 1945, JPL had launched rockets from White Sands, New Mexico, to altitudes of nearly 30 miles. The JPL team eventually developed the technology for two-way radio control of the rockets. In 1947, JPL launched the Bumper-Wac rocket, which first carried an American payload to the edge of space.

By the late 1940's, JPL had developed the Corporal missile, the United States' first operational surface-to-surface missile. By the early 1950's, researchers at JPL had designed the first solid-fueled antiaircraft missiles. In 1954, JPL proposed Project Orbiter, which would use a Redstone rocket as a first stage and either Loki or Sergeant rockets as upper stages, to put an artificial satellite into orbit around the earth by as early as 1957. The project was rejected. In October, 1957, however, the Soviet Union placed its Sputnik satellite into orbit. After Sputnik, JPL was given the go-ahead on its orbital project. Redstone would provide the missile, but JPL would design the payload and upper stage of the rocket to put the satellite into orbit. JPL would also handle tracking of the satellite. Finally, on January 31, 1958, the United States launched JPL's satellite, which was named Explorer 1.

With Explorer 1, JPL had once again shifted its emphasis, which now focused on the electronics and communications involved in fabricating a satellite rather than on the rocket used to launch the satellite. Following Explorer 1, JPL, under the Army's supervision, was responsible for the development and operation of several other uncrewed Explorer spacecraft.

The NASA Years

Prior to launch of Explorer 1, several different government agencies were involved in space-related activities. It was deemed advantageous, however, to put all space-related activities except for certain military applications, under one civilian agency's jurisdiction. Thus, on October 1, 1958, the National Aeronautics and Space Administration (NASA) was created. On December 3, 1958, JPL was transferred from the jurisdiction of the Army to that of NASA but would continue to be operated by Caltech, under contract with NASA. The role of JPL under NASA would be primarily one of satellite and space probe design and operations. Although JPL was responsible for the Deep Space 1 spacecraft, which successfully tested an ion-drive propulsion engine, very little rocket propulsion work continued at JPL after this time.

NASA continued the expansion programs at JPL's Pasadena site that had begun under the Army's administration. Additional scientists and engineers were hired, and new facilities were built, so that JPL came to be situated on 177 acres of land near where von Kármán's team had done its original rocket propulsion experiments. Although under NASA, the Jet Propulsion Laboratory ceased research in jet or rocket propulsion, its original name remains in use.

By the year 2001, JPL had been responsible for nearly 60 spacecraft missions, as well as numerous payloads flown on space shuttle missions. Although a few of these missions failed to perform as expected or were lost due to launch vehicle or spacecraft failures, most missions were successful. Several JPL missions, such as the Voyager missions to the outer solar system, many of the Mariner missions to the inner planets, the Galileo mission to Jupiter, the Magellan mission to Venus, and the Viking missions to Mars, have enjoyed spectacular successes. Under NASA, JPL has achieved dominance in the field of lunar and planetary exploration, having successfully handled missions to every planet in the solar system except for Pluto, as well as missions to several asteroids. Although studies of Earth were largely carried out by other NASA centers, JPL has also played a key role in several missions studying the planet Earth.

The Deep Space Network

When Explorer 1 was to be placed into orbit in 1958, scientists immediately realized that there would be difficulty monitoring it. As the earth turned beneath the satellite, the groundtrack, or location on the surface of the earth underneath the spacecraft, would shift to the west with each orbit and not all of the orbits would pass over the United States. The satellite would be overhead in the United States only for a short period of each orbit that did pass over the United States. To track and monitor the satellite, therefore, JPL was responsible for deploying portable radio tracking equipment to several sites around the world. Two other Explorer spacecraft were successfully launched, and two more were lost during launch vehicle failure, before JPL was transferred from the Army to NASA. All these satellites needed remote facilities for tracking, telemetry, and control. The original equipment and sites used for Explorer 1 would suffice for the later missions, so that new facilities for each mission would not have to be built and deployed. This decision paved the way, however, for more permanent tracking and telemetry stations.

After JPL was transferred to NASA, a decision was made to build permanent tracking and telemetry stations to support the large number of planned space missions, both crewed and uncrewed. These stations formed the backbone of the Deep Space Network (DSN), operated for NASA by JPL. The core of the DSN is composed of three large communications complexes located near Madrid, Spain, near Canberra, Australia, and at Goldstone, in California's Mojave Desert. These sites are located nearly 120 degrees apart on the earth's surface and thus can provide whole-sky coverage. Nearly any portion of the sky is above the horizon from at least one of the DSN sites. Each site has several antennas for telemetry and two-way communications with spacecraft.

Because many of NASA's space probes have traveled a long way from Earth, the signals from these space probes have become increasingly weak. The DSN has located at each site a 230-foot diameter parabolic dish, forming one of the most sensitive and powerful telecommunications systems on Earth. Also located at each site are 112-foot-diameter, high-efficiency dishes for use with slightly stronger signals. Each site also holds 85-foot-diameter dishes on mounts designed to track satellites in fast-moving orbits near Earth. Each site also holds a 36-foot-diameter dish, each of which can be linked together with those of the other sites for astronomical use in a technique known as long-baseline interferometry.

Other Projects

Although JPL is known primarily for its roles in the early years of American rocket research and in the design and control of NASA spacecraft, JPL has also been involved in several other noteworthy projects. Many of these projects are natural spin-offs and extensions of the technologies that were developed for uncrewed spacecraft operations. JPL has played an important role in the study of solar energy as an alternate source of energy. JPL has also worked to develop an airborne, infrared fire-spotting system for the U.S. Forest Service. JPL has been involved in the advancement of robotics and automation and the development of miniature sensors and instrumentation. To deal with the enormous volume of data returning from space probes, JPL has also developed new, more powerful computer technologies, many of which have found their way into everyday non-space-related applications.

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See also: Aeronautics; Aerospace industry, U.S.; Robert H. Goddard; Jet engines; National Aeronautics and Space Administration; Orbiting; Propulsion; Ramjets; Rocket propulsion; Rockets; Satellites; Spaceflight

Amy Johnson

Date: Born on July 1, 1903, in Kingston upon Hull, Yorkshire, England; died January 5, 1941, in Thames estuary, London, England

Definition: Pioneering female pilot, considered by many to be the British equivalent of Amelia Earhart.

Significance: In the early years of aviation, Johnson held many long-distance flying records and was the first woman to fly solo from London to Australia.

Amy Johnson earned a bachelor of arts degree in economics from the University of Sheffield in 1926. Despite her education, she found it difficult to find suitable employment in an era when few women worked outside the home. She reluctantly accepted a secretarial position and instead chose to challenge herself through hobbies.

One of those hobbies was the relatively new field of aviation. During the winter of 1928-1929, Johnson learned to fly at the London Aeroplane Club. She earned private and commercial pilot's licenses and was qualified as a navigator. She was also the first woman in England to be certified as a ground engineer.

Determined to find an area in which women could compete equally with men, Johnson focused her attention on distance flying. She planned a solo flight from England to Australia, with the intention of beating the previous record of sixteen days, held by Bert Hinkler. With the support of her father, a successful merchant, and financial backing from Lord Wakefield, Johnson purchased a used De Havilland DH-60G Gipsy Moth. She named the open-cockpit biplane *Jason*, after the trademark for her family business.

Johnson set off from Croydon, a suburb of London, on May 5, 1930, making her first stop in Karachi, India, and breaking the record for that distance by two days. Bad weather and damage from a landing near Rangoon delayed her progress, however, and she landed in Darwin, Australia, on May 24, 1930, after 11,000 miles and nineteen and one-half days in the air. Although Johnson did not break the record, she did gain fame as the first woman to fly solo from London to Australia. She was nicknamed "Queen of the Air" by the British press and named a Commander of the Order of the British Empire.

More records followed. In July, 1931, Johnson and copilot Jack Humphreys set the England-to-Japan record. They followed with record-breaking flights from England to Capetown in 1932. In 1932, Johnson married leading British pilot and long-distance flier Jim Mollison, with whom she attempted an around-the-world flight. They crashed in Connecticut, however, and were divorced in 1938.

In 1939, at the start of World War II, Johnson joined the Air Transport Auxiliary (ATA), a pool of experienced pilots ineligible for duty in the Royal Air Force (RAF) who ferried planes from factories to bases. While flying a mission from Blackpool to Oxford, Johnson was caught in a storm and blown off course. Her plane ran out of fuel and she was forced to ditch into the Thames Estuary. Although observers spotted a parachute, her body was never recovered, and Johnson was presumed drowned. After her death, a song, "Amy, Wonderful Amy," was written in her honor.

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See also: Military flight; Record flights; Women and flight; World War II

Johnson Space Center

Also known as: Lyndon B. Johnson Space Center

Date: Established September 19, 1961; began operations March 1, 1962

Definition: The principal facility for oversight and operations of crewed spaceflight by the National Aeronautics and Space Administration (NASA).

Significance: The Johnson Space Center (JSC) has been responsible for astronaut training, crewed spacecraft development, and control of all U.S. crewed space missions in flight since 1965. JSC is also the site of the primary control center for the International Space Station (ISS) and is the location of the Lunar Receiving Laboratory, which studies Moon rocks and meteorites.

History

As early as 1957, engineers and scientists at the Langley Aeronautical Laboratory at Hampton, Virginia, were collaborating on the possibility of crewed exploration of space. With the United States rapidly increasing the number of planned space missions, the National Aeronautics and Space Administration (NASA) was created on October 1, 1958, to coordinate the rapidly expanding U.S. space program and to consolidate the various space projects under one civilian agency. Realizing that crewed space missions would be much more complex and challenging than uncrewed missions, on November 4, 1958, NASA created a special task force, called the Space Task Group (STG), to deal with the issues of crewed spaceflight. The STG was based at Langley but was charged with oversight of the crewed spaceflight. STG's first crewed space program was Project Mercury. In May of 1959, STG was made one of six departments of the newly formed Goddard Space Flight Center, in Greenbelt, Maryland. Because of STG's rapid growth during this period, however, STG never physically moved to Goddard. On March 1, 1961, STG was made an independent entity within NASA.

On May 25, 1961, President John F. Kennedy made public a challenge and a goal for NASA to send a crewed mission to the Moon. This was an enormous jump from Project Mercury, and it required a major expansion of the roles, duties, and personnel associated with the STG. With the expansion of the STG to such levels, NASA administrator James Webb created the Office of Manned Space Flight, a special NASA division that included STG. One of the first goals of the new Office of Manned Space Flight was to secure a location for a new NASA center dedicated to crewed space missions. Cape Canaveral, NASA's primary launch facility, was also a military missile test facility, and the Langley site was not fully suitable for expansion to include all of the facilities envisioned for the new center.

The selection of a permanent site for the new NASA center near Houston, Texas, was not without contention. Many NASA personnel wanted the new center to be either in California, near the Jet Propulsion Laboratory, or in Florida, near the launch facilities. Most of the STG team at Langley preferred establishing a facility adjacent to or near Langley. Pressure from then-vice president Lyndon B. Johnson and Speaker of the House Sam Rayburn, both of Texas, together with several influential Texas legislators, caused NASA to consider a more centrally located site. Longtime associates of Johnson at Humble Oil finally helped the Houston site to win NASA's favor. Humble Oil donated 1,000 acres of land to Rice University in Houston, with the stipulation that the land be made available to NASA. Although land costs were not a major issue, it would not have been prudent for NASA to turn down the offer of free land for the center, especially in light of the political pressure placed upon the agency to locate a major NASA center in Texas.

Thus, on September 19, 1961, NASA announced that the new center would be located on the outskirts of Clear Lake City, a suburb of Houston. On November 1, 1961, the new NASA installation became officially designated the Manned Spacecraft Center (MSC), at which time the STG ceased to exist as a separate entity and was absorbed into the new center. Some operations began at once in leased office spaces in the Houston area, and, on March 1, 1962, Robert Gilruth, director of the new MSC and former head of the STG, moved his headquarters to Houston, officially making the MSC an operational NASA center. MSC was formally opened in February, 1964.

Construction on Mission Control began soon after the Houston site was selected, and MSC's Mission Control served as the backup command center for the Gemini 2 and Gemini 3 missions, the first crewed Gemini missions. Beginning with the Gemini 4 mission in June of 1965, Mission Control in Houston has acted as the principal mission-command center for all U.S. crewed space missions.

Astronaut training facilities were constructed at MSC to prepare the astronauts for the conditions that they would face in space travel. Spacecraft were designed and tested at MSC, and the Lunar Receiving Laboratory was constructed to house and study the Moon rocks returned to Earth by the Apollo astronauts. Nearly adjacent to MSC was Ellington Air Force Base, later renamed Ellington Field after it was decommissioned by the Air Force, where training aircraft were kept for the astronauts. On February 17, 1973, the Manned Space Flight Center was formally renamed the Lyndon B. Johnson Space Center (JSC) in recognition of the late President Lyndon B. Johnson, his role in the Houston site's selection, and his support for crewed spaceflight.

Mission Control

The Mission Control Center (MCC) is the part of JSC with which the public is most familiar. Mission Control occupies a prominent building, designated Building 30, near the center of JSC. On the first floor of the MCC, advanced computer systems analyze the telemetry data collected during crewed space missions. The most visible part of the MCC is the Flight Control Room (FCR). There are actually several FCRs in the MCC. Nearly identical FCRs exist on the second and third floors, with the third floor FCR used primarily for military missions. Down the hall from the primary space shuttle FCR is a slightly different FCR used for the International Space Station (ISS) operations. The FCR consists of rows of flight-control consoles facing a large display at the front of the room. Each flight-control position has computer screens and other readouts, and the controller at that position is responsible for monitoring a specific part of the mission. The lead flight control position is that of the flight director, who is ultimately responsible for all decisions related to the mission. Although the FCRs are the most publicly visible part of the MCC, they are only a small part of Mission Control. Each flight-control position is assisted by a team of engineers and technicians, many of whom work in small rooms adjacent to the FCR.

Training Systems

To prepare astronauts for the various situations to be encountered in spaceflight, numerous training facilities were built at the Johnson Space Center and at nearby Ellington Field. Some of these facilities, such as a large centrifuge built to simulate the high accelerations experienced on lift-off, were built for the Gemini and Apollo missions and were later dismantled to make room for space shuttle training systems. Other training systems include mock-ups of the various spacecraft used in crewed spaceflight. The mock-ups were used as simulators to train astronauts to deal with various situations that they would encounter in space travel. The space shuttle simulators are still used.

A Space Environment Simulation Laboratory (SESL) was constructed at MSC/JSC. The SESL consists of several chambers that are designed to reproduce the environment experienced by astronauts and equipment in space. The atmospheric pressure within the chambers can be reduced to that of a vacuum, and high intensity lamps and other electromagnetic radiation sources can be used to simulate the radiation environment in space. These chambers were used to test spacecraft, equipment, and space suits. The SESL can also be used to train astronauts to deal with the difficulties faced by such harsh environments.

To simulate the near-weightless conditions of spaceflight, JSC constructed a Neutral Buoyancy Training Facility (NBTF) at Ellington Field. The NBTF consists primarily of a very large tank of water. Astronauts wearing space suits and equipment are weighted to have a buoyancy equal to their weight. This simulation of weightlessness gives astronauts a chance to practice working and handling equipment in such an environment. A smaller but similar facility, the Weightless Environment Training Facility (WETF), where the centrifuge used to operate, was constructed in the early days of the space shuttle program.

Aircraft Operations

The Johnson Space Center operates several aircraft from Ellington Field. Some of these aircraft are used for astronaut training, and others are used in support of JSC's mission as lead NASA center for crewed spaceflight operations. One of JSC's training aircraft is a KC-135A transport aircraft, known as the "Vomit Comet," which flies parabolic arcs that yield a few seconds of near-zero-gravity environment inside the aircraft. The KC-135A is used to train astronauts and perform experiments at very low gravity in a manner far superior to that of the NBTF. Unfortunately, it is unable to maintain a low-gravity environment for more than a few seconds at a time, so many parabolic arcs are needed per flight.

Many of the astronauts act as pilots for their spacecraft. These astronauts must keep current in flight training. JSC maintains T-38 jet trainers at Ellington to allow the astronauts to train in high-performance aircraft. Furthermore, at least one of the T-38 trainers is fitted with control systems that mimic the very sluggish and difficult flight controls of the space shuttle. Pilot astronauts can use this trainer to practice the maneuvers needed to pilot the space shuttle to a safe landing.

In addition to the training aircraft at Ellington, JSC also is the home to a very large turboprop cargo aircraft called the Super Guppy. This aircraft has a cargo bay 25 feet tall, 25 feet wide, and 111 feet long. It is used to transport large pieces of equipment, such as ISS components. A similar aircraft, nicknamed the Pregnant Guppy, carried components of the Saturn rockets used in the Apollo missions.

Lunar Receiving Laboratory

In 1967, construction began on a special laboratory at MSC designed to handle the Moon rocks expected to be brought back to Earth by the Apollo astronauts. Not knowing at the time whether the Moon had any indigenous life, NASA constructed the laboratory with special safeguards designed to prevent any cross-contamination of the Moon rocks with the Earth environment. Although it was soon determined that there is no life on the Moon, this sterile laboratory environment permits researchers the opportunity to analyze Moon rocks without accidentally contaminating them with Earth material. Although the last Moon mission returned to Earth on December 19, 1972, NASA maintains the Lunar Receiving Laboratory as a repository for the precious Moon rocks brought back to Earth. Facilities were constructed at the laboratory to analyze the geological properties of the Moon rocks and to study any lifeforms that may exist in them.

Because the Lunar Receiving Laboratory was designed to study Moon rocks without contaminating them with Earth material, it was natural for scientists to think of using the same laboratory to study meteorites found on Earth. Numerous meteorites found during the late 1970's and 1980's were sent to JSC's Lunar Receiving Laboratory for study. Among these meteorites, one called ALH-84001 created a great deal of excitement when researchers at JSC, working with scientists at Stanford University, announced in 1996 that ALH-84001 appeared to be a piece of the planet Mars thrown loose during a giant meteorite impact on that planet long ago. Furthermore, these researchers announced findings that indicated that this meteorite may contain fossil remains of Martian life. These findings remain in doubt, but it is clear that the unique facilities of the Lunar Receiving Laboratory present an ideal location to study extraterrestrial samples.

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See also: Apollo Program; Crewed spaceflight; National Aeronautics and Space Administration; Space shuttle; Spaceflight; "Vomit Comet"

Jumbojets

Definition: The term jumbojet was coined to refer to the Boeing 747, and by extension, to any wide-bodied plane that seats five hundred or more passengers.

Significance: Jumbojet planes carry more passengers per flight, reducing costs and providing more efficiency for airlines.

The Jumbojet has been so popular that the U.S. Post Office recently put it on a 33-cent stamp in the Celebrate the Century series, honoring the most significant people, places, events, and trends of the 1970's. Once airlines discovered that jets were significantly cheaper to operate per passenger mile than even the most efficient piston-engine planes, it was only a matter of time before jumbojets came on the market. The first jumbojet was the Boeing 747, capable of carrying five hundred passengers. However, most

747's were designed for about four hundred passengers, allowing room for mail, freight, and baggage. The 747's inaugural commercial flight was made in 1970.

The Boeing 747 has four jet engines and reaches a cruising speed of 550 miles per hour. Other manufacturers soon produced their own versions of wide-body jumbojets. McDonnell Douglas built the DC-10, a three-engine plane. McDonnell Douglas later modified this design to produce the MD-11. Lockheed had its own jumbojet, the L-1011 TriStar, which is no longer produced. Airbus Industrie produced the A300 twinjet wide-body.

The 1980's witnessed changes in jumbojets. McDonnell Douglas manufactured the MD-80 series of twin-engine jets, while Boeing introduced the 757 and 767 twinjets. The 757 was a narrow-body jet, complementing the wide-body 767. Meanwhile, Airbus introduced the A310 twinjet and its own narrow-body A320. The A320 twin was unique, featuring a sidestick controller for pilots, replacing the typical control columns and wheels. Airbus also came out with the A330, a larger twin-engine, and the A340 four-engine plane, designed for longer flights. Airbus plans to manufacture superjumbos that will carry more than 550 passengers.

Other manufacturers also have plans to build larger jumbos. Boeing's 777 wide-body jumbo currently holds up to four hundred passengers. Boeing purchased McDonnell Douglas in 1997, and in 1999 revealed plans to expand the 747 to hold up to 524 passengers.

History

In the early 1960's, Douglas, Lockheed, and Boeing were in competition for a U.S. Air Force contract for an order of a new heavy cargo jet. The Lockheed Galaxy was the Air Force's choice. However, even though Boeing lost the contract, the company put its experience to good use in a project to build a new civil aircraft. This aircraft would have a huge passenger capacity, made possible by General Electric and Pratt & Whitney's new engine. Boeing engineers built the fuselage as one long tube, including an upper flight deck. The new plane would have a maximum of five hundred passengers in rows of ten seats (divided into set of three, four, and three). The 747 became popularly known by its nickname, the "jumbojet."

The jumbojet was revolutionary in many ways. Its wing concept was different from that of other planes. It was the first civil plane to have four huge, powerful engines such as the Pratt & Whitney JT9D, which were needed to power an airplane with a weight of nearly 335 tons.

On February 9, 1969, the 747 made its maiden voyage. Twenty-six airlines had ordered the 747. Pan American was the first airline to make a commercial flight with the jumbojet, on a New York-to-London flight on January 22, 1970. The success of the first 747's led to the development of new engines by Pratt & Whitney, as well as General Electric and Rolls-Royce. On October 11, 1970, the first 747-200 flew. The 747-200 weighed about 378 tons and sported a larger fuel capacity. There is a version for passengers, the 747-200B, and one for cargo, the 747-200F. The 747-200C can be converted to passenger or cargo use. The 747-200 had 650 units delivered, easily the most successful jumbojet.

Boeing wanted a shorter version of the 747 and in 1973 produced the 747SP (Special Performance). It was a challenge to the Lockheed TriStar and the Douglas DC-10. The 747SP can fly very long distances. Furthermore, 90 percent of the parts used in the 747SP are the same as those used in the 747-200. It has a higher tail than the 200, as well as a longer elevator unit. Boeing manufactured forty-four 747SP's. From a shorter plane, Boeing turned to a larger one, the 747-300. It had a stretched upper deck that could seat sixty-nine passengers. Ninety of these planes were manufactured. The first of this series flew commercially on October 5, 1982.

The next of the 747's was the 747-400. It had a new wing design and new fuselage material as well as a two-pilot glass cockpit. These features made the 747-400 the most advanced and economic jumbojet. Its new engines allow the 747-400 to carry over 394 tons. It also has both cargo and the convertible models.

Other Jumbojets

McDonnell Douglas decided to improve its DC-10, and in the 1960's produced the longer DC-10-60. It was able to seat up to four hundred passengers. The DC-10-60 was supposed to have better engines and a better wing performance. However, it had more accidents than Douglas was comfortable with, and the company decided not to produce any new versions of the DC-10.

In 1981, McDonnell Douglas began trying various winglets and better engines on DC-10's. These proved sound, and in 1984, McDonnell Douglas debuted the MD-11. The first version, the MD-11X-10, was the same size as the DC-10. However, it had more powerful engines and a higher gross weight. In July, 1985, McDonnell Douglas released its passenger version. The standard version has a two-pilot cockpit, is longer than the DC-10, and has a 28 percent longer range. Nevertheless, it is a more economical plane; expenses are about 31 percent less. The MD-11 was a success. There are three versions available, a passenger, cargo, and convertible. The passenger version can hold up to 405 passengers and has a range about 7,000 miles.

In 1996, McDonnell Douglas manufactured the MD-11ER. This version has longer range and larger tanks than previous versions. Boeing's takeover of McDonnell Douglas in 1997 means that no further MD-11's will be produced after current orders are filled.

Airbus Industrie, a European consortium founded by France and West Germany in 1970, is the largest European producer of large jets. They shared the goal of Hawker Siddley, sponsored by the British government, to develop, construct, and market a European short- and medium-range airliner. The first Airbuses to be certified for flight in Europe and the United States were the A300-B1 and the A300-B2, in 1974. The first commercial A300-B2 had a takeoff weight of 138 tons and was sold mainly to European airlines, particularly Air France and Lufthansa.

Eastern Air Lines ordered thirty-eight A300-B4's, which had a higher takeoff weight and greater fuel capacity than did previous models, as well as optimized flaps. This was Airbus's medium- and long-range airplane. After the Airbus A310 made its successful debut, Airbus added new features: a two-pilot cockpit, improved wing design, and nonmetallic structures, creating the A300-600, which made its first flight in 1983. The A300-600 has the same cockpit as the A310-300, and both aircraft can be operated with the same type rating. However, the A300-600 has a stronger engine and a higher fuel capacity, for long-range flights, and the usual freighter and convertible versions. Its shape has led to it being nicknamed the Beluga.

Freight Carrying

Jumbojets are increasingly turning their efforts toward the hauling of freight. Boeing has turned more toward the freight or mixed use of its 747. The success of even Airbus's proposed superjumbo may depend on its ability to haul freight. In fact, Airbus has secured orders from Federal Express and others for freighter versions of its superjumbojet.

There is speculation that smaller widebodies, such as Boeing's 777 and 767 and Airbus' A330 and A340, eventually will fill the market for jumbojets. The reason for this move to smaller jumbos is that passenger routes are fragmenting as passengers' travel preferences shift toward fre-

Image Not Available

quent nonstop flights between cities and away from hub-to-hub trips. The shorter flights use smaller aircraft, while the longer flights are most efficient for the jumbojets.

This preference is not a problem in the cargo business. The economies of scale favor large hubs from which cargo can be sorted and dispatched, a situation that favors the largest possible planes. Airbus's proposed superjumbojet, for example, would be able to carry 150 tons of freight, compared with the 747's 120 tons.

The Future of the Jumbojet

Although there were many innovations in jet travel in the 1960's, no jetliner has yet matched the impact of the original jumbojet, the Boeing 747. At that time, there was increasing danger from crowded skies, which was averted through the use of more powerful engines. The 747 is still the world's largest commercial jetliner. With nearly 1,200 delivered, the 747 is the best-selling twin-aisle jet in the industry. The 747's longevity and popularity are based on its unbeatable low seat-mile costs, flexibility, long-range dominance, and unmatched comfort. During its lifetime, the 747 worldwide fleet has logged more than 50 million flight hours, 12 million flights and 20 billion miles, enough to make 42,000 trips to the Moon and back. The 747 is capable of carrying up to 568 passengers, depending on the model and its interior configuration. The 747-400, the only model in production in 2001, entered commercial service in 1989 and has sold more than any other 747 version.

The jumbojet is moving into the age of the superjumbojet with not only increased size but also increased range. The first jumbojet engines have been greately improved upon in later models. Their range has expanded to over 8,000 miles. The next increase will be in its size.

Boeing, however, has stated that it will not build a successor to the 747. It has yielded the market for large jets to Airbus and its A380. Boeing will instead develop its Sonic Cruiser, a jet that can fly faster and farther than commercial jets currently flying. Except for the Concorde, no commercial jet flies significantly faster than 550 miles per hour, the 707's cruising speed. Boeing says its new sonic cruiser will fly at 648 miles per hour. It will also be more economical. Thus, the company that pioneered the jumbojet appears to be taking another direction. Airbus says that its new A380 has chased Boeing from the field.

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See also: Air carriers; Airbus; Airline industry, U.S.; Airplanes; Boeing; Lockheed Martin; McDonnell Douglas; Manufacturers; 707 plane family

K

Kamikaze missions

Date: From 1944 to 1945

Definition: Aerial suicide attacks waged by Japanese pilots against Allied forces as Japan faced catastrophic defeat in World War II.

Significance: Kamikaze missions inflicted high losses upon Allied naval forces and convinced Americans of Japan's overwhelming desire to avoid defeat.

Background

Tales of suicidal acts of bravery and extremely dangerous missions are found in many nations' war histories and heroic legends. During the Battle of Midway (1942) in World War II (1939-1945), American torpedo bomber pilots pressed on with their attacks despite impossible odds and severe losses. However, various religious, social, and military influences led Japan at World War II's end to conduct a sustained attack campaign that obviously entailed the attackers' deaths.

For the Japanese, mixed religious influences had bred their extreme reverence for one's lord and ancestors, strong allegiance to one's family and emperor, and a desire not to bring shame upon one's family or country. According to Japanese tradition, both life and death with honor guaranteed a godly standing in the afterlife.

The rise of militarism in early twentieth century Japan engendered a widespread embrace of the Bushido code of conduct espoused by the samurai warrior class. The Bushido code emphasized a profound sense of loyalty and honor, that would extend even to suicide if defeat or disgrace loomed.

Wartime Influence

In June, 1944, defeat directly confronted the Japanese, as the Americans crushed its naval, land, and air forces during the Marianas Islands invasion and the accompanying naval battle in the Philippine Sea. Japanese air losses were so severe they prompted U.S. Navy fighter pilots to nickname the battle the "Marianas Turkey Shoot." Stuck with increasingly inferior planes and unable to replace fallen pilots, Japanese military leaders explored other means of averting defeat and shame. Despite some opposition, lower-ranking officers had already suggested that, given inevitable high losses, crashing an airplane or other craft into an American ship would be a relatively inexpensive trade of one person, or at most, a few people, for an entire enemy vessel. Advocates felt this "body-crashing" tactic would also openly demonstrate superior Japanese willpower. In early October, 1944, Japanese rear admiral Masafumi Arima crashed a bomber into and damaged the aircraft carrier USS *Franklin*. His act signalled an apparent sanction by higher command and galvanized further action.

First Organized Attacks

In mid-October, 1944, as American landings in the Philippine Islands appeared likely, the swashbuckling, air-power-minded Vice Admiral Takijiro Onishi assumed command of part of Japan's land-based air defenses there. Hoping to support the Japanese fleet as it attempted a desperate counterattack, he pushed for the creation of the first suicide air groups. Composed entirely of volunteers, they embraced the battle nickname "kamikaze," meaning "divine wind," recalling the typhoons that had saved Japan from Mongol invasion in the thirteenth century.

The Japanese did not make many kamikaze attacks during the ensuing Battle of Leyte Gulf (1944), but they seriously damaged several ships and sank one small aircraft carrier, providing one bright spot in their otherwise overwhelming naval defeat. Thus, with their navy practically destroyed, and their overall war situation growing more dire, Japanese leaders expanded the kamikaze effort from an extraordinary battle tactic to a full-fledged campaign.

After Leyte Gulf, Japan fielded a variety of suicide units. The Japanese navy produced midget submarines that functioned as human-guided torpedoes. Both the army and navy deployed small boats carrying bombs to thwart amphibious landings. Although these sea-based efforts yielded some success, kamikaze air attacks were by far more productive.

Air Campaigns

As the Americans commenced amphibious landings at Leyte Gulf and further north on Mindoro Island through the end of 1944, the Japanese intensified their aerial kamikaze operation. The U.S. landings required that many American ships remain stationary offshore, thus easing the

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kamikazes task. Smaller, less heavily armored ships such as transports, destroyers, minesweepers, and escort aircraft carriers were especially vulnerable. Kamikazes damaged and sank several ships during this time, but the effort eliminated Admiral Onishi's air force.

When the Americans and their allies commenced landings at Luzon Island's Lingayen Gulf in January, 1945, the remaining Japanese air units on the Philippine Islands commenced almost continual kamikaze attacks that sank or damaged dozens of ships until almost no Japanese planes were left. As the Americans advanced closer to Japan, other air units eagerly assumed the kamikaze role. Forming a new kamikaze outfit on Taiwan, Admiral Onishi directed attacks that crippled a few carriers and destroyers operating nearby. Suicide planes disabled the aircraft carrier USS *Saratoga* and sank an escort carrier just prior to the February, 1945, landings on Iwo Jima. Because Japanese fighter planes had difficulty shooting down B-29 bombers raiding Japan, individual pilots conducted ramming attacks.

The most spectacular kamikaze assault occurred during the Battle of Okinawa (1945). Under the command of Vice Admiral Matome Ugacki, southern Japan-based kamikaze units not only attacked ships involved in the Okinawa landing, but also attempted a raid on the U.S. naval anchorage at Ulithi, an atoll island group east of the Philippines. From March through June, 1945, successive waves of massed kamikaze attacks, known as *kikusui*, or "floating chrysanthemum," for spiritual purity, exacted a fearful toll. More than twenty U.S. ships were sunk and an equal number were severely damaged. However, the kamikaze threat was dissipated before the war ended by U.S. air raids on kamikaze bases and by the obvious operating cost of the kamikaze raids themselves. Although their own surrender later preempted an invasion of their homeland, the Japanese husbanded resources for a kamikaze campaign against it. On the war's last day, Admiral Ugaki died in a failed kamikaze mission, and Admiral Onishi committed suicide.

Pilots and Planes

One reason for Japan's conservation of resources for an expected invasion of its homeland was an increasing lack of trained fliers. Japanese leaders embraced the kamikaze strategy in part because relatively unskilled pilots could be used. Up until the Okinawa fighting, Japanese pilots willfully sacrificed themselves to national adoration. However, the continued loss of pilots required ever more replacements. This relentless operational toll spurred more aggressive recruiting, and Japanese army aviation units eventually drafted nonvolunteers to fly kamikaze missions. However, a desire to avoid shaming one's peers, family, and emperor amid Japan's desperate situation ensured deliberate sacrifice by all, including conscripts.

Although Japan's fuel and aircraft construction problems hindered the kamikaze effort somewhat, kamikaze planes needed only to crash into their target, therefore the shortages had less effect than they might have in a conventional air campaign. Although the Japanese kamikazes used many types of airplane, such as twin-engine bombers, dive-bombers, trainers, and even seaplanes, they most often used the venerable Mitsubishi Zero fighter. Kamikaze planes usually carried bombs for extra destructive effect.

The Japanese created a specially designed suicide plane, the Okha, or Cherry Blossom, which the Americans nicknamed "Baka," or "Crazy." Launched from a bomber plane's belly, the Okha's small rockets initially propelled it for a high-speed glide, with target impact detonating a warhead in its nose. Okhas and their "Thunder God" pilots achieved moderate success, but often their bomber carriers were shot down before they reached the Okhas' fifteen-mile range.

Tactics

Kamikaze units carefully considered their tactics. Reconnaissance planes located American ships and helped guide the kamikazes, who favored traveling in formations in order to mass their overall attack. Experienced fighter pilots escorted the formations to provide navigational assistance, protection, and after-action reports. Given strong American defenses, kamikaze formations sometimes snuck toward their targets by following American carrier planes returning home. Additionally, attacks from land, as during the Lingayen Gulf amphibious operations, allowed kamikazes a better element of surprise than did attacks from the sea, as at Okinawa. Kamikazes preferred twilight attacks, in which low visibility hindered the defenders target spotting, although it could also hinder the kamikazes as well.

Once in the target area, the formations split up for individual attacks. Kamikaze forces would have liked to mass their attacks against their prized targets, aircraft carriers. However, a combination of too few kamikazes, too many carriers, and too strong air defenses often prevented this strategy. Kamikazes apparently picked the best vessels available as they encountered swarming fighters and a hail of defensive fire. During the Okinawa campaign, for example, destroyers on the U.S. fleet's defensive perimeter were popular targets.

The kamikazes preferred either high-altitude, steep-dive attacks, or very low target runs culminating in a pop-up climbing maneuver that went into a steep dive. Sometimes, they quickly shifted away from one ship to strike another one nearby. In order to maximize damage, they tried to hit aircraft carrier elevators and ships' superstructures. Some even strafed their targets during their final approach. For all this effort, however, the mission's inexorable attrition degraded tactical sophistication as more inexperienced pilots became kamikazes.

Defenses

Intense kamikaze assaults such as those at Lingayen Gulf and Okinawa shook Allied sailors who had never experienced this type of warfare and understood that the only way to prevent being hit was to destroy a kamikaze plane outright. Lesser-caliber guns that scored well against conventional attacks failed to stop a determined kamikaze, and concentrated barrage fire by guns of 5-inch caliber or greater was a better solution. However, even small-caliber guns had some effect as long as gunners led their target and sustained fire.

The United States used airplanes against the kamikazes; fighters intercepted them and bombers attacked kamikaze airfields. One reason kamikazes attacked the destroyers on the outer perimeter of the Okinawa invasion fleet was that these ships controlled the interceptor fighters. Kamikaze formations, with their inferior planes and their pilots' inexperience and resolve to press on toward their targets, were decimated by the Americans. Indeed, U.S. Navy fighter aces such as Commander Eugene Valencia achieved impressive aerial victory tallies during the Okinawa fighting. Airfield attacks eased the kamikaze scourge at Lingayen Gulf and Okinawa.

Damage-control strengths, such as the Americans' water fog firefighting technique, also saved stricken ships. The aircraft carrier USS *Bunker Hill* endured an attack that killed four hundred crew members. British carriers with armored flight decks better withstood kamikaze hits than their unarmored American counterparts. Finally, many ships survived because kamikazes hit their upper superstructures instead of their hulls, nearer to the waterline. Kamikazes also lacked the mass and velocity of a well-directed heavy shell or properly released bomb.

Overall Air Campaign Results

Kamikaze air attacks were costly to both sides. Although kamikaze missions took many Allied ships and sailors, they also required the attackers' self-destruction. For a loss of nearly 4,000 aircrew, over 3,000 kamikaze sorties scored roughly 360 hits on about 350 different boats and ships. Of these, fifty-six sank, including three small escort carriers, seventeen destroyers, and dozens of transports. Eight large aircraft carriers, five smaller carriers, and six battleships were among the many vessels whose damage required at least some time away from combat. Total human casualty estimates vary, but the Okinawa kamikaze campaign alone resulted in the deaths of approximately 3,000 U.S. Navy sailors.

For all the havoc wreaked by kamikazes, the United States possessed the resources to overcome it. Further, kamikaze attacks incurred an assured depletion of Japan's own air forces. As the statistics show, kamikazes more frequently crashed or were shot down than achieved their objectives. Still, they confronted Americans with an unprecedented level of commitment that at times adversely affected American sailors' morale. This commitment may have seemed foolhardy to the Allies, but it served as a human model for late-twentieth century mechanical "smart" weapons. It also convinced Americans that an invasion of Japan would involve heavy casualties.

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See also: Aircraft carriers; Fighter pilots; Navy pilots, U.S.; Pearl Harbor, Hawaii, bombing; Superfortress; World War II

Kennedy Space Center

Date: Established on March 7, 1962

Definition: The primary launch facility for the National Aeronautics and Space Administration.

Significance: All crewed spaceflights currently launch from the Kennedy Space Center. Additionally, KSC coordinates NASA missions launched from the adjacent Cape Canaveral Air Force Station.

History

After World War II, the United States began serious development of long-range missiles. Work to extend the range of missiles quickly encountered a major public safety issue. Missiles fired from existing test sites would have to fly over populated areas. Early missiles were inherently unsafe and unreliable, so civilian overflight was deemed unacceptable. A coastal or island launch facility was considered ideal, since flights over unpopulated ocean would result in minimal civilian risk. Many sites were considered. Soon, however, the Cape Canaveral area of Florida became the choice for most of the large missile tests. Cape Canaveral prominently juts out from Florida's eastern coastline. This provides a large margin for safety if a missile were suddenly to go off course. Furthermore, the area around the cape was marshy and had a low civilian population density. Despite its relative isolation, major roads, rail lines, and port facilities were nearby, so logistics were less of a difficulty at the Cape Canaveral site than many others suggested.

Limited tests were conducted in the Cape Canaveral area as early as 1947, but full-scale missile tests began in earnest in July, 1950. Missiles and rockets have been fired from Cape Canaveral ever since. The Cape Canaveral site began in 1940 as the Banana River Naval Air Station. The site was transferred to the Air Force in 1950 and renamed the Patrick Air Force Base. The launch facilities were designated the Atlantic Missile Range and the Missile Firing Laboratory. The launch facilities are now part of the Cape Canaveral Air Force Station, associated with the Patrick Air Force Base, under the jurisdiction of the Forty-fifth Space Wing.

Most early missiles, and nearly all intercontinental ballistic missiles (ICBMs), were tested at the Cape Canaveral launch facilities. Working under the principle promoted by Wernher von Braun, the chief missile designer in the United States, each launch facility was built for a different type of missile. Fueling equipment, servicing equipment, and a service tower, called a gantry, were all built specifically for each rocket. Furthermore, control systems for each rocket were housed near the launch pad in a reinforced concrete bunker called a blockhouse. Missiles and rockets were generally assembled at the launch site, so each launch complex required vehicle assembly equipment. Each launch complex received a numerical designation, based on the order of its construction.

When the United States made the decision to send humans into space, it made sense to use the facilities at Cape Canaveral to launch the rockets carrying the astronauts. Launch Complexes 5 and 6 served as the launch sites for the first U.S. crewed spacecraft, the Mercury/Redstone flights. With the decision to go forward with the Apollo Program, Launch Complexes 34 and 37 were constructed to test the Saturn I rockets.

Launch Operations Center Establishment

Two key factors played a role in the creation of a separate launch facility for the crewed spaceflight program. One of these factors was a Department of Defense study in April, 1960, in which the Atlantic Missile Range was described as being nearly saturated with launch facilities. Additional facilities could not be built on site without the safety hazard of overflying other launch facilities. A second factor was the directive associated with the National Aeronautics and Space Act of 1958, in which a separate civilian space organization, the National Aeronautics and Space Administration (NASA), was created and dedicated to the peaceful exploration of space. While NASA continued to use Department of Defense facilities at Cape Canaveral for the Gemini missions and early Apollo tests using the Saturn I rocket, various government officials felt strongly that NASA should have its own launch facilities.

In selecting a launch site for the rockets used for the Apollo Program, NASA was faced with several considerations. The farther south the launch site was located, the easier it would be to launch a spacecraft into an equatorial orbit around Earth. Furthermore, a launch site from which spacecraft could be launched in an easterly direction would enable the rocket to use Earth's eastward rotation to assist in achieving the necessary velocity for Earth orbit. Numerous sites were studied, including several Pacific islands as well as barrier islands off Georgia and Texas. Ultimately, the logistic capabilities, together with the need to use some of the tracking systems of the Atlantic Missile Range, led NASA to a site adjacent to the Cape Canaveral Air Force Station (CCAFS). Shortly after the selection of the Cape Canaveral site, NASA acquired over 111,000 acres on Merritt Island, just northwest of CCAFS. On March 7, 1962, NASA made the Launch Operations Center a separate NASA field center, and was made the controlling entity for the new Merritt Island Launch Area on January 17, 1963. The launch area was designated Launch Complex 39. On November 29, 1963, the Launch Operations Center was renamed the John F. Kennedy Space Center (KSC) in honor of the assassinated president a mere week after his death. Cape Canaveral was also renamed Cape Kennedy at this time, but in 1973 the state of Florida changed the name back to Cape Canaveral. KSC headquarters moved to Merritt Island on July 26, 1965, and KSC became a fully functioning space center.

Though a separate facility, KSC continued use of launch complexes constructed at CCAFS for launches of uncrewed missions until 1990. During 1989 and 1990, control over uncrewed launches shifted from KSC to the Air Force and to rocket manufacturers. Most of the uncrewed NASA missions, however, are still launched from CCAFS, and payload processing often occurs at KSC, though the launch itself is no longer under KSC direct control.

Launch Complex 39

The heart of KSC is Launch Complex 39, designed initially for the Saturn V rockets, but adapted for use with the space shuttle. Launch Complex 39 has two virtually identical launch pads, 39-A and 39-B. Earlier rockets were generally assembled at the launch pad, fueled, and then launched. Such an approach was fine for the smaller rockets. However, the time needed to assemble the massive rockets needed for lunar missions would require a launch pad to be tied up for many months. Additionally, the corrosive, salty ocean spray and the potential for tropical storms at Cape Canaveral made a spacecraft exposed on the launch pad susceptible to damage. Launch Complexes 34 and 37 at CCAFS had louvers on a mobile service structure to protect the spacecraft. The Moon rockets would be too large, however, for that approach to protecting them. Additionally, with pads tied up for months, it was projected that NASA would need up to several dozen launch pads. A better, less expensive approach was needed.

The solution was to build a Vehicle Assembly Building (VAB) a safe distance from the launch pad. The rocket would be assembled in the VAB while sitting on a Mobile Launch Platform (MLP) which would then be transported to the launch pad when the craft was completed. Three MLPs were constructed. A Mobile Service Structure (MSS) was used with the Saturn V rockets to prepare them for launch. The MSS was removed prior to launch, and the gantry at launch was part of the MLP. The MLP system was redesigned for the space shuttle without the large gantry. A Fixed Service Structure (FSS) is now built at each launch pad, which contains orbiter crew access and umbilical arms for fueling the space shuttle. Attached to the FSS is a Rotating Service Structure (RSS) that swings into position to cover the orbiter while it is on the launch pad, permitting access and servicing of the payload bay. A system of flame deflectors and trenches channels rocket exhaust away from the rocket as it takes off.

Vehicle Assembly Building

To protect the Saturn V during assembly, and to promote a faster launch pad turn around, the Vehicle Assembly Building was constructed. The VAB, one of the largest buildings ever built, covers 8 acres of land, and measures 716 feet long, 518 feet wide, and 525 feet tall. It consists of four high bays and a low bay. The high bays were originally used to assemble the Saturn V. Two bays are now used to mate the space shuttle orbiter with the solid rockets and the external fuel tank. The other two bays are used for external tank checkout and storage, solid-rocket contingency handling, and orbiter contingency storage. The low bay is used for engine maintenance shops and as a storage area for certain solid-rocket aerodynamic parts.

Launch Control Center

Advances in electronics technology by the time of the Apollo Program meant that launch control no longer needed to be housed in a blockhouse adjacent to the launch pad. Thus, KSC's launches are directed from the Launch Control Center (LCC) located over three miles away from the launch pads. The LCC is a multilevel building containing offices, computers, and data analysis equipment on the first three levels. Offices and conference rooms are on the fourth level. The third level contains the firing rooms, where launches are directed. Two firing rooms are fully operational and can be used to direct launches. The other two are used for software development and analysis and for data and engineering analysis. Controllers have a view of the launch pads from large windows at one end of the firing rooms. Large, heavy steel shutters are designed to close rapidly to protect the windows in the event of a catastrophic accident at the launch pad.

Shuttle Landing Facility

The Shuttle Landing Facility (SLF) is essentially an airport-like facility for the space shuttle. Its main feature is a 15,000-foot-long, 300-foot-wide runway on which the space shuttle can land upon returning from orbit. Adjacent to the runway is a Recovery Staging Area where a convoy of recovery vehicles can wait for the shuttle to land. These vehicles extract the poisonous fuels from the shuttle and make sure that there are no poisonous vapors in the area prior to crew egress. Also adjacent to the runway is the Orbiter Processing Facility (OPF), where the orbiter can be serviced. The OPF has facilities to mate or remove the orbiter from the back of a modified Boeing 747 used as a transport between NASA facilities.

Transporters

To carry various components and equipment from place to place within the facility, KSC has a variety of transporters. Most have special functions, such a solid-rocket transporter, an orbiter transporter, or a payload-canister transporter. The most impressive, however, are the two oldest transporters used, the crawler transporters (CTs). The CTs, originally designed to carry the MLP from the VAB to the launch pads carrying the Saturn V, now carry the MLP with a space shuttle on board to the launch pad. Moving at about one mile per hour, the CT is 131 feet long and 113 feet wide, and carries loads as heavy as 12 million pounds. The crawler is able to deliver the MLP to its proper position to within 2 inches precision. Each crawler is able to travel about 35 feet per gallon of diesel fuel.

The Future

As the United States' spaceport, KSC is looking ahead to the next-generation launch vehicle that will replace the space shuttle. The modular design of Launch Complex 39 permits great flexibility in adapting to new launch vehicles. Unlike previous launch complexes that generally became obsolete along with the rocket that they were originally designed for, Launch Complex 39 was readily adapted from Saturn V operations to space shuttle operations. Thus, it is expected that similar adaptations would be possible for most of the foreseeable designs of launch vehicles in the coming decades.

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See also: Air Force, U.S.; Apollo Program; Wernher von Braun; Crewed spaceflight; Mercury project; Missiles; National Aeronautics and Space Administration; Rockets; Saturn rockets; Space shuttle; Spaceflight

Kites

Definition: A heavier-than-air, flexible, fabric structure or lightweight, covered frame flown at the end of a long line.

Significance: As the first heavier-than-air device to fly, the kite has contributed to humans' understanding of flight. Over a long and rich history, the kite has in-

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grained itself in the folklore, religion, celebration, military, art, science, sport, and recreation of many cultures.

History and Evolution

Kites have played a special role in the folklore, legend, art, recreation, and religious ceremony of many cultures. As the first heavier-than-air flight vehicle, the kite also has been used in science and military applications.

The first documented evidence suggests kites originated in China more than 2,500 years ago. Originally constructed from bamboo and silk, kites became more widespread with the development of inexpensive paper in the second century C.E. Buddhist missionaries most likely introduced the kite to Japan and Korea, from where it spread to Indonesia and the Malay Peninsula. By the year 700, kites had been introduced to the Middle East and were used in recreation and in a sport known as "fighting kites." The explorer Marco Polo noted seeing both kite flying and crewed kites in thirteenth century Asia. Through trade routes, kites reached Europe in the early Middle Ages and were brought to the United States from both Europe and Asia.

Military Uses

Over its long history, kites have been used by militaries around the world to signal, carry messages and food to troops, to carry out crewed aerial observations, and for rescue. About 200 B.C.E., a Chinese general attached a humming device to a kite. When it was flown overhead at night, the enemy, believing the sounds came from evil spirits preparing to attack, fled. Another Chinese general used a kite to measure the distance between his troops and an enemy palace. Early Japanese prints depict archers carried by large kites.

In the mid- to late 1800's, kites were used by the British military. In 1897, a young officer, Captain B. F. S. Baden-Powell, built a 36-foot kite to be used for crewed aerial observations over enemy territory. Baden-Powell also developed a series of tandem kites. In 1901, Samuel F. Cody patented a kite system for crewed observations; the system included a basket which could support the weight of a person. Although further major developments in crewed kite flight were stunted by the introduction of crewed powered flight by the Wright brothers in 1903, the Germans used crewed aerial observation kites from submarines in World War I and World War II.

Science

Kites have been used in scientific investigations of climate and weather, aerodynamics, and electricity. In 1752, statesman and inventor Benjamin Franklin used a kite for his famous investigation into the nature of electrical charges in clouds. Kites have been used in climatic and meteorological studies. The U.S. Weather Bureau has used large box-type kites flown on piano wire that have reached altitudes over 31,000 feet. A variety of meteorological instruments, such as thermometers, anemometers, and barometers, have been attached to kites to investigate temperature, wind speed, and pressure differences at different altitudes.

Sir George Cayley, who developed the first practical glider, flew those gliders as kites. Alexander Graham Bell, the inventor of the telephone, used kites to study weather and to understand flight. He developed the tetrahedral cell, a strong, light-framed kite capable of supporting a person in the air. Early aviation pioneers such as Otto Lilienthal, Octave Chanute and the Wright brothers used kites to experiment with and learn about forces, stability, and control. The Wright's early airplane attempts were flown as kites.

Cultural Importance

Throughout many centuries and cultures, kites have been used in recreation, religious ceremony, celebration, hunting and fishing, sports, and as art. Throughout the world, kite festivals are held annually. These events educate participants and teach kite building and flying, as well as providing an exciting recreational activity.

From the time of the kite's invention, early Chinese drawings depict elegantly sculptured and beautifully decorated kites. Some cultures have used kites to communicate with spirits or gods. In Thailand, kites have been used to ask the gods for good weather and crops. In some cultures, kites are associated with good luck. It is believed when the line of the kite is cut, the kite takes away bad luck or evil spirits. In Japan, one form of kite, called a windsock, is made in the shape of a carp fish, which symbolizes the strength and will to overcome great obstacles. In ancient Rome, windsock banners designed to look like dragons were used for military and religious purposes. Koreans fly kites to announce the birth of a child. European hunters used kites to flush birds from bushes. In the Solomon Islands, kites have been used in fishing.

In the late 1990's, a new extreme sport, kite boarding, was introduced in Europe and spread rapidly throughout the world. Large, harnessed kites pull individuals on boards, similar to surf boards, across water or even snow. At the highest competitive level, professional athletes perform exciting acrobatics with these kites.

Kite Flight

Kites, like other flight vehicles, have different shapes, sizes, and components based on the mission or type of work the kite will perform. Although the variations are endless, basic forms include flat, bowed, box, cellular, and semirigid or nonrigid (soft fabric shape). Regardless of the shape, for a kite to fly, the aerodynamic forces of lift, drag, and the kite's weight must be balanced. The movement of air across the kite's surfaces provides the pressure to balance the kite's forces. Extensions to the kite, such as tails, drogue cups, or cones, add stability and balance to the kite.

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See also: Aerodynamics; Octave Chanute; Forces of flight; Heavier-than-air craft; History of human flight; Wright brothers

KLM

Also known as: KLM Royal Dutch Airlines, Koninklijke Luchtvaart Maatschappij, N. V.

Date: Founded and incorporated in the Netherlands on October 7, 1919

Definition: One of the world's first scheduled international airlines.

Significance: As the oldest continously operating scheduled airline, Koninklijke Luchtvaart Maatschappij (KLM) is the national flag carrier of the Netherlands. With its partner airlines, it serves more than 150 destinations in seventy countries on six continents.

Origins

In 1919, the young Dutch military aviator Albert Plesman founded KLM with support from both industry and government to establish the national airline for the Netherlands. From its early beginnings, KLM had strong government assistance. The Kingdom of the Netherlands had granted the fledgling aviation enterprise the right to bear the "Royal" title as part of its designation. Actual government participation in the company has varied over the years from a majority shareholder position in the early days to about a 14 percent stake in 2001.

Routes and Expansion

KLM began scheduled service on May 17, 1920, with flights between Amsterdam and London. Four years later, the airline initiated its first intercontinental flights to Indonesia, one of the Dutch colonies. From that point on, KLM's route structure expanded steadily until World War II, when all regular flight operations were suspended. During the German occupation of the Netherlands, the KLM headquarters was moved to Indonesia, and only a few unscheduled flights took place.

After the war, scheduled service resumed, and in May of 1946, KLM opened transatlantic services to the United States. During the decades that followed, new services were added to North and South America, Asia, Africa, and some parts of the Caribbean. After airline deregulation in the United States (1978) and initial efforts toward liberalization in Europe, KLM management began to concentrate on establishing partnerships to expand the KLM network. By 2000, KLM and its national and international partners operated a route network connecting about 150 cities in more than seventy countries on six continents.

Fleet and Safety

KLM entered service with a chartered De Havilland DH-16 in 1920. With government support, the KLM fleet grew steadily. Until World War II, the carrier operated aircraft predominantly manufactured by the Dutch company Fokker. After the war, the KLM fleet was rebuilt, mainly with American Douglas and Lockheed aircraft. In 2000, KLM expanded its fleet from 68 aircraft in 1946 to more than 120 airliners, including aircraft owned by its immediate partners. At the beginning of the twenty-first century, KLM's fleet consists mostly of Boeing aircraft, such as the 737 and the 747.

During the decades following World War II, KLM lost several Douglas and Lockheed aircraft in air crashes. Especially notable was KLM's involvement in the world's most deadly aviation accident, the collision of a KLM B-747 and a Pan Am B-747 on March 27, 1977, on a foggy runway at Tenerife Airport, Canary Islands. In the ensuing carnage, 583 people were killed, and nearly all of the survivors were injured to a significant degree.

Following this collision, KLM's safety record improved significantly. In the period from 1978 to 2000, the company lost only one aircraft, a Saab 340, belonging to KLM Cityhopper, the KLM regional carrier. One crewmember and two passengers were killed in that crash.

Company Strategy and Alliances

Beginning in the late 1970's, KLM's management decided to diversify the company to manage the cyclical nature of the airline industry. Hotel chains, technical services, and management consulting became part of the overall busi-

Events in KLM History

1919: The Koninklijke Luchtvaart Maatschappij (KLM) is incorporated in The Hague, Netherlands.

1920: First scheduled KLM flight is made from London to Amsterdam.

1924: Scheduled flights begin between Amsterdam and the Dutch colonies in Indonesia.

1946: KLM begins transatlantic services to New York.

1959: The first jet aircraft, a DC-8, enters service at KLM.

1969: The first widebody aircraft, a Boeing 747, is introduced at KLM.

1977: KLM 747 collides with a Pan Am 747 on a runway at Tenerife Airport, Canary Islands, resulting in one of the worst air disasters in history, with 583 causalities.

1989: KLM acquires an equity stake in Northwest Airlines.

1997: KLM sells participation in NWA but maintains a long-term joint-venture agreement.

1998: KLM establishes far-reaching alliance with Alitalia, which it terminates the following year.

2001: KLM continues the search to become a major partner in a worldwide alliance.

ness activities at KLM. Other Dutch carriers, Martinair and Transavia Airlines, also became part of the overall KLM organization. By 2000, KLM's subsidiaries included the regional carrier KLM Cityhopper, KLM UK, Transavia, and Martinair. Main divisions included KLM Cargo and KLM Systems Services.

When air transportation liberalization efforts got underway in Europe in the 1990's, KLM decided to aggressively develop its hub in Amsterdam by establishing partnerships and alliances with numerous other airlines that would feed traffic into Schiphol Airport, KLM's home base. However, faced with the limited growth capabilities at its hub, KLM began to pursue a multihub system in the late 1990's to guarantee its growth potential into the new millenium.

One of the initial KLM alliances was with Northwest Airlines of the United States. KLM acquired a significant stake in this carrier in 1989 but later sold its equity position at a profit in 1997. KLM and Northwest remained global partners and signed a long-term joint venture agreement that same year. In 1998, KLM established another highly publicized alliance, with Alitalia, the national flag carrier of Italy. Unfortunately, the conditions of the agreement were not met, and KLM management decided to terminate the partnership. Challenges that continue to face KLM include competition on the transatlantic routes from American megacarriers, low-cost Far East carriers expanding their global reach, and integrators with one-stop-shopping freight services. To meet these challenges, KLM management decided to position the carrier as a potential partner in a worldwide airline alliance.

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See also: Accident investigation; Air carriers; Alitalia; Fokker aircraft; Northwest Airlines; Runway collisions; Safety issues

Korean Air

Also known as: Korean Air Lines
Date: Beginning in 1962
Definition: A leading South Korean airline.
Significance: Although Korean Air is South Korea's flagship carrier, the company has also been plagued by several serious air disasters, including a famous incident in which a commercial airliner was shot down over Soviet airspace, killing all 269 people on board.

History and Fleet

In 1962, the South Korean government established a new airline to replace the former national carrier, Korean National Airlines. Korean Air Lines (KAL), as the fledgling company was then known, began to offer domestic flights and international flights to Hong Kong and China on Boeing 707's. Seven years later, the Hanjin Transport Group acquired the airline from the government and began to

Events in Korean Air Lines History

1962: The South Korean government establishes a new national carrier to replace the former carrier, Korean National Airlines.
1969: The Hanjin Group takes over operation of the government-owned Korean Air Lines (KAL).
1973: KAL begins using Boeing 747's on Pacific routes to Japan and the United States and inaugurates its first European route, to Paris.
1983: Straying off course, KAL flight 007 flies into Soviet airspace and is shot down by a Soviet fighter. All 269 people on board are killed.
1987: A bomb planted on a KAL 747 explodes in midair, and the plane crashes into the sea off Burma, killing all 115 people on board.
1997: A KAL flight crashes into a Guam hillside, killing 228 of the 254 people on board.
2000: KAL takes delivery of seventeen new aircraft, including Next Generation Boeing 737-800's and 777's, with further acquisition plans for the following year.

make changes, launching international flights to Japan and Southeast Asia. In 1973, KAL began to use Boeing 747's on their Pacific Ocean routes to Tokyo and the United States. The company also inaugurated KAL's first European route, a service to Paris, using the aging 707 aircraft. In 1984, the company shortened its name to Korean Air and unveiled a new look for its fleet: All the aircraft were repainted a sky blue color on top. Two years later, Korean Air began supplementing its fleet of Boeing 747's with McDonnell Douglas MD-11's. As the airline's passenger traffic has grown, the MD-11s are now used mainly in cargo operations. The airline's passenger fleet is now primarily composed of Boeing and Airbus aircraft, including Boeing 737's, 747's, and 777's and Airbus A330's.

Safety Record

Korean Air has been dogged by its safety record. One of Korean Air's most notable disasters happened on the night of September 1, 1983. Korean Air Lines Flight 007 took off from Anchorage, Alaska, on its way to Seoul, South Korea. The flight plan called for the flight to follow the northernmost international air traffic lane between Alaska and Japan, called R20. Instead, the flight deviated more than 200 miles to the northwest, flying over Soviet airspace.

Along R20, there are seven waypoints. After passing each of these waypoints, flights are supposed to check in with air traffic control and estimate their distance to the next waypoint. Throughout the flight, the jet reported as if it were on course, following the international air traffic lane well south of Soviet territory. However, the jet actually flew over sensitive Soviet military installations on the Kamchatka Peninsula and Sakhalin Island.

As the jet flew over the Kamchatka Peninsula, the Soviet Air Defense Forces monitored the flight's progress. Soviet fighters were scrambled over Kamchatka but were unable to intercept the plane before it passed back into international airspace on the other side of the peninsula. The plane continued on a southeastern course that took it straight over Sakhalin Island. Over Sakhalin, Soviet Air Defense Forces deployed at least four and as many as six Soviet interceptor planes. At 18:26 Greenwich mean time (GMT), one of the interceptor planes fired on KAL 007 and reported, "The target is destroyed."

Explanations for KAL 007

In the wake of the tragedy, analysts tried to account for the plane's deviation from its flight path, advancing four main sets of hypotheses. The first hypothesis suggested that the jet strayed due to causes beyond the control of the plane's flight crew. Scenarios involving equipment malfunction, crew incapacitation, or hijacking fall into this category. At first, Korean Air Lines officials suggested that a passenger's onboard use of a personal computer somehow could have interfered with the navigational equipment.

A second hypothesis proposed that innocent human error was to blame. Seymour Hersh's *The Target Is Destroyed: What Really Happened to Flight 007 and What America Knew About It* (1986) makes a strong argument that the flight engineer made an error of 10 degrees when initially programming the navigational system. Plotting the flight with a heading of longitude 139 degrees west, instead of longitude 149 degrees west, closely approximates the flight's actual path.

A third explanation posits that the crew deliberately flew into Soviet airspace, possibly to save time and fuel, or to fulfill a dare, or out of a misguided sense of adventure. Some commentators have noted that most Korean Air pilots, including KAL 007 pilot Captain Chun Byung In, are former South Korean air force pilots, who are trained to take risks. Most other airlines employ civilian pilots, who are specifically trained not to take risks.

The last hypothesis, and the Soviet Union's explanation for its actions, is that Flight 007 was conducting intelligence missions for the U.S. government. It should be noted that during 1983, the United States routinely flew missions in the area to gather intelligence about possible Soviet missile tests. Although many writers have produced cogent arguments to support each of these explanations, it is impossible to say with any certainty which of these hypotheses is correct.

Other Notable Disasters

Korean Air has suffered other incidents. On August 6, 1997, a Korean Air flight crashed into a hillside in Guam, killing 228 of the 254 people on board. A navigational aid called a glide slope was not working that day. The crew did not understand that the glide slope was out of service and descended below the approach profile, striking the hillside, about 3 miles short of the runway. It has been suggested that the pilot's English was not good enough to understand that the glide slope was unusable.

On March 15, 1999, a McDonnell Douglas MD-82 overran the runway at Pohang, South Korea. The accident occurred on the plane's second attempt to land in high winds and poor visibility. The aircraft broke into several pieces; fortunately, none of the 156 people aboard was killed.

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See also: Accident investigation; Air carriers; Airbus; Boeing; McDonnell Douglas; Safety issues

Korean War

Date: From June 25, 1950, to July 27, 1953

Definition: War between U.S.-led U.N. forces supporting South Korea against Soviet-supported Communist Chinese and North Korean forces.

Significance: As the first jet-age war, the Korean conflict affirmed air power's decisive importance in modern warfare, but its conditions undid some air power expectations.

Overview

After World War II, the Korean Peninsula was divided into two countries, the Republic of Korea (ROK), supported by the United States, in the south, and the Democratic People's Republic of Korea (DPRK), with Soviet and Chinese backing, in the north. After Communist North Korea invaded South Korea on June 25, 1950, the United States led a U.N. effort to help South Korea repel the assault, supplying the vast majority of U.N. forces. At first, neither the United Nations nor the South Koreans were prepared for the North Korean onslaught, but desperate fighting enabled them to retain some of the southeastern peninsula near Pusan during the summer of 1950. The Americans' September 15, 1950, Inchon Landing, combined with a breakout from Pusan, helped the South Koreans to rout the North Koreans that autumn.

The United Nations then resolved to destroy the North Korean Army and to reunite Korea under its sponsorship. However, China, threatened by U.S. aggression in Asia, attacked U.N. forces in late autumn, 1950, forcing their lengthy retreat back into South Korea. The United Nations counterattacked in early spring, 1951, and had stabilized the lines near the prewar boundary by summer. The two sides entered protracted negotiations as their forces fought for limited advantage. The July 27, 1953, armistice terminated active hostilities.

Air Forces

Both sides in the Korean War fought for limited objectives, and the superpowers were concerned with defense needs elsewhere in their worldwide face-off. Thus, neither side fully committed its air forces to this fight. Also, the war occurred during a transition period in air warfare technology.

Thus, World War II-vintage, propeller-driven fighters, such as the Soviet Yak-9 and U.S. P-51 Mustang, did much of the early fighting for the respective sides. Other propeller planes, such as the A-1, Corsair, and British Sea Fury, also provided excellent service as attack planes throughout the war. Because the Americans did not commit their frontline strategic bombers to Korea, World War II-era B-29's accomplished most of the United Nations' long-range heavy bombing tasks. U.S. transport planes were mostly propeller-driven holdovers from the last war. The Communists even used P0-2 biplanes to fly nighttime nuisance attacks, nicknamed "Bedcheck Charlies," against U.N. forces.

Simultaneously, the Korean War introduced jets to air combat. U.S. F-80's and F-9F Panthers were among the straight-wing, subsonic jets that mostly flew attack missions. The most noteworthy jet development occurred with the appearance of the Soviet-built Mikoyan-Gurevich MiG-15. This swept-wing, transonic fighter seriously threatened the U.N. air effort until the Americans quickly fielded a counterpart, the F-86 Sabre jet. Jets such as the U.S. F-94 Starfire and F-3D Skyknight also served as radar-equipped night fighters.

The Korean War also witnessed the first extensive use of helicopters. These early, underpowered, piston-engine models flew light logistics missions. However, they also demonstrated impressive utility for rescue missions and covert operations.

Air War Conduct

The war's limited scope precluded nuclear weapons usage by both sides. Also, the combatant air arms attacked targets only in Korea, not Communist targets in the Soviet Union and China, or U.S. targets in Japan. Both sides thus emphasized tactical air combat, though each remained wary of the other's capacity to escalate the air war, and with it, the war itself.

At the war's start, U.S. fighters quickly vanquished the inexperienced North Korean Air Force, thus allowing attack planes to maul the North Korean Army's supply lines. These interdiction air raids, along with close air support (CAS) missions against frontline troops, were major factors in repelling the Communist invasion.

U.N. air forces pulverized North Korean transportation links during the autumn, 1950, U.N. advance. As they entered the war, the Chinese introduced the MiG-15, flown by Chinese and Soviet pilots, to check this effort. They failed partly because of the MiG's short range and partly because F-86 pilots were better trained. Although U.N. air raids destroyed Communist air bases in North Korea, MiG-15's could still fly from their safe havens in China and harrass U.N. planes in far northeast Korea, nicknamed "MiG Alley." The Chinese did have bombers, but they kept them only as an in-place air raid threat.

Air power was important in stopping the late-1950 Chinese advance. On two occasions, U.N. CAS and air supply saved large units surrounded by Communist armies. As the battle lines stabilized and truce talks stalemated, U.N. leaders approved several U.S. Air Force-led attempts to interdict the Communist supply lines. These interdictions inflicted serious damage and kept many troops and supplies from the front, but they did not compel capitulation or even perceptibly affect the truce talks. The Communists were

Korean War, 1950-1953

(1) Main U.N. base. (2) Russian-Chinese naval installation. (3) Sept. 15, 1950, U.N. forces land. (4) Oct. 8, 1950, U.N. forces land. (5) Nov. 26, 1950, Chinese attack. (6) Dec. 9, 1950, U.N. forces evacuate. (7) July 27, 1953, armistice signed.

Image Not Available

masters of primitive improvisation, and because both sides attempted no major offensives, interdiction's true effect could not be assessed. More dramatic were the MiG Alley air battles between F-86's and MiG-15's, in which U.S. pilots increasingly dominated their opponents.

Air War Results

The Korean War ended after the death of Soviet dictator Josef Stalin and a veiled American threat to use nuclear weapons. U.N. aerial successes probably helped convince the Communists of the war's futility, but the later interdiction campaigns remained controversial because they did not meet their proponents' claims. Indeed, the war demonstrated that not all post-World War II conflicts would be decided exclusively by nuclear bombing campaigns by or conventional interdiction, as some air power advocates asserted.

Instead, the Korean War revealed an ever-widening air warfare spectrum. Per the air power ideal, jet fighters remained necessary to achieve air superiority, and heavy bombers and attack planes remained decisive with behind-the-lines attacks. However, in Korea, tactical missions such as CAS rose in importance. Aircraft carrier-based planes were especially valuable early in the war, when battle conditions eliminated land bases. The performance of helicopters did not match that of airplanes, but their utility showed great promise for future conflicts. Although U.S. leaders saw Korea as an aberration, they encountered similar conditions in the Vietnam War.

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See also: Air Force, U.S.; Aircraft carriers; Bombers; Fighter pilots; Helicopters; Military flight; Superfortress; Vietnam War

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Landing gear

Definition: Equipment that supports an aircraft on the ground, allows it to maneuver between runways and parking places, and supports the aircraft during takeoffs and landings.

Significance: Landing gear allows aircraft to move effectively around the surface and provides for safe takeoffs and landings.

Purpose

The weight of an airplane in flight is supported by the lift force on its wings. However, the airplane must pass through two transitional stages: takeoff, when the airplane leaves the ground, and landing, when it returns to the ground. The demands upon the landing gear during takeoffs differ from those during landings. During takeoffs, the airplane may accelerate to a speed of more than 140 miles per hour in a runway distance of less than 5,000 feet. Should the pilot stop the airplane during its takeoff run, the tires and brakes must sustain heavy mechanical friction loads without failure. During a routine takeoff, the landing gear must not only support the airplane but also respond to the pilot's directional commands. During landing, the wheels must absorb the descent speed of the airplane as it makes contact with the runway. The tires, on first contact with the runway, spin to a rotational speed that matches the airplane's landing speed. The brakes contained in the landing gear must then bring the airplane to a stop.

In the routine landing of heavy commercial airplanes, reverse thrust is obtained from the engines, whether propeller or jet. However, in an emergency, the brakes must be capable of stopping the airplane without any engine assistance.

Purpose

Airplanes have landing gear for three reasons: to maneuver the airplane along the ground, to support and control the direction of the airplane during takeoff until the lift on the wings is able to support the weight of the airplane, and to support the weight of the airplane during landing as the wings gradually lose lift. The wheels and the connecting structure must be able to absorb the vertical or descending speed of the airplane at the instant of touchdown. During the critical landing phase, the pilot must have sufficient skill to keep the descent rate within a small enough magnitude to prevent damage to the landing gear and the rest of the airplane. During takeoff and landing, the pilot must be able to control the airplane during both routine conditions and emergency conditions, such as tire blowouts.

Airplanes that operate from an aircraft carrier must have very strong and resilient landing gear. The relative velocity between the wheels and carrier deck might be much higher than that experienced by a land-based airplane and the course is not entirely under the control of the pilot.

In addition to the requirements of landing, takeoff, and ground maneuvering, some landing gear must be retracted into the airplane's wings or fuselage. Except for low-performance general aviation airplanes, retractable landing gear is a feature of nearly all modern airplanes. The reason for retracting the landing gear is to reduce aerodynamic drag that would otherwise be caused by the extended gear.

Because the space in either the wings or fuselage is limited, there is an incentive to limit the diameter of the wheels. To meet the airplane's takeoff, landing, and maneuvering requirements, the tire pressure can be as high as 200 pounds per square inch for typical military airplanes; the tires in commercial airplanes might be as high as 140 pounds per square inch. An important part of the design of an airplane's landing gear is the selection of the proper tire, and a significant part of the routine maintenance of an airplane is the regular inspection and replacement of tires.

Types of Landing Gear

The most obvious part of the landing gear is where and how the wheels are attached to the airplane. There are many common arrangements. In the so-called conventional arrangement, two main wheels are placed near the front of the airplane and well ahead of the airplane's center of gravity. A much smaller tail wheel is placed at the rear, just under the elevator. For the first four decades of powered flight, nearly all airplanes, both civil and military, used this arrangement. Except in some limited-production aerobatic, sport, or homebuilt airplanes, this wheel arrangement is no longer in use. The increasingly inappropriate term "conventional" has been replaced by the more descriptive term "tail-dragger."

Landing gear supports the plane on the ground, absorbs friction, and provides maneuverability during takeoff and landing. (NASA)

The tricycle arrangement has become the most common form of landing gear. In the tricycle gear, there is a wheel and strut placed forward, with the main wheel of the tail-dragger moved back past the center of gravity of the airplane. The tail-dragger arrangement, nevertheless, has certain advantages over the tricycle arrangement, one of which is that the presence of two rather than three wheels means less drag in flight. The tail-dragger arrangement also provides for better propeller clearance when the aircraft is on the ground. Because the tail-dragger lands at a higher angle relative to the wind, it can use more lift in the wing and consequently land at a lower speed and therefore require a shorter runway. Because of its lower landing speed, the tail-dragger might be better suited to rough-field landings.

The tail-dragger's disadvantage is the location of the center of gravity behind the main wheels, an inherently unstable condition. Unless quickly corrected, the response of a tail-dragger to a slight side motion, or drift, at landing is the ground loop, a maneuver in which the airplane turns suddenly to one side, rolling the airplane to touch down the opposite wingtip. Damage to airplane from a ground-loop can include a crushed wingtip or a collapsed landing gear. The tail-dragger pilot must have sufficient skill to keep the airplane completely aligned with the runway during landings, even at low speeds.

The advantage of the tricycle gear, used in most airplanes except heavily loaded transport aircraft or sailplanes, is the reduced likelihood of ground loops, as the center of gravity is ahead of the two main wheels. In addition, the pilot has better visibility on the ground. The cabin floor is horizontal on the ground, facilitating the loading of passengers and cargo.

The bicycle, or tandem-wheel, arrangement is a specialized arrangement occasionally used on military airplanes and common on sailplanes. The advantage is the reduced weight of a third wheel. Weight reduction is especially critical on aircraft intended for vertical takeoff, such as the Harrier jet.

Large transport airplanes often employ multiple-wheel arrangements to distribute the weight of the aircraft on the runway. The C-5A aircraft has a double wheel at the nose. In the rear, there are four sets of double bogies. A bogie is wheel arrangement in which the wheels are mounted one at each of the four corners of a cart. The center of the cart is strut-connected to the airplane.

Conclusion

An airplane's landing gear permits it to take off, land, and maneuver on the ground. The landing gear also allows control of the airplane during the critical landing and take-off operations and provides brake force as needed in emergency conditions. Although there are several types of landing gear arrangements depending upon the performance and weight of the airplane, the tricycle landing gear remains the most common.

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See also: Airplanes; Flight control systems; Landing procedures; Pilots and copilots; Taxiing procedures

Landing procedures

Definition: Steps which, when followed, achieve the safe return of an aircraft from the sky to the surface.

Significance: Landings, an essential part of flight, allow little room for error, because speed, ground proximity, winds, and momentum must all be balanced for reasons of safety and economy.

Background

A common aviation joke attests that although takeoffs are optional, landings are mandatory. Although landings may seem effortless to nonpilots, landing procedures comprise a large portion of any student pilot's flight training. As student pilots become more comfortable and proficient at landings, however, they may treat them more lightly. The first aviators, who had no teachers, had to learn how to fly through trial and error. Some early fliers could commit their attention only to getting airborne and allowed landings to take care of themselves, often with tragic consequences. Landing procedures have an obvious purpose: to return the aircraft and its passengers safely to the surface. The first generation of pilots seemed happy to walk away after just about any landing.

Orville and Wilbur Wright equipped their first *Flyer* with skids instead of wheels, expecting the sands at Kitty Hawk, North Carolina, to intervene and soften the blow of the first landings and the area's average 16-mile-per-hour winds to allow the *Flyer* to touch down as slowly as possible. Fortunately, the brothers had gained previous landing experience with gliders designed similarly to their *Flyer*. However, the powered *Flyer* differed from the Wrights' earlier kites and gliders not only in its engine and propellers but also in its substantial pair of skids, which traversed the machine's length. Later versions of the *Flyer* repositioned the pilot from a prone to a seated position and strengthened the landing skids and their supports. Wheels remained absent from Wright airplanes until 1910, when the U.S. Army's purchase demanded specific modifications.

Pilots and designers learned quickly that landing was to be as new a science as was flight itself. At first, there were as many designs and combinations of skids and wheels as there were airplanes. For example, although the Wright brothers did not add wheels to the *Flyer* design until 1910, in 1909, Louis Blériot used two main wheels on a single axle under the engine and equipped his airplane with a non-steerable tailwheel. In the same year, the Antoinette airplane was built, with two main wheels behind the engine, a spoon-shaped skid poking ahead of the main wheels, and another skid beneath the tail. These skids absorbed the shock of landings performed by inexperienced pilots.

Landing Fields

Early aviators used landing fields that were, as their name implies, open fields, in which pilots could point their airplanes directly into the prevailing winds. This orientation ensured that each landing could be made directly into the wind, for early airplanes' controls were usually too weak or unbalanced to permit reliable crosswind landings. Crosswind landing capabilities are essential in modern airplanes, because runways long ago replaced landing fields. Whenever winds blow cleanly down the runway's length, crosswinds pose no challenge. The greater the wind's angle to a runway's centerline, the more skill a pilot must demonstrate to make a safe landing. Much of the reason for this difficulty is because airplanes in flight move about the concentration of mass that pilots call the center of gravity. If an airplane could be held off the ground by a cable attached at its center of gravity, it would remain balanced, with both wings and nose level. As runways became more prevalent after the 1930's, pilots had to develop techniques to prevent any crosswinds from pushing on their airplanes' vertical stabilizers. As an airplane slows after landing, side winds hit the vertical stabilizer, much as they fill the sail of a boat. More force concentrates on the tail, as the wind pushes against the entire airplane, and the tail moves downwind, as the nose swings in the opposite direction. As the airplane slows, the crosswind's force can become great enough that the rudder can no longer overcome it, causing the pilot to lose control and forcing the airplane off the runway. Crosswind landing techniques emerged to counter this threat.

Landing Techniques

The earliest and most basic landing technique involves the pilot crabbing the airplane into the wind until just a moment before touchdown. At the split second before the tires contact the runway, the pilot straightens the nose relative to the runway using the rudder. This technique causes the airplane's wheels to touch the surface with little sideload but requires that the airplane be stopped quickly. Because so many early airplanes were tailwheel types, quick stops were not always possible. Many airplanes ran off the runway, or ground-looped. However, the technique found wide acceptance on broad grass runways. From the 1950's on, more costly, and, therefore, more narrow, paved runways became the norm. Landing accidents increased, not because pavement was a more difficult landing medium to master, but because crosswind techniques on pavement required a crisper, more certain control technique.

In the days before airplanes had landing flaps, pilots could lose altitude quickly and safely by slipping, a technique wherein the pilot lowers one wing and keeps the airplane from turning by using the opposite rudder. The same technique, refined by a pilot's delicate touch, worked well to land an airplane in a strong crosswind. By lowering the wing into the wind, a pilot could use the airplane's lift to maintain position on a runway's centerline. Touching down on the upwind wheel allowed pilots to maintain directional control by using the rudder. An airplane's fuselage, no longer streamlined into the wind, provided welcome aerodynamic drag to slow the airplane quickly, so the moment between the flight controls losing effectiveness and the airplane slowing to the point that most crosswinds would not push the tail became minimum.

The point at which a wind becomes too strong to allow a proficient pilot to land safely is called the maximum crosswind component of the airplane's performance envelope. At end of the twentieth century, the U.S. Federal Aviation Administration (FAA) recognized only the slip-to-landing crosswind technique. Straightening the nose at the last moment required too unreliable a sense of timing and was simply less safe than the slip-to-landing technique.

The particular technique that a pilot uses to land an aircraft depends on several things, including the airplane's landing gear, the length of the runway, and the runway's surface. The three basic landing techniques are the normal landing, the soft-field landing, and the short-field landing.

Normal Landings. Pilots elect to make normal landings when the available runway length allows plenty of room, there are no obstructions to approach, and the runway surface is smooth, hard, and dry. Practiced normal landings appear effortless to observers but require much skill and judgment on the part of the pilot. Student pilots normally begin their flight training with normal landings, the simplest of landing techniques.

In normal landings, pilots must align their airplanes with the runway centerline and, maintaining an appropriate airspeed, plan a stable approach path to the runway. Airspeed control is critical during all types of landings, because the goal is always to touch down with as little downward motion as possible in order to prevent damage to the landing gear. The second critical part of landing is airspeed control. If the airspeed is too slow on approach, the pilot may lose control of the airplane. If the airspeed is too fast, the pilot may not be able to touch down at the appropriate point, using up too much runway and damaging the airplanes at the end of the runway.

Soft-Field Landings. Soft-field landings require a high degree of pilot awareness, because the pilot essentially handles the controls as if to keep the airplane flying until the wings simply stop producing enough lift for flight. This procedure must be timed so that all of the aircraft's wheels touch the runway surface at the same moment. After the wheels touch, the pilot must apply just enough power to reduce the nosewheel's pressure on the runway by applying back pressure on the stick, or yoke, by pulling the stick forward with very light hand pressure. The pilot continues to apply back pressure until the airplane slows so much that the weight of the nose finally rests fully on the rolling nosewheel.

Because there are so many types of runway surfaces, pilots must use extreme care and near-faultless judgment to analyze and properly land on a soft field. Pilots must avoid portions of the runway that might damage their airplanes. Obstacles such as broken concrete, badly eroded asphalt, snow packed to iceberg hardness, or windborne debris can contaminate a landing field. Special caution is also essential on grass or dirt runways after a rain. Muddy surfaces can stop an airplane so suddenly as to flip the airplane over.

Short-Field Landings. Pilots use the short-field landing technique when a runway is shorter than normal. Short-field landings demand skill and practice, because they require pilots to touch down on or near a specific point at the lowest safe airspeed. After all wheels have made contact with the surface, pilots must apply heavy braking to stop the airplane in the shortest distance. Successful short-field landings require a pilot's heavy reliance on the pilot's skill and judgment. Student pilots practice short-field landings throughout most of their training, and their flight instructors emphasize them with increasing frequency as students approach their practical test. Airspeed control, pitch attitude control, and power control blend together through the pilot's hand in a ballet of momentum management that ends in a thrilling dissipation of energy.

U.S. Navy pilots are, in effect, making short-field landings when they land on aircraft carriers. They rely on shipboard signal officers, who manually signal essential corrections, as they concentrate on lighted approach-slope aids. A properly flown approach to the short field of an aircraft carrier results in the airplane's tailhook grabbing a landing cable, which slows the airplane violently but certainly on a pitching, rolling runway. A civilian pilot has only the airplane's brakes and flap retraction to stop the airplane on the runway after the pilot's visual judgment places the airplane on its touchdown point.

Regardless of the type of landing a pilot selects, consistency is the key to success. Pilots attain and maintain consistency by keeping in practice. U.S. regulations have long required pilots to have landed at least three times within the ninety days preceding a flight carrying passengers.

Landings have fulfilled aviators, met schedules, thrilled passengers, and even saddened those experiencing flight's end. Aviation has inspired poets in most of its aspects, but landings have received rare poetic treatment. In 1956, F. Pratt Green recounted his emotion at the moment of landing, and of exiting the airplane to meet loved ones at the fence in his five-part poem "Return to Earth."

> Odd, then, that to alight on a runway
> was to die another death. Required
> to declare our love, we found nothing
> to say to those who at barriers waited
> to embrace us. Our return to earth,
> we felt, was to be mourned, not fêted.

David R. Wilkerson

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See also: Aircraft carriers; Airplanes; Airports; Landing gear; Pilots and copilots; Runway collisions; Takeoff procedures; Training and education; Wright brothers; Wright *Flyer*

Samuel Pierpont Langley

Date: Born on August 22, 1834, in Roxbury, Massachusetts; died on February 27, 1906, in Aiken, South Carolina

Definition: Late nineteenth century American scientist who made important contributions to aerodynamics, astrophysics, and meteorology.

Significance: Through pioneering research in aerodynamics, Langley established the principles of flight and demonstrated the practicability of mechanical flight with self-propelled heavier-than-air machines, building a steam-powered model aircraft that flew in 1896 and a gasoline-powered aircraft that flew in 1901.

Born in 1834, Samuel Pierpont Langley concluded his formal education upon graduation from Boston High School. He then worked for several architectural firms while pursuing his passion for building telescopes. The latter skill led to several academic appointments, culminating in 1867 with a post at Western University in Pittsburgh, Pennsylvania, where for twenty years Langley taught and was the director of the Allegheny Observatory. Langley made landmark contributions to the study of sunspots and invented the bolometer, a device to measure infinitesimal temperature variations across the light spectrum. In 1881, he led an expedition to Mount Whitney, California, to measure the amount of heat received from the Sun by Earth's atmosphere, a partially successful effort that resulted in the unit of measure named after him.

Langley's study of aerodynamics began shortly before his appointment in 1887 as secretary of the Smithsonian Institution, a position he held until his death. Throughout the early 1890's, Langley built successive models of what he called "aerodromes," uncrewed flying machines driven by gasoline-fueled, steam-powered engines. He launched his aerodromes from a track atop a houseboat on the Potomac River near Quantico, Virginia. On May 6, 1896, his 16-foot-long aerodrome model number 5 was catapulted out and flew for 90 seconds over a range of 3,000 feet. This epochal event marked what was arguably the first sustained flight of a heavier-than-air craft.

Although Langley intended to set aside aeronautical work after that success, he was persuaded by President William McKinley to develop a crewed craft in 1898. When European firms could not supply a suitable engine, Langley's assistant, Charles Manly, built a light but powerful internal combustion engine. In 1901, an uncrewed aerodrome model using such an engine became the first gasoline-powered vehicle to fly. A houseboat rigged with a cumbersome 85-foot-long track on its roof served as the launch for the 850-pound crewed machine, which Manly piloted. When it was launched on October 7, 1903, 40 miles south of Washington, D.C., it became caught in the launch mechanism and plunged overboard. A similarly disastrous second launch was attempted nearer the city on December 8, 1903. Nine days later, Orville and Wilbur Wright, operating independently of Langley and without government aid, made a successful flight at Kitty Hawk, North Carolina. Langley, discouraged by his failures, died of a stroke on February 27, 1906.

Langley's successor at the Smithsonian, Dr. Charles Walcott, in 1914 enlisted aviation pioneer Glenn H. Curtiss to reconstruct the 1903 Langley machine and launch it from pontoons. The effort was successful, but the revisions made by Curtiss as well as Curtiss's own financial interest in undermining the Wright brothers' aircraft patents, leave open the question whether Langley's original craft might have flown had it not been for his unfortunate launch mechanism.

David M. Rooney

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See also: Aerodynamics; Glenn H. Curtiss; Heavier-than-air craft; History of human flight; Wright brothers; Wright *Flyer*

Learjets

Date: First production Learjet flew in October, 1963

Definition: The first successful small-business jets.

Significance: The Learjet, with its combination of attractive styling and high power, quickly became the industry standard in small business jets and dominated the business jet market for many years.

The Need for Business Jets

Prior to the development of business jets, options for business air travelers were varied but limited. For corporate travel, corporations could purchase their own small, propeller-driven aircraft, modify full-sized commercial airliners, charter full-sized aircraft, or book regular passenger seats on commercial airliners. The use of full-size aircraft often entailed more expense than could be justified by the number of people flying, and the use of small, propeller-driven aircraft lacked the range, speed, and comfort provided by commercial airliners. Flying on regularly scheduled commercial flights also meant that corporate travelers had to adjust their schedules to match those of the airlines.

Business jets filled a niche that had been unfulfilled by these various options. They were small enough to be affordable, yet large enough to provide amenities, such as galley kitchens and onboard restrooms, that small general aviation aircraft could not. They had cruising ranges and speeds to rival those of full-sized airliners. Perhaps most importantly, business jets provided flexibility: Corporate officers could now fly anywhere at any time.

Lear Jet Corporation

The Learjet was developed by William Powell Lear, a pioneering figure in the airline industry. Born in Hannibal, Missouri, in 1902, Lear left high school before graduating and lied about his age to enlist in the U.S. Navy at the age of sixteen. He learned basic electronic skills while serving in World War I. As an inventor and entrepreneur, Lear built a successful corporation specializing in avionics systems. His wide-ranging inventions included the first successful car radio and the eight-track audio cassette player.

Some of Lear's innovations, particularly in electronics and avionics, became integral components of larger technological systems. His development of the automatic pilot in the 1930's, for example, revolutionized aviation. Often Lear's success as an innovator and entrepreneur was based not on his ability to invent totally new devices, but instead on his genius at recognizing new possibilities for existing technologies and on his ability to market his innovations.

In the late 1950's, Lear founded the Swiss American Aviation Corporation (SAAC) to design and manufacture corporate jet aircraft. By 1963, he had moved the company from Switzerland to Wichita, Kansas, and renamed it the Lear Jet Corporation. Like many successful entrepreneurs, he had a knack for envisioning the market for a product before there was such a market. This was certainly the case with the Learjet. Although industry analysts were intially skeptical about the Learjet's business prospects, for several years after Learjet production began, demand outpaced supply. Although the original market had been corporate travelers, buyers soon included celebrities for whom ownership of a Learjet had become a necessary status symbol.

The biggest challenge faced by Lear and his design team in building the Learjet was to develop an airframe that was strong enough to withstand the forces created by jet engines, that could incorporate a passenger cabin with sufficient headroom to qualify as a desirable travel option, and that could be small and light enough to be economically feasible. The airframe, engines, and other components all had to be integrated carefully into a complete aircraft system. Lear knew the potential market existed for a business jet, but he could not simply scale down an existing full-sized commercial airliner. Instead, Lear looked to the military for inspiration, incorporating many of the features of the P-16, a small fighter-bomber used by the Swiss Air Force.

The resulting aircraft combined sophisticated good looks with speed and power. The first Learjet, the Model 23, carried seven passengers and made its first flight on October 7, 1964. Powered by two General Electric CJ610-4 turbojet engines, it had an effective range of 1,875 miles and a top speed of 564 miles per hour. Learjet produced and sold approximately one hundred Model 23's before introducing the Model 24 in 1966.

In 1969, Lear resigned from the board of Lear Jet Industries, and the company merged with Gates Aviation to become Corporation Gates Learjet. Learjet changed corporate ownership several times before becoming part of Bombardier, a Canadian corporation, in 1990. Learjets continue to be built in Wichita, Kansas, and the Learjet Model 45 was introduced in 1995. The Model 45, powered by two Allied Signal TFE 731-20 turbofan engines with 3,500 pounds of thrust each, accommodates a two-person crew and up to nine passengers.

Nancy Farm Mannikko

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See also: Airplanes; Corporate and private jets; Jet engines; Manufacturers

Leonardo da Vinci

Date: Born on April 15, 1452, in Vinci, Tuscany, Italy; died on May 2, 1519 at Cloux Château, Amboise, France

Definition: The first person to design flying machines and a parachute.

Significance: Leonardo da Vinci drew up plans for several fanciful human-powered flying machines and a heliocopter-like airscrew. He also sketched a potentially practical pyramidal parachute.

Leonardo da Vinci is best known as the painter of the *Mona Lisa* (1503). Owing to the enormous breadth and range of his talents and interests, he is considered the original Renaissance man. Among his interests was an obsession with flying machines.

Although da Vinci was given a good education for a boy from a small Tuscan town in Renaissance Italy, he was never a scholar and cheerfully acknowledged the accusation of critics that he was "a man without learning." He wrote well but, being left-handed, he also developed for his notes an idiosyncratic and almost indecipherable mirror-image style of writing that ran right to left with the letters also reversed left to right. He never published these personal notes and sketches. On his death, his papers were willed to his apprentice and friend Francesco Melzi, who kept them for about fifty years. On Melzi's death, the collection was sold and scattered.

For all these reasons, da Vinci's work had little impact on developments in science and technology. Nonetheless, his sketches of flying machines were recognized well before the era of workable flying machines. Da Vinci favored flapping wings powered by the combined efforts of arms and legs because he recognized the impossibility of flight powered by human arms alone. His early preference for "bat wings" faded as articulation problems became clear. An intensive study of bird flight left him uncertain of how to coordinate the timing of wing motions with the powering arm and leg motions. Although he spent some thirty years studying flight, none of his designs seem to have led to actual models or trials.

The weaknesses of human power were fully apparent to later pioneers of flight, as were the deficiencies of flapping wings. Hence, da Vinci's designs made no contribution to the details of realistic flying machines. Although Octave Chanute suggested the wing warping of the Wright brothers was an extension of Leonardo's plans, the Wrights explicitly denied the connection. Da Vinci's only confirmed

Image Not Available

contribution to actual flight was as a stimulator and encourager of the dream.

It is also doubtful that da Vinci's airscrew design, which might at least have made a good toy, had any direct influence on the development of helicopters. On the other hand, working parachutes dating from the late eighteenth century may have been inspired by Leonardo's design.

John A. Cramer

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See also: Aerodynamics; Octave Chanute; Helicopters; History of human flight; Human-powered flight; Parachutes; Wing designs; Wright brothers

Lighter-than-air craft

Definition: Craft that float in the sky because of lighter-than-air (LTA) gas, including both balloons that float with the winds and dirigibles that can propel themselves and direct their course.

Significance: Although LTA craft have been supplanted by heavier-than-air (HTA) for most tasks, many techniques and technologies later adopted for HTA were developed with LTA craft. LTA craft provide a number of niche functions, such as weather sampling, advertising, telecommunications repeaters, high-altitude science platforms, and heavy-cargo transporters.

Design Principles

A balloon is a fabric container for LTA gas that allows the balloon to float. Usually, a balloon also lifts a payload (often called a gondola) hanging beneath the balloon. A dirigible, which is a shortened form of the term "dirigible balloon" (meaning directable balloon), has one or more balloons plus the propulsion system and payload. Balloons and dirigibles are called LTA craft to compare them with airplanes and helicopters, which are heavier-than-air (HTA) craft that stay in the sky because of the application of some form of propulsion.

Buoyancy is the key factor for LTA craft. Archimedes (287-212 B.C.E.) derived the principle stating that a body immersed in a fluid is buoyed up by a force equal to the weight of the displaced fluid. The LTA uses gases including warmed air (which has expanded and is thus lighter than the surrounding air) or gases with densities less than air.

Two low-density gases widely used to provide buoyancy are hydrogen and helium. Typically, hydrogen lifts 60 pounds per thousand cubic feet. Helium lifts 14 percent less (53 rather than 60 pounds) per thousand cubic feet, but helium has the major safety advantage that it does not burn, while hydrogen can ignite explosively.

Unfortunately, helium was not available until the 1920's, and even then the United States government (which had most of the world's supply) was slow to allow exports. Consequently, most LTA craft until the late 1930's flew with hydrogen, and there were many catastrophic fires.

Hot air gets only 17 to 20 pounds of lift per thousand cubic feet, about one third that of hydrogen. Thus, hot-air balloons must be three times larger to lift the same payload, which makes hot-air dirigibles very inefficient. However, for balloons, the lesser complexity and cost of avoiding hydrogen or helium is a major advantage.

Heating air for buoyancy is usually done by burning propane or kerosene. Heat is constantly drained away at the surface of the balloon, so hot-air balloons require frequent firings of their burners. Consequently, they tend to have shorter range than balloons using low-density gas. However, the rapid changes in the buoyancy of hot-air balloons do allow their pilots to ascend or descend to catch different winds and thus get some control of their craft's direction.

LTA craft pilots can decrease buoyancy to drop lower or land by valving out some of the lifting gas. They can increase buoyancy by dropping ballast (water, sand, or other material carried along for dropping as needed). In extreme conditions, balloonists have dropped everything in the gondola and even the gondola itself.

There are several more-sophisticated methods of modifying buoyancy, particularly for craft on long-duration and/or high-altitude flights, where warmth during the day causes the craft to rise too high and cold at night causes it to sink too low. Shiny upper surfaces, reflecting sunlight that would cause the balloon to expand and rise too high, and transparent lower surfaces, absorbing infrared radiation (heat waves) from the ground at night, often help. The Rozier balloon has a hot-air balloon, providing buoyancy variation, beneath a low-density gas balloon, providing endurance.

Conversely, superpressure balloons maintain buoyancy by having an envelope strong enough to keep the same volume even if the gas inside them expands. This comes at a cost of additional weight compared to zero-pressure balloons, which expand and contract with changes in surrounding pressure.

Another aspect of buoyancy is that the density and pressure of the surrounding air decreases with altitude. Hence, there is less lift available per unit volume, so LTA craft must be larger to carry a given payload to higher altitudes. Consequently, LTA craft with heavy payloads tend to be limited to low altitudes of a few thousand feet. For higher altitudes, designers can compensate for decreased lift per unit volume by using lighter payloads, such as remotely controlled instruments to operate the craft instead of people.

Light materials are vital for LTA construction. The best material for the early balloons was light, strong, and expensive silk. By the mid-twentieth century, synthetic materials, such as polyester and polyethylene-coated nylon, improved on silk's performance at a lower price. By the beginning of the twenty-first century, composites of a number of synthetic materials allowed even greater strength and lighter weight. Similarly, the electrolytic process for purifying aluminum, invented in 1886, allowed structures light enough to fly dirigible structures and pressurized gondolas carried by balloons. Composites in the late twentieth and early twenty-first centuries allowed all of these structures to become lighter still.

Dirigibles are of three types: nonrigid, a streamlined balloon with the car and engines below; semirigid, the same with a strengthening keel below so the craft can be larger; and rigid, an enclosed structure holding any number of gas bags so the size can be very large.

History of LTA Flight

In 1782 and 1783, Joseph-Michel and Jacques-Étienne Montgolfier, two French brothers, flew hot-air balloons with animals as their first aeronauts. On November 21, 1783, they were ready for a human crew. Their pilot, Jean-François Pilâtre de Rozier, and another man flew over Paris for twenty-five minutes while desperately stoking their lifting fire and sponging out fires in their rigging caused by sparks from the lifting fire.

Only a few days later, on December 1, 1783, Jacques-Alexander-César Charles, of the French Academy, flew a hydrogen balloon. The flight illustrated the advantages of hydrogen balloons over hot air. Because hydrogen is more buoyant than hot air, the balloon could be one-third the size of a comparable hot-air balloon. Rather than just twenty-five minutes, Charles flew for two-and-a-half hours, dropped off his passenger at sunset, and then rose high enough to be the first person to see the sun set twice in one day.

Shortly thereafter, balloonists began attempting not just to fly, but to go places. Jean-Pierre Blanchard, another Frenchman, and John Jeffries, an American, were the first aeronauts to fly across the English Channel to France on January 7, 1785. However, their flight illustrated the major problem of balloons as transportation. They had to drop all their cargo to reach land, and their destination could be only roughly planned—they could have no more specific intention than to land somewhere in France. That vagueness increased as balloonists made longer flights. Inventors tried vainly for decades to make their balloons steerable, but they always failed because engines powerful enough to move a craft against strong winds were too heavy to be lifted.

Still, balloon flights in the nineteenth century supplied entertainment, scientific data, and observation data for armies. Balloon rides and balloon-borne fireworks were connected with most major celebrations. For scientists, balloonists discovered that the atmosphere grew thinner and cooler with increased altitude but that the magnetic field retained its strength. For armies, tethered balloons allowed observers to see several miles beyond the enemy's lines. Such balloons were first used during the French Revolution in 1793, and again in the American Civil War (1861-1865). By the end of the nineteenth century, observation balloons were in wide use.

Dirigibles, Balloons, and Their Competition

As with HTA aircraft, dirigibles only became practical when light and powerful internal combustion engines were developed. On September 20, 1898, Brazilian Alberto Santos-Dumont first used a 3.5-horsepower, 66-pound motor to propel himself and *Number 1*, an 82-foot nonrigid craft with 64,000 cubic feet of gas volume, around Paris. Santos-Dumont made steady improvements over the next several years, inspiring many other nonrigids.

Events in the History of Lighter-Than-Air Craft

1782-1783: Joseph-Michel and Jacques-Étienne Montgolfier fly hot-air balloons with animals as their first aeronauts.

1793: French armies use tethered balloons to see several miles beyond enemy lines during the French Revolution.

1861-1865: Balloons are used for observation of enemy positions during the American Civil War.

1870-1871: The French use observation balloons during the Franco-Prussian War.

1899-1902: The British use balloons and kites for observation purposes during the Boer War.

1900: The first zeppelin is built.

1904-1905: During the Russo-Japanese War, the role of balloons leads to later military systems for employing aircraft for reconnaisance and artillery spotting.

1920's-1930's: The U.S. government, which controls most of the world's supply of helium, operates four rigids for long-range reconnaissance.

May 6, 1937: The hydrogen-filled German airship *Hindenburg* explodes at Lakehurst, New Jersey, convincing the public that large dirigibles are unsafe.

Meanwhile, in Germany, Count Ferdinand von Zeppelin built a large rigid dirigible, *Luftschiff Zeppelin Number 1* or *LZ-1*, which translates as "airship number one." It was 420 feet long and 42 feet in diameter, with a gas volume of 460,000 cubic feet, sixty times greater than Santos-Dumont's *Number 1*. The *LZ-1*, which first flew in July, 1900, had seventeen separate gas cells held together by an aluminum framework and covered with fabric. After ten more years of work, von Zeppelin had dirigibles in commercial service carrying sightseeing passengers and mail.

With the beginning of World War I, rigid dirigibles did well at first, staging the first long-range bombing attacks in 1915. However, airplane technology rapidly improved, and pilots found the rigids to be large, slow, highly flammable targets. Likewise, airplanes replaced observation balloons because the airplanes could cover more territory and also attack targets. The only dirigibles successful throughout the war were nonrigids used to guard convoys against submarines.

Still, the long flights by rigid dirigibles during the war suggested that intercontinental passenger service, or even flying warships, might develop. All these dreams eventually crashed. France abandoned large rigids when the *Dixmude* exploded in 1923. Great Britain abandoned large rigids when the *R-101* crashed and burned in 1924.

In the 1920's and 1930's, the U.S. government operated four rigids as military ships intended for long-range reconnaissance. Two of the airships, the *Akron* and *Macon*, carried their own fighter planes for defense. Because the United States had most of the world's helium supply and used helium for its LTA gas, none of these craft exploded. However, three of them were lost in storms, and the United States abandoned the giant rigids after the third, the *Macon*, went down in a storm at sea in 1935.

The Lufftschiffbau Zeppelin company in Germany had the best safety record because it had built more than a hundred rigids and had thoroughly worked out the design details. In 1928, the company's *Graf Zeppelin* began a commercial flight life that circled the world, made regular flights to Brazil and North America, made an Arctic expedition, and flew one million miles before being retired.

The last and greatest rigid was the *Hindenburg*: 803 feet long and 135 feet in diameter. Its seven million cubic feet of gas allowed it to carry fifty passengers and sixty crew in absolute luxury at a speed of 84 miles per hour and a range of 11,000 miles.

Unfortunately, the Luftschiffbau Zeppelin company still flew with hydrogen, and the doped-cloth skin was also quite flammable. Lightning, leaking gas, or anti-Nazi sabotage caused the *Hindenburg* to catch fire while preparing to land at Lakehurst, New Jersey, on May 6, 1937. Within one minute, the craft was destroyed, and filmed footage of the event convinced the public that large dirigibles were unsafe.

That left only nonrigids, which were again a major part of antisubmarine warfare in World War II. However, they were retired in the 1950's when helicopters provided the same hovering capability with greater dash capability and easier storage. In the last third of the twentieth century, the few working nonrigid dirigibles were limited to flying advertising billboards and carrying television cameras for overhead views of sporting events. The only new application came in the 1990's, when tethered balloons returned to service as aerostats, providing platforms at altitudes as high as ten to fifteen thousand feet for radar stations and communications repeater stations.

Balloons fared better than dirigibles. Development of small radio transmitters combined with remotely operating weather instruments made possible balloon-borne radiosondes to report temperature, pressure, and relative humidity. Angle data from antennas tracking the radiosondes yielded wind speed and direction at different heights. Use of radiosonde balloons continued into the twenty-first century, helping predict weather, plot sky conditions for aircraft, and fire artillery more accurately.

Larger balloons have carried science payloads and human crews to high altitudes for decades because they can reach altitudes as high as 30 miles, which airplanes cannot reach, carrying large payloads that would not fit in an airplane fuselage. From the 1930's through the early 1960's, balloons were the frontier of human-crewed aviation that led to higher flights by HTA craft and eventually to space capsules.

The greatest problem at high altitudes is low pressure, which Swiss balloonist Auguste Piccard surmounted with a pressurized cabin, essentially the first space capsule, and he suggested similar pressurized cabins for high-flying transports. On May 27, 1931, Piccard and an assistant reached 51,793 feet (9.8 miles), making them the first to reach the stratosphere. More importantly, they discovered that cosmic rays increased with altitude, proving that they came from somewhere in space rather than the other suggested source, radioactivity within the earth. Such flights carried personnel and instruments to steadily greater heights and developed many technologies that were later used in the space race. In fact, on May 4, 1961, the American Stratolab V balloon reached an altitude of 113,700 feet (21.5 miles) with an open gondola so the two pilots could test space suits in near-space conditions for the Mercury orbital-flight program.

After the 1960's, scientific balloon flights using improved robotic instrumentation allowed balloons to shed the weight of the balloonists and their life-support gear. In the closing decades of the twentieth century, astronomic balloon-borne instruments conducted sky surveys in a number of frequency bands that cannot penetrate the lower atmosphere and provided valuable weather data from the lower stratosphere.

By the late twentieth century, advances in fabrics allowed the U.S. National Aeronautics and Space Administration (NASA) to begin replacing zero-pressure balloons with superpressure balloons, which do not need to vent excess helium when warmed by the sun and which consequently can fly for weeks or months. By the early twenty-first century, NASA had begun flying large superpressure balloons with several-ton payloads in a program called the Ultra Long Duration Balloon (ULDB).

Ballooning for Fun and Adventure

Although the aviation frontier passed ballooning by, a balloon ride is still a beautiful and awe-inspiring experience. A panoramic view floats by below and sounds from the ground float up to balloonists.

This was a rare experience until the renaissance of hot-air ballooning, started by American Edward Yost. While developing high-altitude balloons for the United States government in the 1950's, Yost realized that polyethylene-coated nylon is a lighter, less flammable material than that used in the Montgolfiers' balloons. He used an acetylene welding torch as a less labor-intensive source of hot air than the Montgolfiers used. After some development, such as replacing the welding torch with a propane burner, Yost made the first modern hot-air balloon launch from Bruning, Nebraska, on October 10, 1960.

Beginning in the 1960's, the new hot-air balloons radically reduced the cost and complexity of supplying buoyant gas. Thus were born ballooning clubs, competitions, and tour services. Also, for advertising, hot-air balloons have flown in shapes varying from spark plugs to human faces, and even a mansion.

For more ambitious flying, Yost's hot-air technology (plus lightweight insulating material lining the gasbag, and helium) made the Rozier balloon practical for long-distance flights. Varying the amount of heat in the inner balloon provides altitude control for hunting favorable winds. That capability, along with worldwide weather reports, made balloon flights possible across the Atlantic and then the Pacific Oceans. In March, 1999, another Piccard, Auguste's grandson Bertrand, and Brian Jones spent twenty days flying 30,000 miles to make a complete circumnavigation of the globe.

For astronomical and meteorological observations, balloons are still a much cheaper alternative to spacecraft, with shorter turnaround times and without the vibration and acceleration of a rocket launch.

Dirigible Economics and Prospects

By the beginning of the twenty-first century, dirigibles were enjoying a resurgence in several niche markets. However, dirigibles will probably never recover aviation primacy from HTA's for several reasons.

First there is a massive investment cost for building and developing dirigibles. Several factors make dirigibles more efficient as size increases. In particular, lifting volume increases by the cube while surface volume (and thus drag) only increases by the square. However, the large size makes the design and building of a dirigible as expensive as that of a ship. Large size also reduces the number of units made, so dirigibles have less chance to go down the learning curve toward lower costs and improved designs than HTA craft, which are typically made by the hundreds or thousands.

Second, hangar costs are high. Dirigibles are kept inflated because their helium lifting gas is expensive and would require too much time and effort to pump back into tanks. However, inflated dirigibles can easily be swept off their parking area by winds. Consequently, dirigibles must have their own special hangars rather than be casually parked on runways, as airplanes are.

Third, dirigibles are vulnerable to and limited by bad weather. The giant buoyant structures can be seized by freak gusts of wind on takeoff and landing, and they are more vulnerable than airplanes to icing. Zeppelin passenger flights were not scheduled in winter. In the sky, dirigibles are so large that winds may pull them in different directions and destroy them, as happened to the U.S. *Shenandoah*, *Akron*, and *Macon*. Moreover, unless specially designed for high altitude, dirigibles cannot readily climb above storms as jet-propelled airplanes can.

Fourth, due to the drag from the great size per unit mass of cargo, dirigibles are significantly slower than HTA competition. At best, they can obtain half the speed of propeller-driven planes and a fifth that of jets. Thus, a jet with one fifth of the cargo capacity of a dirigible can deliver the same cumulative mass of cargo. This longer time makes dirigibles uncompetitive in the passenger market.

Still, dirigibles have potential for certain markets because they can run quietly, run smoothly, linger for long periods, carry heavy and awkwardly large payloads, and land without runways. Lighter and more fireproof materials have increased these advantages. The number of advertising dirigibles increased steadily beginning in the 1980's. At the start of the twenty-first century, the Zeppelin Company was marketing sightseeing semirigids a third the size of the *Hindenburg*. CargoLifter in Berlin was designing a cargo-carrying rigid larger than the *Hindenburg*.

Meanwhile, an entirely new concept was being developed: dirigibles in the lower stratosphere serving as high-altitude platforms. Such platforms could serve many functions of communications satellites and astronomical satellites at a fraction of the cost. However, as with most LTA tasks, there is competition from airplanes.

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See also: Balloons; Blimps; Dirigibles; Experimental aircraft; Goodyear blimp; Heavier-than-air craft; *Hindenburg*; Hot-air balloons; National Aeronautics and Space Administration; Auguste Piccard; Alberto Santos-Dumont; Ferdinand von Zeppelin

Otto Lilienthal

Date: Born on May 23, 1848, in Anklam, Prussia (now in Germany); died on August 10, 1896, in Berlin, Germany

Definition: An aviation pioneer and creative genius who was the first man to build and fly a successful heavier-than-air flying machine.

Significance: Lilienthal was the first person to prove that flight could be achieved and sustained with the cambered, or curved surface, airfoil wing. He built and successfully flew a number of heavier-than-air flying machines before anyone else in history had done so.

Image Not Available

Otto Lilienthal's passion to fly blossomed early in his life. Although there was no formal science of aviation during Lilienthal's youth, ther e is evidence that Lilienthal studied birds in grammar school. At the age of twenty-five, Lilienthal joined the Aeronautical Society of Great Britain, where he gave his first lecture about the theory of avian flight. He then began systematic experiments and tests with models and kites on the force of air on human-made wings. No mere tinkerer, he was an accomplished engineer, with his own business engineering boilers and steam engines. He obtained a patent for a mining machine, the first of his twenty patents, four of which were aviation patents.

Lilienthal's ongoing experiments and studies culminated, in 1891, with his building his first heavier-than-air flying machine, which flew for a distance of 80 feet. This machine would be described today as a hang glider. Over the next five years, he built a total of eighteen flying machines and made more than two thousand sustained and replicable flights.

In 1892, Lilienthal built a new glider with improved flight characteristics. The following year, he built a flight station near his home, where he made a number of flights with distances of up to 800 feet. Lilienthal not only designed, engineered, and built a machine that could fly, but he also taught himself to fly it.

Although Lilienthal's flying machines were difficult to control and to turn, they did accomplish sustained flight. His outstanding contribution to the science of flight was the cambered, or curved surface, wing. This wing form, with a rounded top surface and a concave or flat underside, produces the lift needed to make an airplane fly and is still used today on most airplanes.

By 1895, Lilienthal's flight accomplishments were widely reported, and Lilienthal was visited by flight enthusiasts from many different countries. He corresponded with and shared his ideas with other aviation pioneers, such as Octave Chanute and Orville and Wilbur Wright. He generously published and shared the results of his aviation theories and experiments.

On August 9, 1896, at the age of forty-eight, Lilienthal crashed while flying one of his machines and died the next day. He is famous for the following quotation, "To invent an airplane is nothing. To build one is something. But to fly is everything." Lilienthal was a creative genius whose ingenuity, observations, engineering, and daring laid the cornerstone for the development of aviation.

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See also: Airfoils; Octave Chanute; Heavier-than-air craft; History of human flight; Wing designs; Wright brothers

Charles A. Lindbergh

Date: Born on February 4, 1902, in Detroit, Michigan; died on August 26, 1974, in Hana, Maui, Hawaii

Definition: A pioneer of early aviation, who became the first aviator to fly an airplane nonstop from New York to Paris.

Significance: While Lindbergh's 1927 New York-to-Paris flight made him a national and worldwide hero, he was more than another flier who set a record. In the forty-seven years between the flight and his death, he contributed significantly to civil and military aviation, scientific research, and conservation.

Early Life

Charles Augustus Lindbergh, whose family moved about a great deal, was raised more by his mother, Evangeline Land Lindbergh, than by his father, Charles August Lindbergh, who served in the U.S. House of Representatives from 1907 until 1917. During his precollege years, Lindbergh, an unimpressive student, attended eleven schools. He showed considerable mechanical ability, however, and was entranced by automobiles, motorcycles, and especially airplanes.

Interest in Flying

Lindbergh first saw an airplane in 1910, when a single-engine aircraft flew at treetop level up the river alongside the Minnesota farm where his family was living. From that time forward, Lindbergh thought of little but flying. He wanted to study aeronautical engineering in college, but no universities offered such programs. Finishing high school in 1918, he farmed for two years before entering the University of Wisconsin to study civil engineering. By 1920, he owned an Excelsior motorcycle, on which he rode to Lincoln, Nebraska, in 1922 when, bored by his studies, he dropped out of the university to attend flying school. Although the school closed before he earned his pilot's license, he knew by then that he wanted to spend his life flying.

Lindbergh apprenticed as a mechanic to a barnstorming pilot. He earned the nickname "Daredevil Lindbergh" by walking on the wings of the planes piloted by his boss, dazzling and delighting the assembled throngs below. By 1923, he was able to pilot planes himself. He traded his motorcycle for a war-surplus airplane, a Curtiss Jenny, in which he barnstormed on his own until, determined to perfect his skills as a pilot, he joined the U.S. Army Air Service Reserve in 1924.

In 1925, the U.S. Postal Service inaugurated airmail service to the Midwest, and Lindbergh became one of its earliest pilots, flying between St. Louis and Chicago, a treacherous route because of its severe winter weather. Twice Lindbergh had to parachute from his plane. While flying this route, Lindbergh learned that an affluent Frenchman, Raymond Orteig, was offering a $25,000 prize to the first person to fly nonstop from New York to Paris. Seven people had attempted this feat and failed. Lindbergh immediately began to work toward winning the prize. He designed a plane, the *Spirit of St. Louis*, to be built by Ryan Airlines in San Diego with funding from both Lindbergh and a group of St. Louis businessmen.

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Setting Records

Those who had failed to fly nonstop across the Atlantic Ocean had attempted the flight in dual-engine planes. Lindbergh designed a single-engine plane that would conserve weight. An enormous fuel tank occupied the area from the engine to the pilot's seat, totally blocking forward vision. A periscope was installed on the left window to overcome this problem. The plane carried 450 gallons of fuel, which so impeded its takeoffs that it barely cleared trees at the ends of runways.

After battling eight days of bad weather conditions that made a takeoff impossible, Lindbergh finally was ready to fly out of New York's Roosevelt Field on May 20, 1927, taking off at 7:52 A.M. To minimize weight, he carried only five sandwiches and a quart of water. He further lightened the plane by having no radio or parachute aboard.

Lindbergh flew the great circle route over Cape Cod, Nova Scotia, Newfoundland, and, after the long Atlantic crossing, Ireland, England, and France. The most hazardous leg of the flight, the crossing of the Atlantic, occurred at night. Ice formed on the wings shortly after Lindbergh passed Newfoundland. Fortunately, it soon dissipated. Lindbergh's chief battle now was against sleep. He would doze off and then quickly be jarred into wakefulness, realizing he was flying off course.

The *Spirit of St. Louis* flew through rain while passing over the southern tip of Ireland, but as the plane approached southern England, the weather cleared. The weather over Cherbourg, France, was so good that Lindbergh finally took a first bite from one of his sandwiches. He followed the Seine to Paris's Le Bourget Airfield where he landed on May 21 at 10:22 P.M., having flown more than 3,500 miles in 33.5 hours. Cheering crowds greeted him, and Raymond Orteig later awarded him the promised $25,000 prize.

Once home, the bashful Lindbergh was lionized. He was given a ticker-tape parade down New York City's Broadway. He became a roving international goodwill ambassador for the United States. In the course of these travels, he met Anne Spencer Morrow, the daughter of the U.S. ambassador to Mexico, whom he married in 1929.

The Down Years

Celebrity perplexed the ever-reticent Lindbergh. He tried increasingly to evade public notice. He and his wife traveled throughout the world and became ardent conservationists. Their first son, Charles Augustus, Jr., born in 1930, was kidnapped and murdered in 1932. In 1935, the Lindberghs, longing for privacy, relocated to England, where Lindbergh worked with Dr. Alexis Carrel to develop an early heart pump machine for use in open-heart surgery.

In Lindbergh's later years, his pro-Nazi, anti-Semitic sentiments were condemned by his once-adoring public. He gradually withdrew from public life, spending many of his remaining years at his favorite home in Hana, on the island of Maui, Hawaii, where he died of cancer in 1974.

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See also: Airline industry, U.S.; Airmail delivery; Barnstorming; Jennys; Military flight; Record flights; *Spirit of St. Louis*; Transatlantic flight

Lockheed Martin

Definition: Aerospace company formed by the 1996 merger of Lockheed and Martin.

Significance: Lockheed was founded in 1916 and became a leader in the American aerospace industry. The smaller Martin company was founded in 1912 and eventually focused on space travel.

Early Years

Lockheed was originally founded by brothers Allan and Malcolm Loughead in 1916. The Loughead brothers had broken into the aircraft manufacturing business three years earlier when they constructed a seaplane under the auspices of their Alco Hydro-Aeroplane company in San Francisco. The Loughead Model G seaplane carried visitors to the Panama-Pacific Exposition over San Francisco Bay at a cost of $10 per person. The company folded when the exposition ended, and the Loughead brothers decided to move to sunnier Los Angeles, where they formed the Loughead Aircraft Manufacturing Company.

During World War I, the company built two patrol bombers for the U.S. Navy, but these did not lead to additional orders. The Loughead brothers then decided to capitalize on the popularity of aviation in the United States by building a sport airplane for the masses. The program produced an aircraft known as the S-1. The S-1 was a technological breakthrough, but a commercial disaster. The U.S. government dumped thousands of war surplus aircraft into the market and Loughead did not sell a single S-1. The Loughead Aircraft Manufacturing Company went out of business in 1920.

Six years later, Allan Loughead and his former employee Jack Northrop decided to begin manufacturing airplanes again. They incorporated the Lockheed Aircraft Company in December, 1926. Irritated by mispronunciation of his name, Allan Loughead decided to use the phonetic spelling for his new company. The company immediately began work on a planed designed by Jack Northrop. Lockheed dubbed the aircraft the Vega, starting a tradition at Lockheed of naming planes for celestial phenomena.

Charles A. Lindbergh's solo flight across the Atlantic in 1927 sparked widespread interest in aviation and the Vega quickly became a popular aircraft. The first well-known Vega pilot, George Hearst, Jr., disappeared during a race from San Francisco to Honolulu, but this did not spoil the Vega's reputation. Australian George Hubert Wilkins bought the fourth Vega, and he and his pilot, Ben Eilson, used the plane to become the first men to fly over the North Pole on April 15, 1928. Famous American aviator Wiley Post and his navigator flew the Vega around the world in 8 days and 16 hours in 1931. Two years later, Post made the same journey solo in 7 days, 19 hours. Post also flew the plane to an unofficial altitude record of 55,000 feet in 1935.

The success of the Vega created a great deal of interest in Lockheed, and in 1929, the company accepted a buyout offer from the Detroit Aircraft Company. Allan Loughead opposed the sale, but the company's board of directors did not agree. Bitter at this defeat, Loughead resigned and, despite repeated attempts, never established another viable aircraft or manufacturer. At the same time, Jack Northrop also left Lockheed to form the Avion Corporation, which later became the Northrop Corporation.

The Lockheed company continued on as part of Detroit Aircraft's "General Motors of the Air" and produced three more notable aircraft before World War II. The Sirius immediately became famous when Charles A. Lindbergh bought the first model. He and his wife Anne Morrow Lindbergh used the plane in 1930 for a number of well-publicized flights over the North Pacific and North Atlantic. Lockheed followed up the success of the Sirius with the Altair. Both the U.S. Army Air Corps and the U.S. Navy acquired Altairs, which were the first aircraft with fully retractable landing gear to be purchased by either service. Sir Charles Kingsford-Smith also used an Altair to fly from Australia to San Francisco in 1934, becoming the first person to cross the Pacific in that direction. Lockheed continued its success by constructing an airliner. The Orion made its first flight in April, 1931, and soon became a fixture in airports around the world. American, TWA, Northwest, and Swissair all made Orions part of their fleets. The Orion was particularly suited for high-speed routes, with one plane making the trip between San Francisco and Los Angeles in just 65 minutes.

Wartime Production

In 1931, the Detroit Aircraft Corporation went bankrupt, another victim of the Great Depression. A group of investors, including several employees, managed to get Lockheed out of receivership and founded the Lockheed Aircraft Corporation on June 6, 1932. The company began work on a new aircraft, the Electra. Amelia Earhart flew an Electra on her ill-fated attempt to become the first woman to fly around the world in 1937. Subsequent variations of the Electra would see service in airlines around the world. Also in 1932, Clarence "Kelly" Johnson became an engineer with the company. The Model 14 Super Electra, designed by Johnson, became the basis for the Hudson bomber, which ushered in a new era in Lockheed's history.

From the company's beginning, Lockheed had sought military contracts, but had enjoyed only marginal success. The war clouds looming over Europe in the late 1930's gave the company a fresh opportunity. Britain agreed to purchase more than two hundred Hudson bombers in 1938. Lockheed's factory in Burbank, California, produced 2,941 Hudsons during the war for a number of armed forces, including the U.S. Army and Navy.

Lockheed made a valuable contribution to the U.S. fighter arsenal during World War II with the creation of the P-38 Lightning. Designed by Kelly Johnson and Hall Hibbard, the plane featured an unusual twin-fuselage design to accommodate its engines. Lockheed secretly constructed the first Lightning in 1938 and the plane made its first flight on January 27, 1939. The Army Air Force bought more than 9,000 P-38 Lightnings during World War II. The Lightning served in all theaters, accounting for the destruction of 1,771 enemy planes in Europe. In the Pacific, the highest-scoring U.S. World War II ace, Dick Bong, flew the P-38, as did two other top-ten U.S. aces. The P-38 also accounted for perhaps the most famous mission of the war when eighteen Lightnings shot down the plane carrying Japan's famed naval strategist Isoroku Yamamoto on April 18, 1943.

Important Postwar Military Aircraft

Lockheed began work on a jet fighter in 1943. The company gave its top designer, Kelly Johnson, a team of workers and a crude building to start the project. Johnson's secret area in the Lockheed complex became known as the Skunk Works. The Skunk Works eventually designed all the company's high-performance fighters and reconnaissance planes. Ironically, this top-secret part of the company ultimately became famous for its research and development. Besides Lockheed's well-known fighter aircraft, the Skunk Works also produced such famous planes as the U-2 spy plane in 1954 and the SR-71 Blackbird in 1964.

The P-80 Shooting Star, the first plane designed in the Skunk Works, made its first flight in January, 1944. The Army Air Force soon ordered 5,000 Shooting Stars, but only a handful made appearances during the war. Lockheed continued production with successive upgrades of the Shooting Star and the aircraft represented half of the U.S. Air Force's jet fighter strength at the outbreak of the Korean War in 1950. Lieutenant Russell Brown used a P-80 to shoot down a Chinese MiG-15 on November 8, 1950, in the world's first dogfight between jet fighters. However, the Air Force relegated the P-80 to second-line status during the Korean War, as greater numbers of the more advanced North American F-86 Sabre jet became available.

Responding to the input of pilots during the Korean War, Kelly Johnson designed a new fighter that would outperform any aircraft in service. Lockheed started testing F-104 Starfighter in 1954, though early crashes marred the test flight program. Following corrections, the air force adopted the Starfighter in 1958. Despite having wings under 8 feet long, the F-104 flew at more than 1,400 miles per hour and higher than 100,000 feet. The Starfighter saw limited action in Vietnam before the air force phased out the aircraft in 1967.

In addition to building fighters, Lockheed produced a mainstay of the U.S. Navy's air arm, the P-3 Orion. After a three-year test program, the first Orions entered service in 1962. The plane was designed for antisubmarine duty and its four turboprop engines gave it a range of 5,200 miles. The Orion remained in service through the end of the twentieth century.

Lockheed's greatest postwar military planes were the company's transports. The first, the C-130 Hercules, flew in 1954 and the air force adopted the plane two years later. The C-130 family proved its versatility in places as diverse as Vietnam and the Arctic. The company followed up the success of the Hercules with the C-141 Starlifter. The C-141 used jet engines to extend its range and lifting capacity beyond the turboprop C-130. The first model flew in 1963 and entered service two years later. The C-141 played an important role in the Vietnam War because it could fly nonstop from California to Saigon, freeing up the shorter-range C-130's for tactical missions. In 1965, Lockheed won a contract to produce the largest transport plane in history, the C-5 Galaxy. The C-5 flew in 1968 and entered service in 1970. The Galaxy allowed cargo loading through both aft doors and the nose and could take off and land in the same distance as a jetliner. The plane became a foundation of the Air Force's transport system due to its ability to carry more than 100 tons of payload.

Lockheed also developed one of the most successful trainer aircraft in history, the T-33 T-Bird. The first T-Bird flew in 1948 and became Lockheed's biggest-selling jet. Air forces around the world adopted the T-33, and it remained in service in the U.S. Air Force for more than forty years.

Events in the History of Lockheed Martin

1926: Allan Loughead (name later changed to Lockheed) establishes Lockheed Aircraft Company in Hollywood, California, where he and Jack Northrup design the popular and record-setting Vega monoplane.

1929: The Lockheed Aircraft Company is purchased by the Detroit Aircraft Corporation, which declares bankruptcy three years later.

1932: The Lockheed Corporation is reorganized by a group of investors who improve the company's fortunes throughout the Great Depression with the production of the dual-engine Electra airliner.

1940's: Lockheed begins a long-term association with the U.S. military, providing P-38 Lightning bombers during World War II and establishing the Advanced Development Projects division, or Skunk Works, a top-secret facility for military aircraft development.

1980's: Lockheed develops the F-117A stealth fighter.

1995: Lockheed merges with the Martin Marietta Corporation.

1996: Lockheed absorbs the defense electronics and systems integration divisions of Loral.

Postwar Commercial Aircraft

Before World War II interrupted commercial air service, Lockheed and other American manufacturers developed four-engine airliners. In Lockheed's case, TWA and its majority stockholder, Howard Hughes, pushed the company to design the Constellation. In 1939, TWA ordered forty of the new airliners, but the war preparations halted production in May, 1941. TWA finally received its first commercial Constellation on October 1, 1945. Despite two early crashes, the Constellation and its successors, the Super Constellation and the Starliner, became great successes. Airlines from South Africa, India, West Germany, and many other countries made the Constellation part of their fleets. In the United States, the final plane in the series, the Starliner, remained in regular service with TWA until 1967 and made the airline's final piston-engine flight.

The success of the Constellation line ended with the advent of jetliners. In 1966, Lockheed began work on its first jetliner, the L-1011 Tristar. The L-1011 and McDonnell Douglas's competing DC-10 both began sales to airlines in 1968. Unfortunately for both companies, the planes were nearly identical and competed for the same marketplace. This competition, combined with the expense of developing the C-5 and L-1011 at the same time, drove Lockheed to the brink of bankruptcy. The company was saved only when the federal government guaranteed Lockheed's credit to lenders in 1971. Between 1970 and 1985, Lockheed built 250 L-1011's, but the program was not as successful as the company had hoped.

Missiles and Space

To take advantage of the demand for missiles in the Cold War, the company founded the Lockheed Missile Systems Division in 1954. This division developed the weapons for the U.S. Navy's ballistic missile submarines. The first missile, the Polaris, had a range of 1,200 nautical miles and became operational in 1960. Lockheed followed with two more variations of the Polaris, eventually increasing the range to 2,500 nautical miles. The missile remained in service until 1982, when the Navy replaced it with another Lockheed product, the Poseidon, first introduced in 1970. The Poseidon was similar to the Polaris, but had a wider diameter. Lockheed followed the Poseidon with the Trident, which came into service in 1981 and extended the Navy's ballistic missile range to more than 4,000 nautical miles. Lockheed's missile and space division also developed ceramic heat-resistant tiles for the space shuttles and built the Hubble Space Telescope.

Corporate Changes

Following the difficulties of the L-1011 program, Lockheed's directors rededicated the company to military and space products. Lockheed purchased General Dynamics F-16 Fighting Falcon division in 1992. In 1996, the company merged with Martin Marietta to form Lockheed Martin. Martin Marietta had designed the B-24 bomber during World War II and the Titan missile and rocket system. The new company entered the twenty-first century building the Air Force's new F-22 Raptor fighter, as well as working on a replacement for the space shuttle, the X-33 VentureStar.

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See also: Aerospace industry, U.S.; Fighting Falcon; Manufacturers; Mergers; Missiles; Raptor; X planes

Lufthansa

Also known as: Deutsche Lufthansa AG

Date: Founded on January 6, 1953, as a successor to Deutsche Luft Hansa, founded on January 6, 1927

Definition: Flagship air carrier of Germany, and one of the largest airlines in Europe and the world.

Significance: With a careful growth strategy, Lufthansa has been successful in measuring up to the challenges of globalization and liberalization that have been prominent in the airline business. Following its full privatization in 1997, Lufthansa has emerged as one of the largest public companies in both Germany and Europe.

Corporate Structure

Lufthansa is a major German airline headquartered in Frankfurt. It was organized in Cologne on January 6, 1953, as a joint venture of the federal government of Germany,

Events in Lufthansa History

1926: Deutsche Luft Hansa Aktiengesellschaft is formed by the merger of Deutsche Aero Lloyd (DAL) and Junkers Luftverkehr and begins scheduled flights.
1933: The airline is renamed Lufthansa.
1934: Lufthansa makes the first regularly scheduled transoceanic airmail deliveries across the South Atlantic.
1939: The airline initially expands its route network, but it is suspended from operations with the outbreak of World War II.
1945: All Lufthansa flights are canceled, and the airline goes into receivership.
1953: After postwar German air traffic is reestablished, a new company is formed, which renames itself Lufthansa the following year.
1955: Lufthansa resumes scheduled flights.
1960: The airline takes delivery of its first jet aircraft, a Boeing 707.
1970: The airline takes delivery of its first wide-body jumbojet aircraft, a Boeing 747.
1971: Lufthansa retires from its fleet the last of its propeller-driven aircraft.
1990: After Germany's reunification, Lufthansa resumes flights to Berlin, its first in forty-five years.
1997: Lufthansa joins the Star Alliance, a global network of airlines including Air Canada, SAS, Thai Airways, and United Air Lines.

the German National Railway, and the state of Nordrhein-Westfalen. Later, the airline accepted private investors. It was successor to Deutsche Luft Hansa, or DLH, founded on January 6, 1926, which suspended service at war's end in 1945 and was formally liquidated in 1951. The new airline, initially called Aktiengesellschaft für Luftverkehrsbedarf or Luftag, adopted the old name, slightly respelled, in 1954; but whereas the old company had been familiarly called DLH, the new one was popularly called Lufthansa. Lufthansa was fully privatized in 1997. It has emerged, after its privatization, as one of Germany's biggest public companies, with 400,000 shareholders. In addition to flying, Lufthansa is active in several other areas, including ground services, IT services, catering, leisure travel, maintenance repair overhaul, logistics, and passenger services. Lufthansa operates in these areas through several subsidiary companies.

Route Structure

DLH, as the greatest and most comprehensive airline in prewar Europe, had resulted from the merger of Deutscher Aero Lloyd (formed in 1924) and Junkers Luftverkehr (formed in 1921), which together controlled a large network of lines throughout Germany and central Europe, with extensions to London, Moscow, Stockholm, Helsinki, Budapest, and the Persian Gulf. By 1931, DLH was serving Paris, Barcelona, Rome, and Oslo and accounted for one third of all passenger travel and air transport in Europe. The German-built Junkers Ju-52/3m, used by other airlines as well as by DLH, became the most familiar aircraft in European airports, until American-made airliners gradually surpassed it in the late 1930's. In 1934, DLH began the world's first scheduled transoceanic flights—between Germany and South America—but its other experiments in transatlantic and trans-Asian routes were cut short by the outbreak of World War II. Between 1936 and 1938, Lufthansa experimented with scheduled air services across the North Atlantic. After substantial expansion of the route network in 1939, which included flights to Bangkok, Thailand, and Santiago, Chile, the airline suspended air services, with the exception of flights to a handful of European countries.

Only two months after inaugurating scheduled services within Germany on April 1, 1955, Lufthansa began transatlantic flights to New York. In the same year, scheduled service began to Paris, London, Madrid, and Lisbon in Europe, and special flights began to Moscow. In 1956, the first flights were made to Chicago; Montreal, Canada; Rio de Janeiro and Saõ Paulo, Brazil; Buenos Aires, Argentina; Baghdad, Iraq; and Tehran, Iran, followed by initial flights to India in 1958 and resumption of the flights to Bangkok in 1959.

Lufthansa's vast network radiates from Frankfurt am Main and Munich, its two hubs, to such distant cities as Santiago, Chile; Mexico City, Mexico; Los Angeles, California and Anchorage, Alaska in the United States; Tokyo, Japan; Hong Kong, China; Sydney, Australia; and Johannesburg, South Africa, as well as to several airports throughout Europe and the Middle East.

Lufthansa entered the jet age in 1960 with the arrival in the fleet of the Boeing 707, used initially on long-haul routes. Conversion to jet aircraft continued gradually until 1971, when Lufthansa's last propeller-driven aircraft, the Vickers Viscount, was retired. Lufthansa acquired the Boeing 727 and 737 starting in 1964. It took its first delivery of the Boeing 747 in 1970, which was later joined by the McDonnell Douglas DC-10 and the Airbus A300. As of 2001, Lufthansa's fleet included the following aircraft: Boeing 747-400 and 747-200 series, Airbus A340, Airbus

A300-600, Airbus A310, Airbus A321, Airbus A320, Airbus A319, Boeing B-737, Canadair CR1, and AVRO RJ85.

Alliances and Partnerships

Lufthansa, along with Air Canada, SAS, Thai Airways International, and United Air Lines, founded the Star Alliance in 1997. In subsequent years, membership grew to include Air New Zealand, ANA, Ansett Australia, Austrian Airlines, British Midland, Lauda Air, Mexicana Airlines, Singapore Airlines, Tyrolean Airways, and Varig. In 2001, the Star Alliance encompassed fifteen airlines and a network of 130 countries and 815 destinations, making it the world's largest alliance. In addition to its Star Alliance partners, Lufthansa cooperates with several other airlines on such matters as code-share flights and participation in one another's frequent flier programs. Lufthansa's partner airlines as of June, 2001, were South African Airways, Adria Airways, Air Baltic, Air Dolomiti, Croatia Airlines, Czech Airlines, Luxair, Qatar Airways, and Spanair. Additionally, for the regional market, Lufthansa cooperates with several regional carriers: Augsburg Airways, Cirrus Airlines, Contact Air, Rheintalflug, Air Littoral, and Cimber Air. These regional carriers bear the name Team Lufthansa.

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See also: Air Canada; Air carriers; SAS; Singapore Airlines; United Air Lines

Luftwaffe

Definition: Germany's air force from the early 1930's to the end of World War II.

Significance: The Luftwaffe used fast-moving offensives to destroy enemy aircraft. Although it was effective in the early years of World War II, it became less so as the war progressed, losing its air superiority due to aircraft obsolescence, economic inferiority, poor organization, and poor leadership.

History

After World War I, in which Germany had been roundly defeated by the war's length as much as by the economic superiority of its opponents, General Hans von Seeckt, the commander of the German Army, realized that fast, mobile offensives would be necessary to avoid prolonged future wars that Germany could not win. He therefore devised the military strategy of the Blitzkrieg, or lightning war, fast-moving surprise attacks.

The Luftwaffe, designed around the Blitzkrieg concept, was initially very effective during World War II in gaining air superiority via short, independent operations all over the European continent. As the European air war drew on, however, the Luftwaffe was engaged in a contest that it could not win.

From the beginning, the Luftwaffe's leaders saw the necessity of air superiority. Its chiefs of staff noted that air support of ground forces at the start of a war did not mitigate the damage inflicted by functional enemy air forces. From the start of any campaign, the Luftwaffe's primary efforts were focused on the destruction of all enemy aircraft. Its bombers crushed enemy bombers on the ground, disrupting potential sorties, and its fighters hunted down any enemy aircraft able to become airborne.

The Luftwaffe carried out its activities via autonomous air fleets, known as the Luftflotten. Each Luftflotte comprised both aircraft and support units. Technologically, the aircraft were suited for offensive counterair missions (OCAMs) that destroyed enemy aircraft on the ground. German Stuka bombers had the range and payload to reach and damage the air bases that held the most enemy aircraft. Twin-engine fighters escorted bombers, warding off enemy fighters until the OCAM was completed. Single-engine Messerschmitt fighters fought enemy aircraft.

Luftwaffe aircraft enabled short-offensive campaigns but had little use in other types of air warfare, such as attacks on training bases in the rear and other distant sources of enemy air power. German bombers had low ranges, meager payloads, and very little defensive armament. Later failure of newer escort fighters and the short ranges of all existing escorts exacerbated the problem, restricting German air power to use in the battlefield. Germany successfully applied its OCAM doctrine during the first two years of the war. These attacks destroyed numerous aircraft and caused the remainder to operate inefficiently. However, these victories cost the Luftwaffe huge aircraft losses. For example, in the two-month battle for France, 36 percent of all German aircraft were either damaged or lost. Such losses were initially acceptable, because they were suffered in the defeat of several Allied air forces. However, over the course of prolonged warfare, this high loss rate was damaging to the German cause, especially after German offensive campaigns failed against both England and the Soviet Union.

In 1940, the Luftwaffe was unable to defeat the Royal Air Force (RAF) in the Battle of Britain. After unsuccessful battles over the English Channel, a three-week German campaign against RAF bases made some progress but was changed to unsuccessful day attacks and then to nocturnal terror attacks. German inability to win was due to RAF defense strategy and absence of a ground war to distract the RAF.

Similarly, the Germans had initial success in their air war against Russia by employing the OCAM doctrine, but the German ground forces ultimately proved unsuccessful. The unanticipated Siberian air power, the untenable Russian winter weather, and the vastness of the eastern front all led to the campaign's failure and the Luftwaffe's weakening. As General von Seeckt had noted, opponents pushed to defense are broken by destruction of aircraft. German failures in Britain and Russia forced the Luftwaffe into defensive counterair battle (DCAB), as the need to win air battles over its homeland exhausted Germany's hope of air superiority.

The prolonged defensive air war forced the Luftwaffe to adopt a defensive strategy in its organization, equipment, and deployment. Overwhelmed by Allied aircraft production, German strategy consisted largely of annihilating Allied bombers. This strategy was impractical, given the Allied air superiority. Luftwaffe generals, however, clung to false hope that if they could decimate enough Allied bombers, they could cause the cessation of Allied air offensives. By 1944, two whole Luftflotten were used in this way. As the Allied threat grew, the German expansion and refinement of its air defense included the development of radar and automated fighter control systems, an increase in armor and armament, the use of aerial bombs and cannon on board fighter planes.

German aircraft manufacters shifted from the production of bombers to production of fighters, giving the Germans success throughout 1943. Although Allied bomber raids were not stopped entirely, they evolved into less effective, nighttime operations with huge bomber losses. However, these German victories were only temporary, because at the same time, hundreds of German planes and pilots were lost in the battles. The air war became a lost cause.

Although the Germans made other technological advances, including the use of jets and surface-to-air missiles, these came too late to be useful. Huge numbers of Allied air forces drove the Luftwaffe from the sky. Amid failing defenses, the German air force stubbornly held to its offensive practice. Its forces kept declining, however, and the last major OCAM achievements occurred as follows. In June, 1944, a night raid on Poltava, a Ukrainian city on the eastern front, destroyed many U.S. bombers caught on the ground. Operation Bodenplatte, the last major German fighter operation, was waged in Belgium, Holland, and France, in January, 1945. It used the entire German fighter force to raid Allied airfields. There, single-engine fighters and green German pilots carried out a mission in which 30 percent losses occurred. Both operations were destructive, but barely altered the numbers of Allied aircraft available in Europe.

Leadership

Possibly, the Luftwaffe had always been in an untenable position, because Nazi Germany was a dictatorship ruled by its inflexible chancellor, Adolf Hitler. The German General Staff was faced with this problem as well as with the politicking, drug addiction, and incompetentency of high-ranking government officials.

An example is that of Hermann Göring. A former World War I fighter ace and the head of the Luftwaffe, he was unable to function adequately or consistently due to his drug abuse and his inability to counter Hitler's preference for the production of bombers instead of fighters. These weaknesses in the Luftwaffe's command led to the decrease and eventual collapse of the force's fighting ability.

A contrasting example is that of the able Adolf Galland, a fighter ace of the Condor Legion who also participated in the German invasions of Poland and France and the Battle of Britain. In 1941, he became the commander of the Luftwaffe's fighter arm and by 1943, had been promoted to the rank of major general. In 1943 and 1944, he ably commanded Germany's already-failing fighter squadrons against Allied bombers. Despite Galland's resourceful leadership of a crumbling air operation, Hitler and Göring blamed him for weakened Luftwaffe air defenses in 1944 and, soon thereafter, relieved him of his command.

Many critics blame the Luftwaffe's failure on its leaders, based on three flaws. First is the fact that the Luftwaffe high command used training units in battles such as

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Poltava. This decision was seen as damaging, because continued training operations were essential to winning the war. Second is the perception that the Luftwaffe was too slow in recognizing the war's attritional nature and implementing the defense measures needed for any chance of eventual success. Göring has been accused of overconfidence in the offensive air-war strategy and failure to see the need to prepare for failure. The third major Luftwaffe shortcoming was in its inferior equipment and inability to modernize or build heavy bombers that could compete with those of the Allies.

Aircraft

Much of the basis for eventual Luftwaffe failure may lie in Hitler's long-standing preference for bombers over fighters. Under Hitler's dictatorship, it was difficult for military leaders to work around such a prejudice. This theory may partly explain the relative obsolescence of the Luftwaffe aircraft toward the end of the war.

Although efforts were made to produce new aircraft, promising new designs apparently did not work out well. For example, the Junkers Ju-88, a twin-engine bomber planned as the successor to the Ju-87 Stuka, was not airworthy. In its production, designers increased the Ju-88's weight to enable dive-bombing, thereby reducing its effective range and speed and rendering it ineffective against the increasingly faster aircraft being produced by the Allies.

Furthermore, the Heinkel He-117 aircraft, an attempt to produce long-range bombers, was a disaster. Its planned weight was doubled in order to make it suitable for dive-bombing. More devastating was the aircraft's tendency to fall apart during dives and to explode in flight. Moreover, the Messerschmitt Me-210 fighter, planned to replace the Luftwaffe's fighter workhorse, the Me-109, was a dismal failure. This aircraft and others were canceled early in production, and the Germans were never able to build a successful four-engine bomber. These failures occurred at times when Germany could not afford to squander its slim resources.

Consequently, the Luftwaffe relied on a few tried-and-true aircraft, such as the Junkers Stuka bombers and the Messerschmitt Me-109 fighters. These aircraft were, by the early 1940's, relatively obsolete.

The Stuka dive-bomber, a low-winged, single-engine aircraft, was a very successful weapon during the first half of the war. Stukas employed dive-bombing techniques developed by the U.S. Navy, dropping bombs while diving and then moving into getaway flight mode. Special brakes slowed Stuka dives and gave pilots time to aim bombs. The bombers were armed with four 8-millimeter machine guns, two of which were operated by a rear-gunner. Late in the war, the rear-mounted guns were replaced with a heavier gun. The Stuka carried 1,100- or 550-pound bombs and had two 110-pound bombs under each wing. Although the plane was periodically modified throughout the war, its maximum speed remained 210 miles per hour. Eventually, it proved no match for faster Allied fighters.

The Me-109 fighter was used to great effect in World War II. Powered by a fuel-injected, Daimler-Benz engine, this low-winged, single-seater, monoplane had a top speed of 350 miles per hour and a ceiling of around 40,000 feet. It held two 20-millimeter cannons and two machine guns. Me-109's were the pride and joy of the Luftwaffe, faster and much more maneuverable than most Allied fighters. However, the Me-109's range was limited by a small fuel capacity, and by 1944, Allied fighters had outstripped it in every way.

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See also: Bombers; Fighter pilots; Messerschmitt aircraft; Royal Air Force; World War II

M

McDonnell Douglas

Date: Formed in April, 1967; combined with the Boeing Corporation in August, 1997

Definition: In combining the McDonnell Aircraft Company and the Douglas Aircraft Company, McDonnell Douglas became one of the largest airplane manufacturers in the world.

Significance: The corporation produced some of the best-known passenger airplane series, including the DC series and the MD series, such well-known military aircraft as the F-15 Eagle, the F-18 Hornet, the C-17 transport, and the Apache attack helicopter, while providing technical aid in developing the Tomahawk Cruise Missile and Skylab.

The Douglas Company

The McDonnell Douglas Aircraft Corporation was the creation of two pioneers in the commercial and military aircraft industry. Donald Douglas (1892-1981) began the Davis-Douglas Company in 1921. The aircraft company built both commercial and military planes, including the DT-1 and the DT-2 torpedo bombers for the U.S. Navy. The Douglas World Cruisers were the first passenger planes to complete an around-the-world flight. Douglas's partner soon sold his interest in the company, and Douglas incorporated the Douglas Company in July, 1921. Douglas used some of the great airplane engineering minds of his time, including Jack Northrop, to develop commercial airplanes for the burgeoning airline industry. Northrop left the company, but Douglas continued, spreading his military aircraft development to include the C-1 transport and the Devastator torpedo bomber for the United States in World War II.

Upon buying the Northrop Company, Douglas became even further involved in the production of military aircraft. Douglas produced some of the best-known and most reliable fighters and bombers for the Allied air forces. The A-20 Havoc was one of the war's most dependable bombers, able to withstand considerable punishment and fly after heavy damage from ground fire, flying many a crew member back safely. Some seven thousand of the planes were produced during the war. The Dauntless was a carrier bomber used in the Pacific theater and was effective and less likely to be shot down than many other bombers used in the theater. The A-26 bomber was used in three wars, including those in Korea and Vietnam, proving its effectiveness and durability.

The military projects were overshadowed, however, when compared to the company's success in the commercial plane business. In 1933, the Douglas Company began the DC series of passenger planes. It was those planes, particularly the DC-3, built in the 1930's, and the DC-9, built in the 1960's, that revolutionized air travel for ordinary people. It was those planes that also made the Douglas Company an attractive takeover target for one of its competitors.

The McDonnell Company

James McDonnell (1899-1980) started his first aircraft company, J. S. McDonnell & Associates, in 1928 but saw it dissolve under the strain of the Great Depression. After working as the chief engineer for another company from 1933 to 1938, McDonnell started a new company, McDonnell Aircraft Corporation, in 1939 and took advantage of the need for military planes to meet the crises of the time. With the United States rearming and then fighting a war, McDonnell's company, located in St. Louis, Missouri, began to provide parts for the American war effort. After the war, McDonnell became a major supplier for the military and the developing U.S. space program. The company built the F-4 Phantom, one of the fastest fighter jets of its generation. Its greatest contribution during the 1950's and 1960's was the development of rockets capable of lifting large payloads into orbit. In addition, McDonnell was a major player in developing the capsules for early crewed spaceflight. The company constructed the first Mercury spacecraft used for the United States' first crewed orbit of Earth. Through the early 1960's, McDonnell was one of the primary suppliers of spacecraft for the Gemini Program of the National Aeronautics and Space Administration (NASA). Missile technology created more growth for the company. McDonnell was responsible for building the Nike missile system, then the British Skybolt system. It also developed one of the first ballistic missiles, the Thor, capable of short launches, beginning in 1956.

The McDonnell and Douglas Merger

With financial difficulties looming as development costs for the DC-8 and DC-9 ballooned, the Douglas Aircraft

Company sought financial backing by means of a merger. Losses had totaled hundreds of millions of dollars, with many DC-8's completed but lacking engines to fly them. McDonnell proved to be the best fit for Douglas, as it wanted to expand its operations to include transport planes such as those built by Douglas. On April 28, 1967, the two companies formally merged to become McDonnell Douglas. The founders of the two partners continued to serve on the board of directors of the new company and added their input to major decisions. The main production facilities for the company included McDonnell's base of operations in St. Louis, Missouri, and Douglas's in Long Beach, California. While these would remain the major production headquarters, during difficult financial times in the 1970's some of the California subsidiaries were closed.

The first commercial transport developed by the company was the DC-10, the last plane to carry the designation of the DC series; the new company changed future planes to the MD series. First flown in the early 1970's, the DC-10 proved to be a popular aircraft, although it suffered through difficulties at the end of that decade. With the companies' merger, the new MD series was launched, with the first plane coming off the assembly line being the MD-80 or the Super Eighty. The MD-80 represented a different approach to passenger aircraft in the size of the fuselage, the wings, and the engines. During the 1980's and 1990's, the company built on the Douglas Aircraft Company's success with the DC-10 series and modified those planes to include the MD-90, the MD-95, and the MD-11, which was to replace the DC-10. While the MD-80 and MD-95 were partially successful airplanes, the MD-90 was less successful and was discontinued upon McDonnell Douglas's merger with Boeing in 1997.

While the construction of civilian passenger aircraft continued based on the Douglas designs, McDonnell Aircraft's emphasis on military flight gave the combined company another market to meet. One of the company's biggest sellers in the 1970's and the 1980's was the F-15 Eagle. The fighter plane became known as one of the most technologically advanced fighters of its time and one of the most maneuverable planes to fly. The F-15 not only served as the frontline aircraft for the United States Air Force during that time but also was coveted by other nations familiar with its capabilities. As the Air Force began looking for a new, more technologically advanced fighter, McDonnell Douglas began selling F-15's, with government approval, to such American allies as Japan and Israel. The company also built the F/A-18 Hornet for the Navy. The attack plane was based on aircraft carriers, providing the Navy with quick strike capabilities all over the world. Twelve hundred Hornets were built and used both in various combat situations and by the Blue Angels aerobatics team in their demonstration flights. The Hornet continued to be produced even as McDonnell Douglas was merging with Boeing. The next generation of the fighter, the F/A-18E/F Super Hornet began flying in 1995.

The company was also instrumental in developing vertical takeoff and landing aircraft. With experience in building helicopters, McDonnell Douglas began the difficult task of designing an airplane that could land and take off from a sitting stop, much like a helicopter. At the same time, once the plane reached the air, it could fly at speeds approaching many other fighter aircraft, making it less vulnerable in the air than were helicopters. During the 1960's, several prototypes proved to be too expensive to build. Only when McDonnell Douglas joined with British Aerospace was an affordable model built, the AV-8B Harrier jump jet. The planes could take off from a sitting position and land in most small clearings. The Harrier II Plus was a modified and updated version of the original aircraft and began flying in 1992.

The company's military aircraft wing was strengthened in 1984 with its purchase of Hughes Aircraft from General Electric. This combined two of the main competitors in the building of attack helicopters for the U.S. Army. With the addition of Hughes, McDonnell Douglas was responsible for the new generation of Apache attack helicopters used so effectively by American troops during the Persian Gulf War. McDonnell Douglas also continued its tradition of building dependable military transports. The C-17 or Globemaster III was the largest American military plane ever built. It flew for the first time in September, 1991, and allowed the military to move large amounts of matériel and troops across continents and oceans.

Missiles and Outer Space

With its passenger aircraft and military planes competing well with other companies, McDonnell Douglas continued to branch out and remain involved in developing missile technology for NASA and the U.S. military. For the U.S. space program, the company modified one of its Saturn rockets to create a permanent space station that became known as Skylab. Launched in May, 1973, Skylab allowed three people to live in what had once been the hydrogen holding tank for the Saturn rocket. This makeshift orbiting lab was used for little over a year, floating empty for five years before burning up in the atmosphere in July, 1979. It was the first U.S. space station and the only one until the International Space Station began operations in 2000. Closer to Earth, the company worked on some of the most advanced missile technology of the era. With the success of its Talon antiaircraft missile, McDonnell Douglas also developed its Harpoon antiship missile.

Its most important and most difficult task was development of the BGM 109 Tomahawk cruise missile. Cruise missiles are built to deliver ordnance, whether conventional explosives or nuclear weapons, beneath enemy radar. This requires the missile to fly only hundreds of feet above the ground and to have the capability of identifying a single target among all the surrounding ground clutter. The technological achievement in building a guidance system for the cruise missiles earned McDonnell Douglas the contract to build much of the military's missile supply.

The Boeing Merger

With military contracts on the decline and the severe losses suffered by major airlines during the energy crunch of the early 1990's, the orders for military and commercial passenger planes slipped. Failure to win contracts from the U.S. military placed McDonnell Douglas in financial difficulties. It was not alone, as during the 1990's several airplane manufacturers including Lockheed, Martin Marietta, Northrup, and Grumman began merging in order to survive the turbulent market. In August, 1997, McDonnell Douglas was formally merged with the Boeing Corporation. This move gave Boeing two of the largest-selling passenger jet series, the 700 series, including the 740 and 770, and the DC/MD series. Suddenly Boeing became the dominant player in the U.S. market and the main competitor with the European Airbus Companie for overseas contracts. During its thirty-year history, from 1967 to 1997, McDonnell Douglas proved to be an innovator in the development and modification of passenger airplanes. Its work in the military field included such far-reaching weapons as the Tomahawk cruise missile, the Apache attack helicopter, the F-15 Eagle, and the F-18 Hornet. By combining the two companies, each with its own expertise, McDonnell Douglas became a powerhouse in the aircraft production industry during the 1970's and 1980's. While the name itself has disappeared, many of the products created by both the individual and the combined companies continue to fly passengers all over the world.

Douglas Clouatre

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See also: Aerospace industry, U.S.; Air Force, U.S.; Airbus; Airline industry, U.S.; Airplanes; Apache helicopter; Blue Angels; Boeing; Cargo aircraft; Commercial flight; DC plane family; Eagle; Harrier jets; Hornet; Lockheed Martin; Manufacturers; MD plane family; Mergers; Military flight; Missiles; Navy pilots, U.S.; Rockets; Saturn rockets; 707 plane family; Spaceflight; Transport aircraft

Mach number

Definition: The ratio between the speed of an object in a medium to the speed of sound in the same medium.

Significance: The speed of sound is the speed at which the weakest disturbances in pressure propagate through a medium. In a gas, the speed of sound is close to the average speed of random thermal motion of molecules, because disturbances propagate by the collisions between molecules. Thus, the Mach number is also viewed as the ratio between the speed of organized motion of the gas, or a body relative to the gas, and the average speed of random thermal motion in the gas.

Calculation

The Mach number is named in honor of Ernst Mach, a nineteenth century Austrian scientist who conducted experimental research on the aerodynamics of artillery shells. Speed ranges in the field of aerodynamics are classified according to Mach number. A Mach number of 1 corresponds to motion at the speed of sound. The speed of sound thus depends on the temperature of the gas. The speed of sound in air at a temperature of 0 degrees Celsius (273.15 Kelvins) is 331 meters per second. To find the speed of sound in meters per second at other air temperatures in the range 200 to 700 Kelvins (from minus 73.15 to 426.85 degress Celsius), divide 5,471 (obtained as product of 331 and the square root of 273.15) by the square root of the air temperature in Kelvins. The Mach number is then the ratio of an object's speed to this speed of sound.

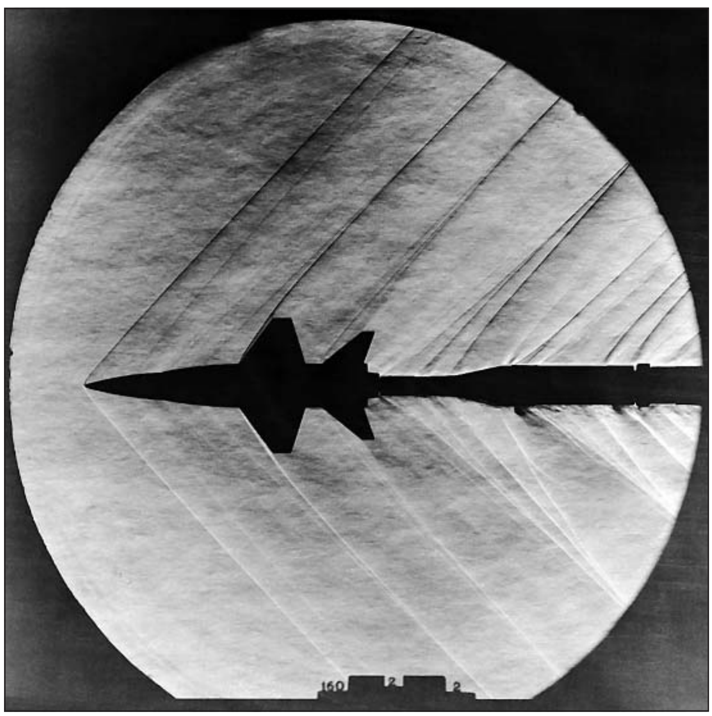
Mach Ranges

The low-speed regime is generally identified with Mach numbers of less than 0.3. In this range, the maximum change in density that can occur when the flow is stopped is less than about 5 percent of the actual density. Hence, such flows are also described as being incompressible. Small propeller-driven airplanes and helicopters fly in this speed range, though their propeller or rotor tips move quickly enough relative to the air to encounter Mach numbers close to 1.

The subsonic range is generally the range from Mach 0.3 to 1.0. In this range, the changes in density associated with changes in Mach number become significant. The lift coefficient and drag coefficient rise more steeply with increased angle of attack as Mach number increases. According to the Prandtl-Glauert rule, the lift coefficient associated with a given angle of attack scales with the number resulting from 1 divided by the square root of 1 minus the square of the Mach number. The drag coefficient also increases with Mach number and with thickness. Thus, aircraft flying in this range use thinner airfoils and smaller angles of attack. Turboprop aircraft reach speeds well into the subsonic regime. Much of the close air combat between fighter planes that involves sharp maneuvers occurs in this speed range.

The range that includes Mach 1 and values slightly greater and less than Mach 1 is called the transonic regime, roughly taken as Mach 0.8 to 1.2. Transonic flows include both supersonic and subsonic regions. Most modern airliners cruise in the transonic regime. Although the actual flight Mach number is below 1.0, there is some supersonic flow over the wings. The critical Mach number is the lowest flight Mach number where sonic conditions, in which the Mach number equals 1, are first encountered on the airfoil.

When the flow speed, or the speed of an object relative to the medium, is clearly greater than the speed of sound, the speed is said to be supersonic. Bullets, artillery shells, surface-to-air missiles, and air-to-air missiles all typically operate in the supersonic regime, with Mach numbers up to about 3.5. Most modern fighter aircraft can fly at supersonic speeds for short durations, with their engines operating on afterburners. The Lockheed Martin F-22 is capable of cruising at supersonic speeds without afterburners. Large aircraft capable of cruising at supersonic speeds are the North American B-70 Valkyrie bomber, the British



The shock waves caused by supersonic flight can be seen emanating from a model of the X-15 as it flies through a supersonic pressure tunnel. (NASA)

Aerospace/Aerospatiale Concorde, the Tupolev Tu-144, and the Tupolev Tu-44 Backfire Bomber.

Speeds greater than five times the speed of sound are described as hypersonic speeds. Spacecraft and missile warheads reentering Earth's atmosphere fly at hypersonic speeds, with Mach numbers as high as 36 for the Apollo capsule and about 25 for the space shuttle.

The importance of Mach number to flight can be seen from the Mach cone. An object moving at a Mach number of 2 through air generates pressure disturbances that propagate in all directions at the speed of sound in the medium of air. If the speed of sound were 300 meters per second, when the object reached a given point, the disturbances it had generated a second before would have spread within a sphere whose radius was only 300 meters, yet the object itself would have traveled 600 meters in the same second. Disturbances generated 0.1 seconds before would have reached a radius of only 30 meters, yet the object would have traveled 60 meters. The disturbances generated at each intermediate point propagate out to smaller and smaller distances, all lying within the Mach cone.

The Mach cone has its apex at the location of the object, and its axis is the path taken by the object to reach that point. The angle made by the axis of the Mach cone surface is called the Mach angle. This is the inclination of the weakest wave front generated by an object moving at supersonic speeds through a medium. Such a weak wave is called a Mach wave.

The region ahead of the Mach cone is called the zone of silence. In this region, the sound from the approaching object cannot have reached at the instant in question. The Mach angle is thus given by the inverse sine of the reciprocal of Mach number. For example, if the Mach number is 2, the Mach angle is 30 degrees, whereas for a Mach number of 3, the Mach angle is 19.47 degrees.

Most disturbances created by moving objects involve large pressure differences. These disturbances raise the temperature of the air, and hence move faster, accumulating along a shock front. Shocks formed by blunt objects can reach a shock angle of 90 degrees: Such shocks are called normal shocks, and they result in subsonic flow on the downwind side of the shock. As the flight Mach number of a wing exceeds the critical Mach number, the drag caused by the occurrence of shocks rises sharply. Early theoretical analyses predicted that the drag would rise to extremely high values, preventing an aircraft from accelerating through the speed of sound. This was called the sound barrier, the existence of which was conclusively disproved when Air Force Captain Charles E. "Chuck" Yeager flew the Bell X-1 rocket plane faster than the speed of sound in 1947 and became the first person to fly faster than Mach 1.

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See also: Aerodynamics; Forces of flight; High-speed flight; Hypersonic flight; Sound barrier; Supersonic flight; X planes; Chuck Yeager

Maintenance

Definition: Regularly scheduled inspections and periodic adjustment and repair of aircraft.

Significance: Ongoing maintenance operations enhance the safety of aircraft and the well-being of the flying public. They also ensure that aircraft operators comply with insurance companies' mandates to reduce risk and liability.

Inspections and Repairs

Every aircraft registered in the United States must be maintained in accordance with Federal Aviation Regulations (FARs) to ensure continued airworthiness. This is accomplished through regularly scheduled inspections and periodic maintenance. The largest segment of American aviation is commonly called general aviation and includes thousands of privately owned aircraft as well as those operated for business purposes. General aviation aircraft range from two-seater trainers to fully equipped corporate jets and also include experimental, or homebuilt, aircraft.

All small aircraft of up to 12,500 pounds gross weight must undergo an annual inspection of the entire airframe structure, the power plant, and propeller, if so equipped, and all accessories and systems. FAR 43 lists the required scope and detail of the annual inspection and includes an approval statement to be written in the aircraft maintenance record, or logbook, which allows that aircraft to be operated for another year. Any necessary repairs must be completed before the inspector signs the approval.

In addition to the annual inspection, there is a required inspection for every one hundred hours of operation, if the aircraft is being used for hire. Rental aircraft, flight training, and all passenger-carrying revenue flights fall in this category. The one-hundred-hour inspection is performed to the same scope and detail as the annual inspection.

In Appendix A of FAR 43, maintenance is divided into three categories: major, minor, and preventive. Major repairs and alterations pertain to the integrity of the aircraft type design, or, the original configuration chosen by the manufacturer and approved by the Federal Aviation Administration (FAA). An authorized inspector must approve such repairs and alterations before returning the aircraft to service. Minor repairs and alterations may be performed and approved by a certificated airframe or power plant mechanic. A licensed pilot may perform preventive maintenance. All these maintenance actions must be entered in the appropriate aircraft and engine logbooks.

Large aircraft of more than 12,500 pounds gross weight are usually maintained under a program designed by the aircraft manufacturer and custom-tailored to suit the particular owner or operator's needs. Each program is unique and must be reviewed and approved by the FAA.

The amount of time an aircraft is not available for use due to inspection and maintenance is known as downtime. To minimize downtime and maximize utility, an operator may place the aircraft in a progressive inspection program. Under the progressive inspection program, the entire aircraft is inspected during the course of a year, but the inspection itself is broken into several smaller segments at specified intervals. A typical progressive inspection program calls for inspection of the wings after one hundred hours of operation, the engine or engines at two hundred hours, the fuselage and tail section at three hundred hours, and the landing gear at four hundred hours, The cycle begins again with the wings at five hundred hours. Each progressive inspection program is designed for a specific operator using a specific aircraft and must be reviewed and approved by the FAA.

Maintenance Facilities

General aviation maintenance is usually performed by a fixed-base operator (FBO) at the local airport. The FBO may be a large, full-service complex offering fuel sales, aircraft rentals, flight instruction, engine overhauls, aircraft refurbishing, and charter flights. Some FBOs are one-person maintenance shops on private airstrips. An FBO may hold a Repair Station Certificate, issued by the FAA, that describes the types of specialized maintenance the FBO is equipped and qualified to perform. Repair stations are regulated under FARs 43 and 145 and may be certified to perform inspections, repairs, and maintenance on instruments, propellers, navigation and communication equipment, and accessory components, as well as on complete aircraft.

Many corporations have full-time flight and maintenance personnel to ensure aircraft availability and readiness. This advantage enhances the convenience of executive travel and provides additional support for corporate growth and development.

Airline Maintenance

Major air carriers are regulated under FAR 121 and usually operate large, transport-category jet aircraft. Their complex and detailed maintenance programs are designed by the aircraft manufacturer. They are tailored to each airline's operational needs and must be separately approved by the FAA.

A typical airline maintenance program may include daily preflight inspections, weekly service checks, and periodic inspections, known as phase checks. Phase checks are usually lettered alphabetically, with each inspection being more detailed and occurring at longer intervals. An A-check may be scheduled every ninety days to check tires, fluid quantities, systems operation, and general aircraft conidition. A D-check, however, is a comprehensive inspection and overhaul of the complete airframe, engines, and accessories, along with electronics upgrades, corrosion control and subsequent repainting. This type of inspection and repair usually occurs about every five to six years and may take several months to complete.

Commuter airlines operate smaller aircraft to serve the outlying areas away from the major hubs of large cities and large airline activity. Commuter airlines are regulated under FAR 135 to operate and maintain less complicated aircraft without compromising safety. A commuter airline maintenance program is generally a progressive inspection and repair schedule designed to interface with that airline's flight profile. It is usually based on the aircraft manufacturer's maintenance manuals and must be approved by the FAA.

Military Maintenance

Military aviation is mission specific. Each type of military aircraft is designed for a particular task. Bombers, fighters, tankers, and trainers play exclusive roles in the overall military aviation effort. Such type division is reflected in military maintenance. Technicians are trained on a specific type of aircraft, on which they may continue to work for several years.

In addition, each aircraft is subdivided by system, such as engines, hydraulics, electrical, and fuel. A different team of trained specialists maintains each system. A crew chief, trained and experienced in several systems, is assigned to each aircraft, and serves as the maintenance coordinator for the specialist teams.

Maintenance Training

The privileges and limitations of aircraft mechanic ratings are listed in FAR 65. Each mechanic must perform maintenance operations in compliance with the regulation.

Maintenance Ratings. Airframe mechanics may inspect, repair, and maintain airframe structures, systems, and components according to the applicable manufacturers' maintenance manuals. They may not repair instruments, navigation equipment, or communication equipment, and they may not approve major repairs and alterations as defined in FAR 43. They may, however, perform one-hundred-hour inspections on airframes and approve them for return to service after repairs.

Power plant mechanics may inspect, repair, and maintain engines, accessories, and propellers according to applicable manufacturers' maintenance manuals. They may not approve major repairs and alterations, and they may not perform major repairs on propellers. They may, however, perform 100-hour inspections on power plants and approve them for return to service after repairs.

Most aircraft mechanics working in the general aviation maintenance industry hold both the airframe and power plant (A&P) ratings. Both ratings are granted indefinitely and are valid until surrendered, suspended, or revoked. Although not required by regulation in the aircraft manufacturing and major airline industries, the A&P ratings usually bring higher salaries and better job positions.

An employee of a FAR-145-certified repair station may qualify for a Repairman Certificate. This certificate is issued after the employee has been sufficiently trained and experienced in the particular maintenance tasks performed. Unlike Airframe and Power Plant Certificates, the Repairman Certificate is valid for the specified tasks only while the holder is in the employ of that particular repair station.

A Repairman Certificate may also be issued to the primary builder of an experimental, or homebuilt, aircraft. The repairman may then perform condition inspections on that aircraft. A condition inspection is similar to the annual inspection required on standard-category aircraft.

Aircraft mechanics holding both airframe and power plant ratings may also hold an inspection authorization. They may perform annual inspections of the entire aircraft and approve or disapprove it for return to service. They may also inspect any major repairs or alterations to the aircraft and approve it for return to service. Unlike Airframe and Power Plant Certificates, the Inspection Authorization must be renewed every year.

License Requirements. The requirements for the Airframe, Power Plant, and Repairman Certificates and for the Inspection Authorization are given in FAR 65. The regulation includes training and experience requirements, as well as written tests for subject knowledge and practical tests for demonstration of acquired skills.

There are two ways to obtain an A&P license: one must either graduate from an approved school or qualify through documented relevant experience. There are approximately 150 certificated aviation maintenance technician schools in the United States. Under FAR 147, these schools must provide a minimum of 1,900 hours of classroom instruction and shop experience. The FAA inspects these schools periodically to ensure regulatory compliance and to assist graduates in the certification process.

Aircraft maintenance personnel wishing to obtain A&P licenses may also present documented evidence of their work experience for FAA review and evaluation. The minimum requirements are eighteen months of full-time appropriate maintenance experience for either the airframe or the power plant rating or thirty months for both ratings together. Applicants may obtain their experience while serving in the military in selected job classifications or while being employed by a certified repair station, airline maintenance base, or aircraft modification facility. After reviewing and verifying the applicants's documents and experience, the FAA issues permission for the applicant to take the written examination for the rating sought.

Testing Procedures. The written examination for the A&P license comprises three parts. The general test covers information that could apply to either airframe or power plant maintenance, such as regulations, publications, proper use of tools and equipment, aircraft hardware, and other related subjects. The airframe and power plant tests are subject-specific, as their names imply. The general test must be taken in conjunction with either of the other tests but is not repeated for the second rating.

After successful completion of the written examinations, the applicant schedules an appointment with the local designated mechanic examiner (DME). The DME is an experienced mechanic who has been appointed by the FAA to administer oral and practical examinations. The oral examination consists of a dialog between the examiner and the applicant to ascertain the applicant's knowledge of aircraft maintenance theory and application. The practical examination is a series of maintenance tasks assigned to the applicant. The DME observes the applicant to evaluate the applicant's use of technical data, mechanical skill, and proper procedures in performing the assigned tasks. Upon successful completion of the practical examination, the examiner issues a temporary mechanic certificate, that is immediately valid. The permanent certificate is mailed from the FAA registry within a few weeks.

The Airframe and Power Plant Certificates are issued for life and continue to be valid unless voluntarily surrendered by the mechanic or suspended or revoked by the FAA. The certificates, however, must be kept current by recent experience. FAR 65 requires that, in order to exercise the privileges of a mechanic certificate, the mechanic must have been actively engaged in aircraft maintenance for six of the preceding twenty-four months.

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See also: Airplanes; Federal Aviation Administration; Safety issues; Training and education

Manufacturers

Definition: Companies that produce vehicles for travel in air or space, or components of those vehicles.

Significance: By the end of the twentieth century, aerospace manufacturers had grown to become one of the most important employers in the industrialized world.

Beginnings

The Wright brothers made the first powered flight in 1903, but the early years of aviation did not prove very lucrative for aircraft manufacturers. Most designers were sons of wealthy families with the time and money to pursue their interest in flying. Experienced engine designers migrated from the automotive industry, but even relatively successful manufacturers such as the Wright Company and the Curtiss Aeroplane Company had difficulty finding a consistent market for their planes. Most companies hoped for military contracts, but armed forces around the world were reluctant to adopt an unfamiliar weapon, and military purchases remained minuscule.

World War I

The demands of modern war soon demonstrated the usefulness of aviation. Aircraft had been used in reconnaissance roles in minor conflicts before the war began, and both sides soon recognized the potential of aviation. At first, aircraft served as spotters for the artillery, but fighters soon developed, followed later in the war by bombers. In Germany, Dutch designer Anthony Fokker created a device that allowed a machine gun to fire through a spinning propeller. Fokker's E-I fighter entered service in 1915 and soon dominated the skies over the western front. Subsequent Fokker models demonstrated continuous improvement, culminating in the highly advanced D-VII, which so frightened the Allies that they demanded the surrender of all D-VII's as a condition of the armistice. Other German manufacturers followed Fokker's lead. Albatros and Rumpler produced excellent aircraft, particularly in the reconnaissance sector. Late in the war, Gotha developed a heavy bomber that Germany used to bomb targets in Great Britain. Despite Germany's defeat, the nation's aviation industry produced more than 44,000 aircraft during the war and utilized twenty-six engine and thirty-five airframe manufacturers.

To meet the German threat, Britain's manufacturers expanded their operations. Sopwith proved one of the most effective, and the company's Pup and Camel models pushed the existing limitations of performance. Other British companies, including Handley-Page and Vickers, competed strongly with Sopwith's aircraft. Perhaps the most important manufacturing outgrowth of World War I on Britain's industry was the development of two important engine manufacturers, Napiers and Rolls-Royce. Rolls-Royce would use its wartime experience to become one of the world's foremost engine designers over the next eighty years.

Interwar Developments

After World War I, manufacturers to turned increasingly to the civilian market. The notoriety of aircraft during the war had done a great deal to increase public interest in aviation. In the United States, the federal government established air mail service and supported research into increased performance. Charles A. Lindbergh's solo transatlantic flight in 1927 also caused a sensation. Responding to these developments, U.S. manufacturers found an increasing market for their products. Lockheed developed its Vega monoplane, which set a number of speed and altitude records. Other manufacturers, notably Douglas and Boeing, recognized the developing airliner market. By the end of the 1930's, both companies had developed planes that incorporated such modern features as a comfortable cabin, retractable landing gear, and all-metal construction. U.S. manufacturers even designed airliners for transatlantic service, but World War II interrupted plans to produce these aircraft.

Despite the newfound commercial market, many aircraft makers still looked to the military as their primary customer. Despite Douglas's success in the airliner sector, more than half of the company's sales went to the military. Military designs took on a greater importance as war seemed more likely in the 1930's. Many theorists, anxious to avoid the stalemate of World War I, saw air power as the deciding factor in future conflicts.

Germany's rearmament program took place in direct contradiction of the Treaty of Versailles, which expressly forbade Germany to have an air force. Despite some resistance from leaders in the industry, most notably Hugo Junkers, Germany's new military expansion began in earnest in 1933. Leaders such as Junkers who opposed the idea were swept aside and their companies became integral parts in the development of a new air force. Junkers, Domier, Messerschmitt, Focke-Wulf, and Heinkel emerged as the leading aircraft manufacturers in Hitler's Third Reich. Throughout the 1930's, these companies perfected designs such as Messerschmitt's Bf-109 fighter, Junkers's Ju-87 dive-bomber, and Heinkel's He-111 bomber. These planes formed the backbone of Germany's Luftwaffe at the outset of World War II and represented a serious challenge to the Western Allies. Germany's aviation industry did not simply rearm the nation, however. Manufacturers provided employment for Germany's depression-ravaged population and helped reinvigorate the economy. In 1934, Britain determined that it had to maintain parity in aviation with Germany and began its own rearmament program. The new surge in defense spending more than tripled employment in the aviation industry between 1930 and 1936. British companies lagged behind their German and American counterparts in terms of modern production facilities, and the sudden demands created by the decision to rearm revealed serious shortages in machine tools and trained personnel. Some companies, including Rolls-Royce, undertook training programs, but manufacturers often resorted to luring trained workers away from competitors. British companies also had difficulty adjusting their designs and manufacturing techniques to the requirements of mass production, something designers in the United States and Germany had already embraced. Nonetheless, British firms turned out such outstanding designs as the Hawker Hurricane and Supermarine Spitfire fighters and the Avro Lancaster heavy bomber.

World War II

World War II meant enormous changes in the technology of aviation. Wartime demands put a great deal of money at the availability of manufacturers. Companies used these funds to design advanced aircraft and to convert their manufacturing processes to mass-production techniques. Most of the companies that came to dominate world aviation in the latter half of the twentieth century gained notoriety during World War II.

In the United States, giants such as Boeing, Douglas, and Lockheed continued work on large bombers and transports, which would give these companies a significant advantage in the postwar airliner market. Other companies, such as Grumman and North American, concentrated primarily on fighters and established themselves as leaders in the sector. Across the United States, thousands of people moved to take jobs in the aircraft industry, located primarily in Southern California, creating a significant demographic shift. The trend toward mass production in the prewar era became an absolute requirement with the demands of war. U.S. companies streamlined designs and production techniques to allow fast manufacturing with unskilled labor.

Britain's wartime experiments with such ideas as jet propulsion and radar made that country's manufacturers leaders in those important fields. The success of the Hurricane and the Spitfire in combat proved that Britain could produce aircraft of the highest quality. Unfortunately, the British aviation industry still had difficulty matching its competitors in the area of production. The creative designs of De Havilland helped make that company a fixture in Britain's aviation industry, but its famed wooden Mosquito fighter-bomber required too much time and skill to produce on the scale demanded by total war. Even more conventional aircraft such as the Spitfire required three times as many man-hours to produce as the German Bf-109. Britain's aircraft industry emerged from World War II with creative designs and world leaders in engine technology at Rolls-Royce and Bristol Siddley Engines, but the United States' greater emphasis on mass production would relegate Britain's manufacturers to a peripheral role in coming years.

Postwar Commercial Manufacturers

Britain emerged from World War II with a great advantage because of the country's research into jets. U.S. companies continued to build planes such as Lockheed's luxurious, piston-powered Constellation, but these models did not represent the future of air travel. The De Havilland Comet became the world's first jet-powered airliner when it began service to the Middle East in 1952. The Comet's smooth, fast performance made it a favorite of air travelers and presented a formidable challenge to U.S. manufacturers. Unfortunately for De Havilland, the Comet suffered a series of in-flight explosions due to metal fatigue that grounded the plane for two years while investigators tracked down the problem. During the interim, U.S. manufacturers caught up to De Havilland's lead. Boeing's 707 and Douglas's DC-8 established American supremacy in the airliner sector. In the equally important engine manufacturing sector, U.S. companies Pratt & Whitney and General Electric overtook Rolls-Royce and Bristol Siddley as the world's foremost manufacturers, adding to the United States's competitive advantage. France's Sud Aviation managed to sell a handful of its Caravelle medium-range jets to U.S. air carriers, but could not hope to compete with the highly efficient U.S. companies. By 1970, U.S. manufacturers produced 80 percent of the world's commercial airliners.

European manufacturers realized by the mid-1960's that they could not hope to compete with the powerful American companies and turned to international cooperation in order to maintain the continent's struggling aerospace industry. Britain and France agreed in 1962 to undertake a supersonic transport program. The resulting Concorde proved to be a commercial disappointment, with only sixteen of the supersonic airliners being produced due to high manufacturing costs. Air France and British Airways began flying the Concorde in the mid-1970's, but operated the transatlantic flights at a loss. Despite the difficulties, Concorde did give British and French manufacturers increased prestige and income at a time when American airliners had almost eliminated European companies from the sector. In an effort to reestablish a European presence in airliner manufacturing, corporate and government officials in Britain, France, and West Germany established a consortium called Airbus Industrie in 1967. After a great deal of political negotiating, Airbus produced the A300B, which entered service with Air France in 1974. Airbus continued to expand its product line in an effort to match Boeing's offerings, and the European conglomerate found customers around the world but fared poorly in the United States. Airbus's success through the end of the twentieth century assured European manufacturers of a promising future, though the consortium could not match the overwhelming success of Boeing.

Boeing's dominance in the airliner industry was a result of the company's diverse aircraft designs. The Seattle-based giant produced planes that offered air carriers a number of options in terms of range, passenger capacity, and engine configuration. Boeing's U.S. competitors, Lockheed and McDonnell Douglas, did not provide the same diversity and assured Boeing's position in the United States market. Airbus provided stiffer competition throughout the rest of the world, but Airbus could not offer anything that matched Boeing's enormous 747 jumbojet, which became a fixture on long-distance routes.

Postwar Military Manufacturers

The prominence of air power during World War II grew during the Cold War, requiring nations to spend a significant portion of their defense budgets on aviation. This dependence proved to be very lucrative for manufacturers. In the United States, the demand for varying kinds of fighters, bombers, and transports offered an opportunity for most of the nation's aircraft companies to find a segment of the market for their products. This new affluence did not come without challenges, the most significant being cost. The United States hoped to offset the Soviet Union's numerical superiority with technology, and the resulting aircraft proved increasingly expensive. Companies sought to combine designs in the hope of saving money. Boeing used the same basic design for both its KC-135 tanker and its 707 airliner. In doing so, the company reduced its expenses by saving time in the design phase and by using many of the same tools, jigs, and other equipment on both aircraft.

European companies found the cost of the new high-tech military aircraft prohibitive, and so these manufacturers looked to combine operations with American or other European firms. When several European nations decided to adopt General Dynamic's single-engine F-16 fighter in the early 1970's, European manufacturers won the right to fill 40 percent of the European orders and 10 percent of American orders. This agreement helped solidify Europe's aerospace industry while drastically cutting costs by eliminating the need for research and development.

In other cases, European nations combined their resources to produce original designs. When North Atlantic Treaty Organization (NATO) countries decided to replace their American-designed F-104 attack fighters in the late 1960's, the various governments decided to create a new European aircraft. The resulting effort, the Tornado, utilized components from Britain, West Germany, and Italy. The Tornado provided European nations with an aircraft that compared favorably with its American counterparts, and though rather expensive, the Tornado program gave European aerospace manufacturers valuable experience. Manufacturers learned the intricacies of managing such an effort in three different countries, each with its own currency, bureaucracy, and interests. The Tornado program also gave European manufacturers much-needed practice in designing high-performance fighters. European nations hoped to repeat the success of the Tornado with the European Fighter Aircraft, or Eurofighter. Work on the Eurofighter began in the 1980's, but the enormously complex program ran into technical and political difficulties and remained in the developmental phase at the end of the twentieth century.

Behind the Iron Curtain, the Soviet Union established its reputation as an aerospace power. The Soviets enjoyed a closed market within their sphere of influence, but they also represented a threat to Western companies by competing in the developing world. The Soviet design bureaus of Antonov, Ilyushin, Mikoyan-Guryevich, Tupolev, and Yakovlev sold military and civilian aircraft to nonaligned nations in an effort to strengthen ties between the Soviet Union and the rest of the world. While less capable than Western aircraft, Soviet models were cheaper and generally adequate for most customers.

Corporate Changes

The escalating costs of manufacturing aircraft forced an ongoing series of mergers around the world beginning in the 1960's. In Britain, consolidation throughout the 1960's and 1970's ultimately led to the creation of a single nationalized British company, British Aerospace (BAe) in 1977. The development of BAe followed a government takeover of bankrupt engine-designer Rolls-Royce in 1971, which had already merged with Bristol Siddley Engines in 1966. The Conservative government of Margaret Thatcher privatized both BAe and Rolls-Royce during the 1980's, but the costs of manufacturing modern aircraft had forced British manufacturers to combine under one single parent company. France's aerospace industry underwent a similar consolidation in 1970 when the government merged the nation's already nationalized manufacturers into one state-owned consortium, Aerospatiale, to handle France's commercial aviation production. Military production in France remained the province of Dassault, a privately held but strictly controlled firm.

American manufacturers fared better but still went through difficult times. Manufacturing giant Douglas merged with the smaller McDonnell Corporation in 1965, starting a series of mergers that continued throughout the remainder of the century. A downturn in orders in the late 1960's and early 1970's damaged the industry severely. Boeing laid off two-thirds of its workforce, and Lockheed was saved from bankruptcy only when the U.S. Congress guaranteed the company's credit. Despite these setbacks, U.S. manufacturers maintained their dominant position in the world market. Boeing's airliners proved enormously popular, while competing models from McDonnell Douglas and Lockheed found niches in the market. Increased military spending during the 1980's also offered greater opportunity for U.S. manufacturers, but the new generation of U.S. military aircraft were extraordinarily expensive, and the government's spending reductions following the end of the Cold War meant that only a handful of the new planes actually entered service.

Increased competition from Airbus irritated American manufacturers, but the U.S. government did not take direct action against European imports. Throughout the 1980's, U.S. companies pressed for protection, but the government settled for a 1992 agreement in which European governments agreed to limit the direct subsidies they gave to Airbus in return for the U.S. government cutting back on indirect subsidies it offered to its own manufacturers. This agreement did little to limit Airbus's continued pressure on the U.S. market, but Boeing remained the world's leading commercial aircraft manufacturer through the remainder of the twentieth century.

Foreign firms also made headway in the small aircraft market, with models from Brazil, France, and Sweden challenging established U.S. companies such as Cessna and Beech.

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See also: Aerospace industry, U.S.; Airbus; Airline industry, U.S.; Beechcraft; Bell Aircraft; Boeing; Cessna Aircraft Company; Fokker aircraft; Learjets; Lockheed Martin; McDonnell Douglas; Messerschmitt aircraft; Military flight; Piper aircraft

Marine pilots, U.S.

Definition: Aviators among the officer ranks of the United States Marine Corps.

Significance: The U.S. Marine Corps is unique among the armed forces in having an aviation component capable of operating independently of the other services. To perform their various tasks, Marine pilots fly a variety of aircraft.

Naval Aviators

U.S. Marine Corps pilots constitute one of three groups of military pilots designated as naval aviators, the other two of which are the pilots of the U.S. Navy and the U.S. Coast Guard. All three groups of pilots undergo their initial aviation training under the auspices of the U.S. Navy, beginning their schooling at the Naval Aviation Schools Command in Pensacola, Florida.

U.S. Marine Corps pilots train to fly transports, fighters, attack aircraft, observation aircraft, and helicopters. Their principal mission is to support U.S. Marine Corps infantry, artillery, and other components in combat operations. Marine amphibious forces include all the equipment necessary to exercise command and control of such operations independently of the other military forces, if necessary. Marine pilots are trained to conduct operations from aircraft carriers and from special naval amphibious ships designed to accommodate helicopters during ship-to-shore landing operations.

Career Marine Corps pilots also serve with ground units one or more times in their careers, typically for periods of about two years. When serving with ground units, Marine pilots often fill the role of forward air controllers (FACs), taking responsibility for guiding Marine and Navy attack aircraft during combat operations. Pilots also serve as advisors to commanders of Marine battalions and regiments and to the commanding generals of Marine divisions and amphibious task forces.

The Making of a Marine Aviator

The close link between Marine pilots and their colleagues on the ground forms early in their careers. Although there are many ways to become a Marine officer, all Marines begin in the same officer procurement programs. Some come from the U.S. Naval Academy; others take what is called the "Marine option" in the Naval Reserve Officer Training Program (NROTC) conducted at many universities. The U.S. Marine Corps also operates several officer procurement programs of its own, including a ten-week, post-baccalaureate Officer Candidate School (OCS) and another program called the Platoon Leaders Class (PLC) that requires two six-week training periods during college summers. Both programs are conducted by the Officer Candidate School at the Marine Corps Development and Education Command near Quantico, Virginia. However future Marine pilots obtain their commission, they must also complete the Officer's Basic Course at Quantico. All officers must complete this rigorous six-month program before reporting for flight training in Pensacola.

During World War II (1939-1945) and the Korean War (1950-1953), the Marine Corps took pilots from the enlisted ranks. They were known unofficially as "flying master sergeants." Most of those who stayed on active duty eventually received commissions. During the early 1960's, when the airlines exchanged propeller-driven aircraft for the first passenger jets, many civilian pilots lost their jobs. Some of these pilots who belonged to the U.S. Marine

Corps Reserve returned to active duty but gave up their lieutenant and captain ranks to become flying warrant officers.

The Organization of Marine Aviation

The U.S. Marine Corps is the only military service with a completely integrated aviation component capable of deploying with its ground combat units. The aircraft flown by Marine Corps pilots include a fixed-wing fighter-attack aircraft, the F/A-18 Hornet, and the multiengine transport and in-flight-refueling aircraft, the KC-130 Hercules. Marine pilots also fly the vertical-takeoff attack aircraft the AV-8B Harrier. In addition, Marine Corps pilots fly several types of helicopters, including the AH-1W Super Cobra, the UH-1N Huey, the CH-46E Sea Knight, and the CH-53E Super Stallion.

Marine Corps aviation is organized into three active-duty aircraft wings and one reserve wing. Each wing is subdivided into air groups, which are, in turn, the parent units of the various squadrons. Each wing is organized to support a corresponding division. The active-duty wings are the First, Second, and Third Marine Aircraft Wings; the reserve wing is the Fourth Marine Aircraft Wing.

When Marine ground units are deployed, they normally travel aboard and are landed from naval amphibious ships. An infantry battalion deploys along with an aircraft squadron as a Marine Expeditionary Unit (MEU). Larger forces include a Marine Expeditionary Brigade (MEB), organized around an infantry regiment and an air group, and a Marine Expeditionary Force (MEF), organized around a division and an aircraft wing. These combination air-and-ground-operational units are collectively referred to as Marine Air-Ground Task Forces (MAGTFs).

Early History of Marine Corps Aviation

May 22, 1912, is considered the birthday of U.S. Marine Corps aviation. It was on that date that a young Marine Corps first lieutenant, Alfred A. Cunningham, reported to the superintendent of the United States Naval Academy in Annapolis, Maryland, for “duty in connection with aviation.” It was the custom of the day for aircraft manufacturers to provide flight instruction, so shortly after arriving in Annapolis, Lieutenant Cunningham was sent to the Burgess Corporation for flight instruction. He was designated Naval Aviator Number 5 on March 4, 1913.

On becoming the Corps’ first aviator, Cunningham joined several other Marine officers to campaign for continued development of Marine Corps aviation. Finally, in February of 1913, he received orders to organize the Corps’ first aviation unit, which was called the Marine Corps Aeronautical Company. This unit, organized at the Philadelphia Naval Yard, had seven officers and forty-three ground personnel.

After World War I broke out in Europe in 1914, Cunningham visited France, where he met the American pilots in the famous squadron known as the Lafayette Escadrille. He also participated in combat flights with French pilots.

After returning from France, Cunningham presented a report of his findings to the commandant of the Marine Corps, helping to further expand Marine aviation. When the United States entered World War I in 1917, Cunningham was directed to organize the First Marine Aviation Force for duty in France. This force was the first Marine aviation unit to ever fly in combat.

Development of Close Air Support

Another date of great historical importance to Marine Corps pilots is July 15, 1927. In what is known as the Second Nicaraguan Campaign, Marines were deployed in Nicaragua to protect American interests during civil strife in that country. On July 15, some Marines came under fire, and, in response, Marine pilots conducted the first of a type of air attack that would come to be called close air support (CAS). From that day forward, the close support of ground combatants would become a governing philosophy of Marine aviation. In the years following the Second Nicaraguan Campaign, Marine pilots worked to perfect the delivery of ordnance close to their counterparts on the ground.

Later Developments in Close Air Support

Precision bombing by aircraft underwent refinement during World War II and the Korean War, and it saw service in the war in Vietnam (1961-1975) and in Operation Desert Storm (1991). During the Korean War, another major philosophical principle emerged in Marine Corps aviation, as the helicopter assumed a large role in medical evacuation, aerial observation, and the delivery of matériel to front-line troops.

From that experience, the Marine Corps, together with the Navy, developed the concept of “vertical envelopment.” They converted some World War II-vintage aircraft carriers to helicopter carriers called LPHs, a term often mistaken to mean “Landing Platform, Helicopter.” The Navy designates amphibious ships with the letter “L” and ships that carry personnel with the letter “P.” Thus, the term “LPH” really means “Amphibious Ship, Personnel, Helicopter.” Today, larger and more efficient naval helicopter carriers support the Marine Corps amphibious forces.

Part of the impetus for developing the concept of vertical envelopment was based on the looming of the atomic age. The naval services, both the Navy and Marine Corps, sought strategies to avoid concentrating in a small beach area troops that could be annihilated with just one nuclear weapon. In the exercise of vertical envelopment, Marine pilots flying helicopters deliver troops from amphibious ships deep into enemy territory, while other Marines land over beaches in more traditional landing craft.

Moreover, Marine pilots in such attack aircraft and helicopters as the AV-8B Harrier and the AH-1W Super Cobra provide troops on the ground with close air support. This mission is additionally important in the landing of Marine forces when the threat of mechanized counterattack exists. Marine mechanized and antimechanized units may not land early in an amphibious operation, and Marine infantry depend on aircraft to play this role in the opening phase of an assault.

Finally, Marine pilots in fighter aircraft can conduct operations to protect the beachhead and landing zones from attack by enemy aircraft. In fact, the main mission of the KC-130 aircraft that some Marine pilots fly is to refuel such fighter aircraft for sustained operations or for moving long distances.

Famous Marine Corps Pilots

Several Marine Corps pilots have become famous for their exploits in the air. One of them, World War II fighter ace Joseph J. Foss, went on to become governor of South Dakota in 1954. After serving two terms in that office, he became the first commissioner of the American Football League in 1966.

During World War II, Foss shot down twenty-six enemy aircraft and was the number-two Marine Corps ace in that war. He was also one of five Marine pilots to receive the Medal of Honor for bravery during the campaign for the island of Guadalcanal. He was shot down once by enemy aircraft.

After the war, Foss took a commission in the South Dakota Air National Guard, which he helped organize, and served in the Korean War as a U.S. Air Force colonel. He retired from the Air National Guard as a brigadier general.

The top Marine Corps ace of World War II, Gregory “Pappy” Boyington, is credited with destroying forty enemy aircraft. Boyington was, for a time, commanding officer of Squadron 214, the famous Black Sheep Squadron.

Both Foss and Boyington served on Guadalcanal in what Marine pilots called the Cactus Air Force, a name derived from the fact that the call sign for the island was “cactus.” The Cactus Air Force was commanded by another famous Marine Corps aviator, Brigadier General Roy Geiger, who had served in France in World War I.

Geiger’s principal legacy, however, centers on the fact that just before his death, he urged the commandant of the Marine Corps to examine the concept of vertical envelopment in conjunction with the nuclear threat. Geiger, who had retired as a lieutenant general, thus hastened the now-standard tactics for modern Marine Corps amphibious operations, tactics in which all Marine pilots play an essential role.

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See also: Black Sheep Squadron; Fighter pilots; Harrier jets; Helicopters; Korean War; Military flight; Navy pilots, U.S.; World War I; World War II

Beryl Markham

Date: Born on October 26, 1902, in Ashwell, Leicestershire, England; died on August 4, 1986, in Nairobi, Kenya

Definition: A bush pilot pioneer and famous adventurer.

Significance: Markham is most widely known for her record-breaking 1936 solo flight from east to west across the Atlantic Ocean and for her best-selling memoir *West with the Night* (1942).

Beryl Markham was born in England and, at age four, went with her father, Charles Baldwin Clutterbuck, to British East Africa, where she was raised on a ranch. She grew up hunting with local tribesmen and learned to speak Swahili and several African dialects. She was married three times, and her second marriage, to Mansfield Markham, produced her only child, Gervase. Markham was the first woman in Africa to receive a racehorse trainer's license, and in 1921, she began an illustrious career as a horse trainer. Her love of horses and her skills as a trainer were known throughout East and South Africa, but her ultimate fame was derived from her adventures and skills as a pilot. After learning to fly during her twenties, she flew between Kenya and Britain several times during the early 1930's. While in British East Africa (now Kenya), she flew for safari companies as an elephant spotter and also transported people and supplies. An active bush pilot, she was eventually considered the best and boldest pilot to fly out of Kenya.

In 1934, Markham was challenged to fly across the Atlantic, alone and against the wind, from east to west. On September 4, 1936, she took off alone, from Abingdon, England, heading west with the night. She made most of this famous twenty-two-hour flight in the dark, flying on instruments. She began having problems halfway across the Atlantic, battling headwinds and a fuel shortage. At one point, her plane dropped from a 2,000-foot cruising altitude, flying only 50 feet above the waves. In a desperate attempt to land near Sydney, Nova Scotia, Markham nose-dived into a bog, slightly injuring herself and totally disabling the plane. She switched planes and flew on to New York City, her intended destination. She became internationally famous and was received in New York with a ticker-tape parade and the cheers of thousands. The fame and attention brought her little financial reward, however. She traveled the world looking for another opportunity to break a flying record, but with no luck.

In 1938, Markham moved to California, where she began writing her memoir *West with the Night*. The book was published in 1942 to wide critical acclaim but little popular success. Disillusioned, depressed, and near penniless, she returned to British East Africa in 1949 to revive her career as a horse trainer. Her book was republished in 1983 to great acclaim and popularity, and the royalties finally allowed Markham freedom from poverty. She died on August 4, 1986, at the age of eighty-three. Through her book, stories, and accomplishments, Markham will be remembered as a pioneer of aviation.

Lori Kaye

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See also: Record flights; Transatlantic flight; Women and flight

MD plane family

Date: First built in 1979, with the first flight in September, 1980, and with modifications and upgrades through the 1990's

Definition: The next generation of passenger aircraft built upon the features of the successful DC series and was intended to replace that series.

Significance: The MD series brought new innovations to passenger airplanes with such features as an expanded fuselage to hold more passengers, large fuel tanks and larger engines to increase the thrust and range of the plane and an expanded flight deck with electronic instruments to allow for easier control of the plane.

With the 1967 merger of the McDonnell and the Douglas Aircraft companies, the popular DC series of passenger planes, originally built by Douglas, became part of the new company. Two of the most popular and widely flown airplane designs, the DC-9 and the DC-10, served as the starting point for the new generation of planes developed by McDonnell Douglas. The MD series maintained many of the features of their predecessors while adding ones for the new generation of planes. The MD class of passenger planes replaced the DCs starting in the 1980's. However, problems in development slowed their construction, while a merger of McDonnell Douglas with Boeing Corporation threatened to end the line before it could become a major contributor to the U.S. passenger air fleet.

From DC to MD

The DC-9's popularity and dominance in the airline industry could be attributed to the willingness of McDonnell Douglas to change the plane's design in response to the requirements of airlines. During the 1970's, McDonnell Douglas developed new planes that expanded on the size and capabilities of the DC-9 series. Some of those modifications were used to develop the MD-80 series. This airplane, the first in the MD class, was a lengthened version of the DC-9, allowing for more passengers and a better-equipped flight deck. It added to the already produced DC-9-50 and was also known as the DC-9 Super 80. It was given this name based on the expectation that the first planes would begin commercial airline flight starting in 1980. Exactly on schedule, the plane had its first commercial flight in September, 1980, and was soon flying in more than a dozen airlines worldwide.

The MD-80 Series

As with the DC-9's, McDonnell Douglas produced several versions of the plane, adding length and seats, improving fuel economy and range, and putting into place new electronic equipment for the flight deck. While the planes were being built and during their early years of flight, the DC name was attached, but as their popularity grew, in 1983 the company changed the name to the MD to represent the company's sixteen-year-old merged name. The DC-9 Super 80 became the MD-81. The next plane, the MD-82, was first flown commercially in January, 1981. Six years passed before the next addition, the MD-83, was used by airlines beginning in February, 1987. All three of the planes closely resembled each other in size, fuel capacity, and range.

The MD-82 was the first modification of the MD-81. It had improved maximum takeoff weight, allowing for more passengers and cargo. The thrust engines were also improved, allowing for easier takeoff. The MD-83 was intended for longer flights with larger fuel capacity on the plane, even greater takeoff weight, and improved thrust over the MD-82 model.

The next modification, the MD-87, eventually served as the main replacement plane for the DC-9. Smaller than the MD-82, the MD-87 included an advanced flight deck that allowed for a larger crew and easier-to-read instruments. The new turbofan engines also improved fuel efficiency. The interior of the plane was changed as to the arrangement of the seats and various classes of passenger. It was able to seat as many as 130 people in a single economy class. Because of that size, it was seen as the true successor to the DC-9. The MD-87 had its first commercial use in November, 1987.

The last of the MD-80 series was the MD-88. It was a combination of the MD-83 and the MD-87. It had the MD-83's engines and airframe while using the same type of electronic readouts in the flight deck and the same interior for the passengers. The plane began commercial flights in 1988. At the same time, a freight version of the MD-80 was introduced by the company but there were few takers.

The MD-80 broke further ground in its production as McDonnell Douglas licensed a Chinese firm, the Shanghai Aviation International Corporation, to build planes in that country. The arrangement lessened production backlogs and allowed the companies to build nearly 1,200 of the planes. The last of the planes, an MD-83, was delivered in December, 1999, and was dubbed the "Spirit of Long Beach" after the plant where many of the MD models were produced in the United States. The relative success of the MD-80 for American and foreign airlines spawned its successor, the MD-90.

The MD-90 Series

The MD-90 series had a similar history as its predecessor, the MD-80. Also built by McDonnell Douglas, the MD-90 began as a modified version of the DC-9 and was known as the DC-9 Super 90. Originally the MD-90 was built as one of the most fuel-efficient planes in the world, but by the mid-1980's the energy crisis of the mid-1970's had passed and that feature became less important. For this reason, the MD-90 became an updated version of the MD-80, with the fuselage, the exterior of the plane, and the flight deck resembling its predecessor. Most of the improvements added to the plane involved an electronic flight instrument system and a pair of new engines. The control system allowed for easier management of the plane by the pilots and for conserving fuel. The new engines lessened the level of noise and also conserved energy. Another change was a slightly longer fuselage—approximately 4.5 feet longer. With the added space, the MD-90 could carry 163 first- and economy-class passengers, 10 more than the MD-81. The MD-90 first carried those passengers in February, 1993, and was purchased by several American and foreign airlines.

Two more versions of the plane were built. The MD-90-30 began flying in April, 1995. It had larger fuel tanks and a stretched fuselage for more passengers. The MD-90-30ER began flying in April, 1997, and had room for 170 economy-class passengers, larger fuel tanks, and greater maximum takeoff weight. Two additional MD-90 versions, the 10 and the 50, were not produced before McDonnell Douglas merged with Boeing. For this reason the MD-90 became a casualty of the merger because it was the main competitor of the Boeing 737 and the company halted its production. Because of this decision, only 117 planes found their way to the airlines between 1995 and 2000.

The MD-95 was the last of this series and went into action only after McDonnell Douglas was purchased by the Boeing corporation. The MD-95 was another replacement for the DC-9 and included many of the features of one part of that series, the DC-9-30. The major improvement over the DC-9 was the flight deck, in which six LCD screens were installed to make it easier for the pilots to read flight information. The interior of the plane was also enlarged, with bigger seats and expanded room for carry-on luggage. The MD-95 began operation in September, 1998, and at that time became known as the Boeing 717-200. Its success spawned the smaller 717-100 and the larger 717-300.

The MD-11

The aging of the DC-10 fleet and the slowdown in production of the plane after a series of fatal crashes caused McDonnell Douglas to search for a plane design to replace it. Several such designs were developed, dramatically changing the exterior and interior of the DC-10 model. These planes, with names such as the MD-100, were ultimately rejected as too costly or not feasible for mass production. It was the MD-11 which became the accepted replacement of the DC-10, a plane built using the major features of its predecessor rather than creating an entirely new plane.

The MD-11 was specifically based on the DC-10-60. Some 18 feet longer than the DC-10, the interior of the plane was reconfigured to expand seating to a possible capacity of 405 economy-class passengers or 323 economy- and first-class passengers. In the MD-11, the pilot and copilot were both given the six-screen LCD layout for monitoring the plane. Winglets were added as one of the major new features to exterior of the plane. Winglets are small, upraised additions to the edge of each of the plane's wings. Pointing skyward, the winglets provided better aerodynamics and increased the plane's range and fuel efficiency. The redesigned tail of the plane also improved fuel efficiency. With added technology in the flight deck, the plane required only two crew members to fly it.

The MD-11 design proved versatile, and four different types of the plane were built. The MD-11P was the main passenger model. The MD-11F was the major freight carrier, favored by many package delivery companies. The MD-11 combi was, as the name suggests, a combination passenger and freight carrier. Finally, the MD-11CF was the convertible model, able to serve as a passenger jet or as a freight carrier depending upon the immediate need.

Despite all of these improvements, the MD-11 proved to be a troublesome aircraft in its production. The development of the MD-11 came at the same time as increased competition in the airline industry created by government deregulation. Then came the oil crunch of the early 1990's, followed by a wave of mergers and bankruptcies as weaker airlines began to collapse. This led to a decline in orders, as airlines no longer had the business that required an up-to-date fleet of planes. Initially, the MD-11 was dependent upon European air carriers, with Finnair being the first company to fly one commercially. In addition, company problems hurt the plane. The MD-11 was consistently behind in meeting its delivery deadlines, leading to many canceled orders from passenger airlines. However, the plane became more widely used by overnight freight companies. After fifteen years of development and ten years of production, fewer than two hundred of the planes were flying. Yet the MD-11 survived the Boeing-McDonnell Douglas merger, unlike some of the other planes in the MD series.

Never as popular as its predecessor, the DC series, the MD series of passenger aircraft represented the new generation that was to take over for the DC-9 and the DC-10. However, the McDonnell Douglas Corporation found that economic factors and production difficulties prevented the MD's from taking hold. Only the MD-80, with its multiple versions for different-range flights and different types of airfields, was able to make a considerable penetration of the airline market. The MD-90 barely got off the ground before production was halted by the Boeing takeover of the company, while the MD-95 became part of the 700 series for Boeing. The MD-11 also failed as a commercial airliner, unable to take the place of the more popular DC-10. Overall, the MD series added little to the DC legend and McDonnell Douglas's reputation as a great innovator in the field.

Douglas Clouatre

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See also: Airline industry, U.S.; Airplanes; Boeing; DC plane family; Manufacturers; 707 plane family

Mercury project

Date: From May 5, 1961, to May 16, 1963

Definition: The first phase of the U.S. crewed spacecraft program in which individual astronauts were launched to extremely high altitudes (over 100 miles) and, later, into Earth orbit.

Significance: Initiated by the National Aeronautics and Space Administration (NASA), Project Mercury opened the first phase of the U.S. crewed space exploration program by sending individual astronauts into space to study the engineering parameters and human factors of spaceflight. The two suborbital and four orbital flights that constituted Project Mercury served as instrumental preparation for the later two-person Gemini spacecraft flights (1965-1967) and the Apollo Program missions to the moon (1968-1972). The seven Mercury astronauts were the first U.S. pioneers in the long, costly, and sometimes tragic exploration of outer space.

Preliminary Developments

In the decade following World War II, high-altitude atmospheric research accomplished with crewed balloon flights, uncrewed sounding rockets, and later, experimental rocket planes such as the X-15, established the feasibility of sending crewed rocket-powered vehicles beyond the upper layers of Earth's atmosphere. These early experimental flights were followed by a number of small electronic satellites, or "artificial moons," launched successfully into orbit. The first of these was the 184-pound Russian Sputnik 1 (launched October 4, 1957). These orbital satellites were followed almost immediately by pressurized space capsules containing live research animals wired for telemetric data (such as the dog Laika, the first living creature in space, launched aboard Sputnik 2 on November 3, 1957). Within four years, Russian cosmonaut Yuri Gagarin became the first human in space when he completed a single orbit of the earth aboard Vostok 1 (launched April 12, 1961).

In these early years of space exploration, great political emphasis was placed upon the attainment of space firsts and, in this area, the United States space program was consistently outpaced by Russian accomplishments. In fact, the space race that eventually developed between the two countries became as much a test of patriotic pride as it was a competition of scientific and technical accomplishment. In October, 1958, at the recommendation of President Dwight D. Eisenhower, the National Advisory Committee for Aeronautics (NACA) was restructured into NASA and placed under the direction of James E. Webb. By utilizing the talents of rocketry experts such as Wernher von Braun, who had headed the German army's V-2 rocket development center at Peenemünde during World War II, the U.S. space program would eventually close the U.S.-Soviet missile gap and succeed in landing the first astronauts upon the Moon, but those successes were still years ahead.

Mercury Mission Highlights

Astronaut	*Spacecraft*	*Date of Flight*	*Duration*	*Orbits*
Shepard	*Freedom 7*	May 5, 1961	15 minutes	suborbital
Grissom	*Liberty Bell 7*	July 21, 1961	16 minutes	suborbital
Glenn	*Friendship 7*	February 20, 1962	4 hours, 56 minutes	3
Carpenter	*Aurora 7*	May 24, 1962	4 hours, 56 minutes	3
Schirra	*Sigma 7*	October 3, 1962	9 hours, 13 minutes	6
Cooper	*Faith 7*	May 15-16, 1963	34 hours, 20 minutes	22

At the Threshold of Space

NASA's launch complex at Cape Canaveral, Florida, in use since 1947 as the Atlantic/Eastern Test Range for military and scientific rockets and missiles, became the staging ground for Project Mercury. (After November 28, 1963, Cape Canaveral was temporarily renamed Cape Kennedy to honor the memory of President John F. Kennedy, who had been instrumental in fostering America's spaceflight ambitions.) Launch Complex 56, located near the southwestern end of "Rocket Row," served as the launch pad for the first two Mercury-Redstone flights. Launch Complex 14, further up the eastern shore, served as the launch pad for all later Mercury-Atlas orbital flights. The Cape Canaveral site had been established near to Earth's equator in order to save fuel by taking advantage of Earth's rotational velocity (amounting to a gain of approximately 1,500 feet per second at the equator), thus reducing the velocity needed for a rocket to attain orbit when launched in an eastward direction.

In 1960, after a regimen of rigorous physical, technical, and psychological testing, seven military test pilots were chosen as the first Mercury astronauts: Commander Alan Shepard, U.S.N.; Captain Virgil "Gus" Grissom, U.S.A.F.; Lieutenant Colonel John Glenn, U.S.M.C.; Lieutenant Commander M. Scott Carpenter, U.S.N.; Commander Walter M. Schirra, Jr., U.S.N.; and Major L. Gordon Cooper, U.S.A.F. The seventh member of the original Mercury 7, Donald "Deke" Slayton, was grounded due to an erratic heart rate and replaced in the Mercury flight lineup by M. Scott Carpenter.

Spacecraft and Booster Rockets

Project Mercury flights utilized existing liquid-fueled launch vehicles such as the 83-foot, 30-ton Redstone rocket, and the 93-foot Atlas missile, as booster rockets. Ironically, the hefty Atlas booster, pressed into service for all of the Project Mercury orbital launches, was actually an intercontinental ballistic missile (ICBM) originally designed to deliver a nuclear warhead payload. The Redstone and Atlas rockets' propellants consisted principally of mixtures of liquid oxygen, liquid hydrogen, and kerosene.

Mounted atop its booster rocket, the black bell-shaped Mercury spacecraft, measuring 9 feet, 6 inches long and approximately 7 feet in diameter, carried a single space-suited astronaut. Sandwiched between the shingled outer hull of the Mercury capsule and its corrugated titanium inner hull was a layer of insulation 1.5 inches thick. Every available niche inside the pressurized capsule's battleship-grey interior was crammed with research instruments, monitoring equipment, and control switches. (Shepard once joked that the tight fit of the capsule's interior made it seem as though the capsule was something he "put on," rather than climbed aboard.) The first Mercury space capsule, produced by McDonnell Aircraft for automatically controlled uncrewed flights and test animals, had only a small porthole and a hatch that had to be bolted into place by hand. For the crewed model, a pilot's viewing portal was added, along with a quick release escape hatch with explosive bolts, and a manual back-up control system for piloting the spacecraft. McDonnell also outfitted the nose of its Mercury spacecraft with a 16-foot cylindrical red abort/escape rocket capable of separating the crewed capsule from the booster and carrying it to safety in the event of a mishap; this eventuality, however, was never encountered on any of the crewed flights.

During liftoff, the Mercury astronaut was positioned flat upon his back in a seated posture, legs elevated, to better withstand the tremendous force produced by the rocket's initial acceleration as well as the stresses of reentry, estimated to reach a maximum gravitational force (g) equivalent of approximately 8 g's on liftoff and 11 g's on reentry. The astronaut remained strapped into his form-fitted couch throughout the flight, which typically lasted several hours. After completing the specified number of orbits, the spacecraft was maneuvered into an ideal reentry position angle of between 5 degrees and 7 degrees approximate negative inclination with respect to the horizon. This reentry angle proved critical; a steeper reentry would cause the spacecraft to fall too fast and burn up, while too shallow an angle would cause the spacecraft to skip off into space, unable to return. After positioning the spacecraft, aft end first, the astronaut fired the retro-rockets to slow the spacecraft sufficiently for it to safely reenter Earth's atmosphere. During reentry, the ionization effect caused by the tremendous friction heating of the capsule's reentry through the atmosphere resulted in a brief radio blackout during which contact with the spacecraft was lost for several minutes. During those most dramatic moments of the flight, the astronaut was protected by an ablative heatshield that absorbed the searing 3,000 degree Fahrenheit heat of reentry. Finally, the spacecraft descended by parachute to a splashdown at sea to be recovered by an aircraft carrier helicopter and a team of navy divers.

Mission Highlights

Each Mercury mission focused upon resolving a specific domain of engineering and design-related problems associated with future crewed spaceflights as well as answering questions of human endurance. The basic flight data of the individual Project Mercury missions are summarized in the accompanying table.

The first two Mercury flights, *Freedom 7*, crewed by Shepard, and *Liberty Bell 7*, crewed by Grissom, were suborbital missions during which, for the most part, the spacecrafts' systems functioned automatically, relegating the astronauts to little more than onboard observers. The spacecraft were launched along a ballistic trajectory to the fringe of outer space and returned by parachute to a recovery in the Atlantic Ocean. During the second Mercury mission, a mishap with the explosive bolts securing the capsule's hatch caused a premature opening after splashdown that foundered the capsule and nearly drowned astronaut Grissom. (The ill-fated *Liberty Bell 7* capsule, lost at sea for almost forty years, was eventually recovered from the bottom of the Atlantic virtually intact in 2000.)

On the third crewed Mercury mission, Lieutenant Colonel John Glenn became the first American to orbit Earth, completing three orbits in his 4-hour, 56-minute flight. A crisis occurred when, halfway through the mission, a sensor aboard the *Friendship 7* spacecraft indicated that the capsule's heatshield had been jarred loose. NASA Ground Control advised Glenn not to jettison his retro-rocket pack after firing, in the hope that the metal straps securing the retro-pack would help to hold the heatshield safely in place during reentry. Glenn later recounted seeing large white-hot fragments of the incinerated retro-pack hurtling past his viewing portal as he endured the awful stresses of reentry. Fortunately, *Friendship 7*'s heatshield held.

During the second Mercury orbital flight, the mission priority shifted from testing the spacecraft's systems in-

The final touches are added to the second Mercury capsule at the Lewis Hangar, now the Glenn Research Center, near Cleveland, Ohio. (NASA) tegrity, now well established, to testing the handling and performance characteristics of *Aurora 7* under astronaut Carpenter's manual control. Near the end of the mission the spacecraft became endangered by excessive fuel usage, hit the atmosphere at a steeper angle than anticipated and, consequently, missed the target recovery zone by 250 miles. After a tense search, astronaut Carpenter was recovered from a life raft, unharmed, along with his space capsule.

Less than three months after Carpenter's flight, Russian cosmonauts Adrian G. Kikolayev (Vostok 3, launched August 11, 1962) and Pavel R. Popovich (Vostok 4, launched August 12, 1962) scored yet another space first when they maneuvered their two Vostok spacecraft to within sight of one another, completing the first crewed rendezvous in space.

The third orbital Mercury flight, *Sigma 7*, crewed by Schirra, logged six orbits in a superbly executed textbook flight, but during the fourth and final Mercury orbital mission a massive electrical systems failure occurred on board the *Faith 7* spacecraft as astronaut Gordon Cooper completed his twenty-second orbit. Having lost all of his spacecraft's automatic systems, Cooper flew the *Faith 7* spacecraft manually to a splashdown, landing east of Midway Island in the Pacific.

Project Mercury effectively concluded with Cooper's *Faith 7* orbital mission of May 15-16, 1963. Less than one month later (June, 1963), Russian Valentina Tereshkova became the first woman in space. The 26-year-old lieutenant completed forty-nine Earth orbits, more orbits than all the Project Mercury spaceflights combined.

The engineering- and human-factors data gleaned from the Mercury spaceflights proved instrumental in the development of the later two-man Gemini spacecraft, which served as the final engineering stopgap before the Apollo Program's lunar landings of 1969-1972.

Of the seven original Mercury astronauts, Cooper, Grissom, Schirra, and Shepard flew on later Gemini missions; Grissom was killed in a launchpad fire aboard the Apollo 1 spacecraft on January 27, 1967; Schirra flew on Apollo 7; Shepard flew on the Apollo 14 lunar landing mission; Slayton flew on the Apollo-Soyuz docking mission; and Glenn, who became a U.S. senator after ending his space career, flew as a mission specialist on the U.S. space shuttle *Discovery* in 2001, nearly forty years after his first orbital mission aboard *Friendship 7*.

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See also: Apollo Program; Wernher von Braun; Crewed spaceflight; Gemini Program; John Glenn; National Aeronautics and Space Administration; National Committee for Aeronautics; Orbiting; Alan Shepard; Spaceflight; Valentina Tereshkova; Uncrewed spaceflight

Mergers

Also known as: Consolidation

Definition: The process of consolidation among air carriers.

Significance: The deregulation of air carriers caused a number of airlines to merge, causing concerns about antitrust issues, customer service, and airfare costs.

Competition and Deregulation

A wave of mergers, or consolidations, hit the airline industry in the 1980's, caused in part by the end of government regulation. From 1938 until the passage of the Airline Deregulation Act of 1978, the Civil Aeronautics Board (CAB) had regulated the industry. The CAB oversaw airline fares, determined routes, and ensured that no major airline went out of business. Any mergers had to be approved by the CAB. During the era of regulation, a significant wave of consolidation eliminated some independent airlines. In 1952, Western Air Lines took over Inland Airways, and Braniff acquired Mid-Continent Airlines. Chicago & Southern merged with Delta in 1953. Continental bought Pioneer Airlines in 1955. Eastern obtained Colonial Airlines in 1956. In 1961, United Air Lines acquired Capital Airlines, thereby becoming the largest airline in the United States.

Congress passed the Airline Deregulation Act of 1978, disbanding the CAB and giving its authority to review airline industry practices to the Department of Transportation. The review process, including the ability to approve proposed mergers, passed to the Department of Justice's Antitrust Division on January 1, 1989.

Consolidation swept the airline industry after deregulation, with twenty major airline mergers occurring in the first eight years of deregulation. The high point of consolidation activity was in the mid 1980's. In 1985, Southwest Airlines bought Muse Air, taking over a Dallas rival. A number of large mergers took place in 1986: Delta bought Western Airlines; Northwest took over Republic Airlines; Frank Lorenzo's Texas Air Group bought Eastern Air Lines; TWA bought Ozark; United Air Lines took over Pan American's Pacific routes. The mergers continued into 1987, when American Airlines bought Air Cal and USAir took over Pacific Southwest Airlines (PSA). USAir also purchased Piedmont. By 1987, there were ten airline holding companies operating nationally: Texas Air, United, American, Delta, Northwest, TWA, Pan American, USAir, Piedmont, and Southwest Airlines. These airlines controlled about 95 percent of the market in the United States.

Several factors explain the wave of airline consolidations in the 1980's. One is the lack of antitrust enforcement by the Reagan administration. Critics of this perspective point out that consolidation swept through many other industries in the United States during the 1980's. Had the airline industry not been regulated until 1978, the consolidations would have taken place earlier. Airline holding companies were seeking critical mass in order to cope with increased costs and the decreased profits caused by fare wars. Economic pressures encouraged smaller regional airlines to merge into larger units.

Consolidation, Legislation, and Backlash

A further wave of mergers struck the airline industry in the late 1990's. By 2001, only five major airlines, American, United, Delta, Northwest, and Continental, plus the discount airline Southwest, remained. Since the end of regulation, more than fifty airlines were acquired or merged. American Airlines bought TWA in 2001, saving the troubled carrier from bankruptcy. Also in 2001, the proposed acquisition of US Airways by United was frustrated by concerns that the combined airline would control up to 95 percent of the departure gates at East Coast airports.

The fresh wave of mergers caused U.S. lawmakers to consider a moratorium on airline mergers. Representative Louis Slaughter, a Democrat from New York, and Representative Peter DeFazio, a Democrat from Oregon, introduced the Airline Merger Moratorium Act of 2001 in the 107th Congress (2001-2002). The bill would have made it unlawful, for a one-year period, for a major air carrier to acquire assets or voting securities of another major airline carrier. In a press release announcing the bill's introduction, Representative DeFazio identified the problem when he stated, "The airline industry should focus on improving customer service and increasing consumer choices, rather than rushing to gobble each other up."

Merger Effects

The intent of airline deregulation was to make the airline industry susceptible to the effects of a free-market economy. The intended goal was to increase competition among the airlines. This competition caused massive consolidation as some airlines failed under economic pressure and poor management and were acquired by stronger airlines. Consumer groups have noted that customer service has suffered because of the numerous mergers, as airlines try to remain profitable to protect themselves from acquisition. In some parts of the country, travelers are not able to choose among airlines, forcing them to pay higher airfares. Mergers also significantly affect airline employees' morale, as a newly merged airline lays off employees to recognize the cost savings of combining two corporations.

Airline consolidation has spread beyond the United States. Particularly in the newly united Europe, national airlines are seeking alliances with each other and with American carriers. Because federal law prevents a foreign carrier from having a controlling interest in a U.S. airline, most of the relationships are in the form of alliances. The oneworld Alliance is an effort by thirty-one airlines traveling to 550 destinations in 130 countries. American Airlines is the major U.S. carrier in the alliance. With the restrictions on foreign ownership of U.S. airlines, these alliances could be the future of airline consolidation.

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See also: Air carriers; Airline Deregulation Act; Airline industry, U.S.; American Airlines; Continental Airlines; Delta Air Lines; Northwest Airlines; Southwest Airlines; Trans World Airlines; United Air Lines; US Airways

Messerschmitt aircraft

Definition: A major make of German aircraft.

Significance: Tens of thousands of various Messerschmitt aircraft were produced and served as the foundation for the German Luftwaffe in World War II. These aircraft aided the early German victories and introduced numerous innovations into the aircraft industry.

Origins

In 1923, engineer Willy Messerschmitt established an aircraft company in Bamberg, Germany. In 1927, he moved his firm to Augsburg, Germany, where he merged with another company and created the corporation of Bayerisch Flugzeigwerke (BFW). BFW, with Willy Messerschmitt as chief designer, initially produced gliders and sport and transport aircraft, but in 1933 it secured a contract from Adolf Hitler's Reich air ministry and began to produce military aircraft (designated by the prefix Bf) for the Luftwaffe. In 1936, Willy Messerschmitt seized complete control of the company, renamed it Messerschmitt AG, and continued to focus production on military aircraft (now designated by the prefix Me). During World War II, Messerschmitt AG produced fifteen distinct series of aircraft, ranging from fighters and bombers, to the first jet-powered aircraft.

Bf-109 Series

The most famous of the Messerschmitt aircraft is the Bf-109; a single-seat fighter used by the Luftwaffe from 1935 to 1945 and produced in greater numbers (approximately 33,000) than any other World War II aircraft except the Russian Il-2. The Bf-109 was the first "modern" German fighter. It possessed such advancements as a light alloy stressed skin construction, low cantilever wings with trailing edge flaps, a retractable tail wheel landing gear, and an enclosed cockpit. The first version of this aircraft, the Bf-109A, was produced in 1935, but met with pilot resistance due to its limited agility compared with biplanes. Newer versions of the Bf-109, the Bf-109B, Bf-109C, and Bf-109D, added greater agility, horsepower, and armament and were delivered in modest numbers to the Luftwaffe in the late 1930's.

By February, 1939, however, such variants were removed from front-line duty and replaced by the Bf-109E, known as the Emil. The numerous versions of the Emil saw the plane used as a fighter, fighter-bomber, and reconnaissance fighter. The Bf-109E-4 was the most widely used of the Emil aircraft. A fighter, weighing 4,685 pounds empty, it had a wingspan of 32 feet, 4.5 inches, was 28 feet, 4.2 inches in length, and 8 feet, 2.42 inches in height. Powered by one Daimler-Benz DB-601 Aa inverted-V piston engine, the Bf-109E-4 had a maximum speed of 348 miles per hour, a cruising speed of 300 miles per hour, a ceiling of 34,450 feet, and a maximum range of 410 miles. It was armed with two 20-millimeter MGFF fixed, forward-firing cannons built into the leading edge of the wing and two 7.92-millimeter MG17 fixed, forward-firing machine guns in the upper part of the forward fuselage with synchronization to fire through the propeller.

The Emil, however, was difficult to maneuver at high speeds, and production ceased in 1942 as the Luftwaffe sought a more aerodynamic and better handling plane. Efforts to provide such a plane resulted in the production of the Bf-109F, known as the Friedrich. The Bf-109F-2 was the best of this series. A fighter and fighter-bomber weighing 5,188 pounds empty, it had a wingspan of 32 feet, 6.5 inches, was 29 feet 3.9 inches in length, and stood 8 feet, 6.33 inches in height. Powered by one Daimler-Benz DB 601N inverted-V piston engine, the Bf-109F had a maximum speed of 373 miles per hour, a cruising speed of 348.88 miles per hour, a ceiling of 36,090 feet, and a maximum range of 547 miles. It was armed with one 15-millimeter MG151/15 fixed, forward-firing cannon and two 7.92-millimeter MG17 fixed, forward-firing machine guns with synchronization to fire through the propellers.

The Bf-109F was used throughout 1942, but was replaced in 1943 with the Bf-109G. The Gustav, as it was known, added a more powerful engine, a pressurized cockpit, and was used solely as a fighter by the Luftwaffe throughout the remainder of the war. Later versions of the Bf-109, the Bf-109H and Bf-109K, were introduced in 1945, and although both versions added new improvements to the Bf-109 line, they were produced in significant numbers. The Bf-109 series served the Luftwaffe over

Spain during the Spanish Civil War and over Poland, France, England, and North Africa during World War II.

Bf-110 Series

The Bf-110 was produced by BFW on request from the Luftwaffe for a heavy fighter. As with the Bf-109, the Bf-110 was produced in several versions, with a total output of approximately six thousand aircraft. The most noteworthy version was the Bf-110C-4. This heavy fighter carried a pilot, navigator/observer, and radio operator/gunner in an enclosed cockpit. Weighing 11,354 pounds empty, it had a wingspan of 53 feet, 1.8 inches, was 39 feet, 8.33 inches in length, and stood 13 feet, 6.5 inches in height. Powered by two Daimler-Benz DB 601A-1 inverted-V piston engines, the Bf-110C-4 had a maximum speed of 348 miles per hour, a cruising speed of 304 miles per hour, a ceiling of 32,810 feet, and a maximum range of 680 miles. It was armed with two 20-millimeter MGFF fixed, forward-firing cannons, four 7.92-millimeter MG17 fixed, forward-firing machine guns, and one 7.92-millimeter MG15 trainable, rearward-firing machine gun.

A later version, the Bf-110G-4c/R3, was reconfigured to serve as a night fighter. Carrying the same three-man crew as the Bf-110C-4, it weighed 11,230 pounds empty, had a wingspan of 53 feet, 3.77 inches, was 42 feet, 9.78 inches in length, and stood 13 feet, 8.5 inches in height. Powered by two Daimler-Benz DB 605B-1 inverted-V piston engines, the Bf-110G-4c/R3 had a maximum speed of 342 miles per hour, a cruising speed of 317 miles per hour, a ceiling of 26,245 feet, and a maximum range of 808 miles. It was armed with two 30-millimeter MK108 fixed, forward-firing cannons, two 20-millimeter MG 151/20 fixed, forward-firing cannons, and one 7.92-millimeter MG81z trainable, rearward-firing two-barrel machine gun. This plane also carried several varieties of radar which, although increasing drag and hampering performance, enabled it to enter night service. The various versions of the Bf-110 served the Luftwaffe over Poland, Norway, England, North Africa, and Russia throughout World War II.

Me-163 Series

The Me-163 Komet was the first rocket-powered aircraft used in World War II. Although it did not come on line until 1944, the Me-163B-1a Komet was the best known of these rocket aircraft. It was a single seater that weighed 4,206 pounds empty, had a wingspan of 30 feet, 7.33 inches, was 19 feet, 2.33 inches in length, and stood 9 feet, 0.67 inches in height. Powered by one Walter HWK 109-509A-1/2 rocket motor, it had a maximum speed of 593 miles per hour, a climb rate of 15,951 feet per minute, and a ceiling of 39,370 feet. It was armed with two 30-millimeter MK108 fixed, forward-firing cannons or two 20mm MG151/20 fixed, forward-firing cannons. The Komet, however, had several problems. It functioned for only 7.5 minutes under power, and frequently suffered from premature engine shutdown at high altitude or immediately after takeoff. Such problems, combined with the late stage of the war when the Komet was introduced, resulted in only 279 of the aircraft actually reaching Luftwaffe service.

Me-262 Series

The world's first operational jet fighter was Messerschmitt's turbojet-powered interceptor fighter, the Me-262. The most popular of the Me-262 class was the Me-262A-1a. This was a single seater that weighed 9,742 pounds empty, had a wingspan of 41 feet, 0.5 inches, was 34 feet, 9.3 inches in length, and stood 12 feet, 6.8 inches in height. Powered by two Junkers Jumo 004B-1/2/3 Orkan turbojet engines, it had a maximum speed of 540 miles per hour, a climbing rate of 3,937 feet per minute, and a range of 652 miles. It was armed with four 30-millimeter MK-108 fixed, forward-firing cannons located in the nose cone. In 1944, Messerschmitt produced the Me-262a-2, a fighter-bomber, nicknamed Sturmvogel (storm bird). This aircraft was basically the same as the Me-262a-1a, with the notable exception that the Sturmvogel was equipped to carry one 1,102-pound (500 kilogram) bomb or two 551-pound (250 kilogram) bombs. Although unstable, difficult to fly, and used in limited numbers by the Luftwaffe, the Me-262 was a nearly unstoppable aircraft that changed the course of the aircraft industry by ushering in the jet age.

Me-323 Series

The most unique of the Messerschmitt aircraft was the Me-323 Gigant (giant). The Me-323E-2 Gigant was a heavy transport plane operated by a pilot, copilot, flight engineer, and radio operator on the flight deck, plus a load master and up to six gunners in its belly. Its empty weight was 65,256 pounds, but the Gigant had a maximum takeoff weight of 99,206 pounds. It could carry a payload of 120 troops or freight up to 34,000 pounds. The Gigant had a wingspan of 180 feet, 5.35 inches, was 93 feet, 6 inches in length, and stood 31 feet, 6 inches in height. It was powered by six Gnome-Rhone 14N-48/49 radial piston engines, which provided a maximum speed of 157 miles per hour, a cruising speed of 140 miles per hour, a ceiling of 14,760 feet, and a range of 808 miles. To protect this rather slow-moving aircraft, the Gigant was armed with one 20-

millimeter MG151/20 trainable cannon in each of two power-operated EDL 151 wing turrets, one 13-millimeter MG131 trainable, forward-firing machine gun in each of two nose positions, one 13-millimeter MG131 trainable, rearward-firing machine gun in the rear of the flight deck, and one 13-millimeter MG131 trainable, lateral-firing machine gun in each of the two forward and two beam positions. The Gigant was used to support the Afrika Corps in North Africa and the Wehrmacht in Russia.

Me-210/410 Series

The Me-210 was constructed by Messerschmitt to replace the Bf-110 and to act as a dive-bomber. The Me-210, however, suffered from serious technical and aerodynamic problems from the beginning. These problems plagued the Me-210 throughout its production and it never acted as a serviceable aircraft. Messerschmitt never gave up on the craft, and in 1943, the Me-410 Hornisse (hornet), a modified version of the Me-210, entered Luftwaffe service. The best known of the Hornisse was the Me-410A-1/U2. This heavy fighter and fighter-bomber carried a pilot and radio operator/gunner, and weighed 16,574 pounds empty. It had a wingspan of 53 feet, 7.7 inches, a length of 40 feet, 11.3 inches, and stood 14 feet, 0.5 inches in height. It was powered by two Daimler-Benz DB 603A inverted-V piston engines, which provided for a maximum speed of 388 miles per hour, a cruising speed of 365 miles per hour, a ceiling of 32,810 feet, and a maximum range of 1,050 miles. It was armed with two 20-millimeter MG151/20 fixed, forward-firing cannons in the nose, two 20-millimeter MG151/20 fixed, forward-firing cannons in a ventral tray, two 7.92-millimeter MG17 fixed, forward-firing machine guns in the nose, and one 13-millimeter MG131 trainable, lateral/rearward-firing machine gun. The Me-410 served the Luftwaffe over France, Russia, and Eastern Europe during the last two years of World War II.

Postwar Messerschmitt

After the war, Messerschmitt AG briefly left the aircraft industry to produce products as varied as sewing machines and motor scooters. By the mid-1950's, the company had returned to the aircraft industry to produce passenger, transport, and training aircraft. The company survived Willy Messerschmitt's death in 1978 and, as a result of mergers and reorganizations, in the 1990's Messerschmitt AG became Messerschmitt Bolkow-Blohm GmbH. The company continues to produce aircraft, but also produces missiles, parts for spacecraft, as well as railroad and highway vehicles.

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See also: Bombers; Fighter pilots; Jet engines; Luftwaffe; Mergers; Manufacturers; Military flight; Rocket propulsion; Turbojets and turbofans; World War II

Microgravity

Definition: A condition in which the apparent effects of gravity are very small.

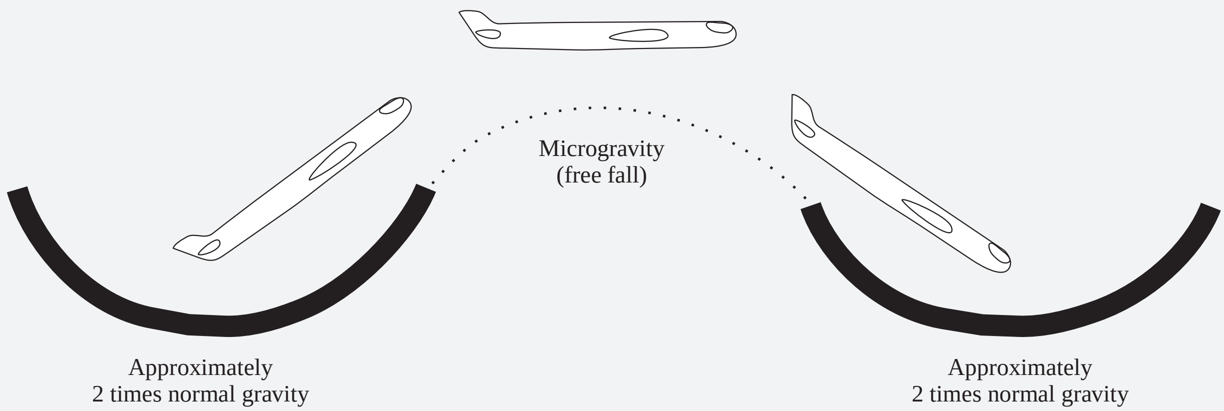
Significance: Microgravity is useful for many scientific applications that cannot be performed in an environment where gravity is a dominating force. It is also a problem humans encounter when traveling in space.

Microgravity Environments

Microgravity is sometimes used interchangeably with terms such as weightlessness, free fall, or zero gravity. However, some of these terms can be misleading. For example, the term microgravity implies a condition in which very little gravity present. This condition would be possible to achieve at very large distances from any planet or star, but it is a condition that is currently not easily obtained.

From a practical standpoint, microgravity environments occur in relatively strong gravitational fields. To obtain the effects of microgravity, an object is dropped or put into a state of free fall. For example, astronauts orbiting the earth in the space shuttle can be described as being in a mi-

Parabolic Trajectory for Microgravity



crogravity environment. However, in this orbit, gravity is still about 90 percent as strong as it is on the surface of the earth. The difference is that the astronauts and the shuttle are in free fall around the earth. They are all falling, but they have enough horizontal velocity so that the earth's surface curves away from them about as fast as they drop and therefore, they do not hit the ground.

Research Uses of Microgravity

Microgravity environments can be used for many different applications that are impossible to achieve in a normal-gravity environment. One such application involves the creation of certain alloys. On Earth, when two materials are mixed, the new compound contains elements that have different densities. In this new compound, the elements that are denser will settle to the bottom of the mixture in a process called sedimentation. In a microgravity environment, sedimentation does not occur, and the material can be cured in a state where the elements with different densities are equally distributed. Many high-quality materials can be manufactured this way.

Microgravity is also used to develop and study many topics associated with biology and life sciences. By studying things such as crystals, plants, animals, and medicines in a microgravity environment, scientists can learn more about how each of these works, both in microgravity and in normal gravity. The result is a better scientific understanding and the potential to create new and better medicines.

Along with the benefits of microgravity also come problems. One of the big problems of microgravity relates to human space travel. Although the human body functions well in a one-gravity environment, when it is subject to a microgravity environment, as in orbit, the body experiences a decreased hydrostatic gradient, a shift of fluid from the lower body to the upper body. The body eventually rids itself of this extra fluid in the upper body, but upon return to Earth, the problem is reversed. When it leaves the free fall environment, the fluid pools in the lower body and can causes light-headedness or blackouts. Vestibular functions that sense a body's orientation are confused by microgravity and can cause space sickness. Fortunately, the body usually adapts within the first few days of orbit. While in microgravity, the muscles in the body begin to atrophy due to the lack of use and bones lose calcium, which causes them to weaken. Vigorous exercise in orbit can help alleviate the muscle atrophy and some of the calcium loss, but no good long-term solution to these problems has yet been developed.

Obtaining Microgravity Conditions

There are several methods that have been used to simulate microgravity via free fall. For centuries drop facilities have been used to create microgravity conditions. In the mid-sixteenth century, artillerists discovered that lead shot for muskets could be made almost spherical by dropping molten lead from a tall tower. During free fall, the lead would cool into a spherical shape and then land in a container of water. There are several different drop facilities around the world and in order to get relatively long periods of free fall, these facilities must be very tall. For example, one of the longest drop times comes from a facility in Japan that has been built in a vertical mine shaft that is 490 meters deep. This drop facility can provide free fall for up to 10 seconds.

Aircraft such as the National Aeronautics and Space Administration (NASA) KC-135 are used for free-fall environments by flying parabolic curves. During these parabolic trajectories, the occupants feel alternating 15- to 30-second forces of near-free fall and twice normal gravity.

Sounding rockets launched to high altitudes are yet another way to simulate microgravity. When their engines shut off, the coasting rockets can experience several minutes of free fall. To obtain longer periods of free fall, orbiting spacecraft can be used. These orbiting spacecraft, such as shuttles and space stations, are in constant states of free fall, achieving very long periods of microgravity. One problem that may develop in these situations is that as astronauts move around, they must push off the walls of the vehicle. The pushing causes small accelerations in the vehicle and this can disturb experiments that require an almost perfect free fall environment.

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See also: Astronauts and cosmonauts; Crewed spaceflight; Forces of flight; Gravity; Orbiting; Rockets; Spaceflight; "Vomit Comet"

Military flight

Definition: The use of aircraft for the purposes of warfare and national defense.

Significance: The development of military flight allowed warfare to be waged more rapidly and more powerfully than ever before.

Background

At the beginning of the twentieth century, despite vastly increased firepower and mobility, armies were still tied to the ground, and strategists thought in terms of smashing enemy defenses through sending literally millions of soldiers against them. The development of military aircraft in the twentieth century changed the nature of warfare, which could now be waged more rapidly and more destructively than ever before. Beginning in World War I and continuing at an ever-increasing pace, military aircraft have performed many functions, including reconnaissance and spotting; the bombing of military and civilian targets; aerial combat and protection for bombers; providing support for ground troops; causing disruption of enemy logistical movement; and, perhaps most important, threatening to deliver weapons of mass destruction in the nuclear age. The twentieth century has been marked by the extremely rapid evolution of more efficient and effective aircraft designs and types, ranging from the slow and awkward biplanes of World War I to the highly sophisticated spy satellites of the late twentieth and early twenty-first centuries.

Pioneering Efforts: 1861-1918

The age of military aircraft began with the use of balloons to gather information on enemy positions. Although military strategists experimented with balloons during the wars of the French Revolution (1792-1802), the first systematic attempt to use balloons in warfare was made during the American Civil War (1861-1865). A new era in warfare dawned on July 31, 1861, in Virginia, when Union general Benjamin Butler sent John LaMountain above the nearby Confederate lines in a balloon. LaMountain, who before the war had achieved fame by sailing more than 1,000 miles in a balloon, reported that the rebel defenses were less strong as Union commanders believed. Although both armies during the Civil War periodically, but often ineffectively, used balloons for reconnaissance and to direct artillery fire, air power did not seriously challenge the use of cavalry for effective scouting and reconnaissance. Balloons, most of which were filled with hydrogen gas, were expensive and cumbersome to maintain and move and were highly vulnerable to enemy fire—few stayed aloft very long. The possibility of aerial photography was discussed during the war but never attempted.

New possibilities were developed for military aircraft in 1903, when Orville and Wilbur Wright performed the first successful series of heaver-than-air, machine-powered flights. By the beginning of World War I in 1914, two-wing, wooden aircraft were able to carry a pilot and observer over enemy lines and back on valuable reconnaissance missions. By 1915, British, French, and German airplanes were equipped with cameras for fixing enemy positions in photographs and with radios for relaying data back from the air. By the following year, armies on both sides considered air reconnaissance vital to the planning of any offensive.

However, as soon as the combatants realized the effectiveness of air power, they set out to stop it by developing single-pilot planes armed with machine guns that were synchronized to fire through the aircrafts' propellers. The first flying aces and dogfights emerged during World War I. Perhaps most famous flying ace was the German fighter pilot Manfred von Richthofen, who was credited with destroying eighty enemy aircraft before he himself was shot from the skies and killed in April, 1918.

World War I also marked the beginning of strategic bombing from the skies. In 1915, bombs rained down on London from a German zeppelin—air power now meant that not even civilians back home, far from the fighting, were truly safe. By 1918, German and British airplanes were regularly bombing enemy cities and civilians. The United States entered the war in 1917, and in 1918, during the first major American offensive against the Germans, ground troops were supported by more than one thousand aircraft. Although air power had not proved decisive in the outcome of World War I, it had proved highly effective as a reconnaissance tool, and its uses had multiplied rapidly. Furthermore, by 1918, engine and structural design was improving. Air power would become even more crucial to the outcome of future wars.

Air Power and Total War: 1918-1945

Between World War I and the outbreak of World War II in 1939, military aircraft were improved through a number of technical developments. First, new and more powerful engines were devised, greatly improving both speed and carrying capacity. Second, aircraft design shifted from that of biplanes, with wings that were supported by external structures, to monoplanes with internally supported single wings. The amount of dead or empty weight dropped dramatically, as the space given to pilots, fuel, and cargo expanded. Third, retractable landing gear appeared. Fourth, aircraft became much more destructive, with additional bombing ordnance and defensive armament. Speed, maneuverability, and firepower all increased as a result. Fifth, aircraft carriers were developed, which greatly widened the range of aircraft in a number of military roles. Sixth, and most significant, the major powers in the world developed aircraft industries that could produce aircraft tailored to specific uses while constantly updating and improving models. Finally, military strategists developed complex theories of air warfare, most of which continued to see air power as playing a supporting role for ground operations.

However, a few analysts devised more ambitious theories of air power. The Italian general Giulio Douhet emphasized the use of aircraft to bomb enemy cities, including not only the military targets in those cities but the people themselves. Such strategic bombing would demoralize the enemy's population while destroying its production capabilities. This theory was put into effect during the Spanish Civil War (1936-1939) by the German Luftwaffe, which bombed undefended civilians in cities with little or no military value. During the Spanish conflict, the Germans also placed voice-operated radios in their bombers and fighters, enabling true coordination between ground and air forces for the first time. Meanwhile, the British had installed the first radar system to provide early warning of enemy attack.

By September 1, 1939, when the Germans invaded Poland, all the major nations who would eventually be involved in World War II had for several years been producing fighters, bombers, and other specialized aircraft. At the beginning of the war, Germany was ahead of the field both in numbers of aircraft and in performance.

One example of the German air arsenal was the Messerschmitt Me-109 fighter plane. More Messerschmitts were produced during World War II than any other fighter by any combatant. The Me-109 saw action in all theaters of the war, and although it was out-performed by the American P-51 Mustang and the British Spitfire, it remained a formidable weapon. Another of Germany's most effective aircraft was the Stuka bomber, a light and small plane designed to prepare the way for the advance of ground troops disrupting and destroying communication and supply routes.

Although German air power dominated the skies of Europe during 1939 and 1940, the Luftwaffe failed in its attempt to reduce England to submission through air power alone in the summer and fall of 1940. British radar stations and the information they provided about the direction and strength of German attacks gave the Royal Air Force (RAF) a great advantage. Equally important, however, was the skill with which British pilots intercepted and destroyed German aircraft during the campaign. Of great importance was the Spitfire fighter plane, which was superior to German fighter planes in both speed and maneuverability.

From 1939 to 1941, air power in the form of bombers and fighters ranged over Europe and the Pacific, wreaking havoc and supporting ground and naval operations, mainly

The increasing use of airplanes in military capacities also required the development of aircraft carriers to provide mobile bases for refueling and maintenance. (Digital Stock)

for the Axis Powers of Japan and Germany. However, the use of aircraft launched from carriers was also introduced. The most dramatic example of the use of aircraft carriers was the Japanese attack on the U.S. naval fleet at Pearl Harbor, Hawaii, on December 7, 1941. The Japanese bombers were protected by the very effective Japanese Zero fighter planes. The Zero had a maximum speed of 330 miles per hour, two cannons mounted on its wings, and two machine guns that fired through its propeller. Despite inflicting considerable damage on American cruisers and destroyers at Pearl Harbor, the Japanese missed the U.S. aircraft carriers, which were not in Hawaii. Only five months after the Pearl Harbor attack, the Americans' carrier-based air fleet inflicted a crushing defeat upon the Japanese at the Battle of Midway, which shifted the momentum of the war in the Pacific.

By the beginning of 1943, the balance of power in both the European and Pacific theaters had shifted to the Allies, who had matched and were rapidly surpassing German and Japanese air power. Moreover, Allied air superiority was crucial to the success of Allied ground troops in 1944 and 1945. For example, for weeks before the D-day invasion of June, 1944, Allied bombers and fighters prowled behind German lines in France, hitting supplies and reinforcements moving by rail and road and thereby helping to ensure a successful landing at Normandy. The dropping of one thousand airborne troops behind German lines was another important part of D day's success.

In 1943 and 1944, a new type of aircraft took center stage in the Allied air campaign—the long-range heavy bomber. Both British and American bombers began raids over German cities in 1943, and despite heavy losses from enemy antiaircraft fire and enemy fighters, these bombing runs did tremendous damage to German war production. By 1944, air fields recaptured in Western Europe were being used as bases from which to reach cities throughout Germany.

The American B-17 Flying Fortress, with a range of 3,750 miles, could carry up to 17,600 pounds of bombs. The B-17 carried a crew of ten. Its ceiling was 35,000 feet, and its cruising speed was 170 miles per hour. The more than 12,000 B-17's built during the war dropped about

640,000 tons of bombs; about 4,750 B-17's were lost in combat. The British Lancaster bomber could hold more bombs than could any other Allied aircraft except the B-29 Superfortress. The destruction produced by such heavy bombers, flying with fighter escorts, was tremendous. In February, 1945, the German city of Dresden was flattened, and more than 100,000 people, many of whom were civilians, were killed. By the war's end, almost 600,000 German civilians had been killed in air raids, while the death toll for British victims of German bombing totaled about 60,000.

By 1945, air power had helped to create what military historians call total war—an expansion of the battlefield to encompass all enemy cities and their civilian occupants, along with a total dedication of a nation's economy to the production of war matériel. A new stage in warfare and military flight was also dawning, with the use of atomic power and the development of jet and missile technology. By 1943, Germany was working toward the creation of a massive bomb that could be delivered not by an airplane, but by a rocket. The V-1 and V-2 flying bombs, as they were called, were the world's first intercontinental ballistic weapons. Although these weapons killed more than two thousand London citizens during 1944 and 1945, they could not change the war's outcome. About 35,000 V-1 rockets were produced, of which about 5,000 actually hit the British. These bombs, with enough power to destroy a city block, indicated the future direction of air power, as did the jet-powered fighter planes that were being produced by Germany by the end of the war.

Of even greater importance for the future of military flight was the use of air power to deliver the first atomic weapons in warfare. The American bombing of the Japanese cities of Hiroshima and Nagasaki in August, 1945, heralded the Cold War, in which enemies could destroy not only each other but the earth itself. In this new era, when the doctrine of mutual assured destruction (MAD) would paradoxically help to maintain peace, aircraft would be an essential part of nuclear arsenals and military strategy.

Military Flight During the Cold War: 1945-1990

After the Soviet Union attained atomic power in 1949, the ensuing arms race included aircraft of many types. The first important innovation in military flight after World War II was the replacement of propeller-driven aircraft with jet aircraft, which were first produced in World War II as fighter planes. The Germans produced the first operational model, the Messerschmitt Me-262E. The Me-262E was clearly superior to its rivals, but it had arrived too late in the war to make much of an impact. In 1943, a British twin-engine jet plane named the Gloster Meteor flew in combat formation. The first U.S. jet aircraft was the Lockheed P-80 Shooting Star, which first flew in 1944 but never saw combat in World War II. The first Soviet jet fighter plane appeared in 1946.

In addition to jet fighter planes, jet-powered bombers also became a part of the Cold War arms race. One such aircraft was the U.S. B-52 Stratofortress, which appeared in 1955 and became an important part of the U.S. nuclear arsenal. A nuclear bomb was first dropped successfully from an airplane in 1956. By 1960, each B-52 could drop up to four nuclear bombs and more than forty 750-pound bombs. By 1955, the Soviet Union had produced its own long-range bombers, including the Tu-95 Bear, capable of reaching U.S. cities from Northern Siberia. By 1960, U.S. bombers substantially outnumbered those of

Events in the History of Military Flight

1861: Balloons are used for reconnaissance during the American Civil War, one of the first effective uses of military air power.

1903: The Wright brothers achieve the first heavier-than-air sustained flight, laying the foundation for future development of military aircraft.

1914: Airplanes provide vital reconnaissance for the first time in a major conflict during the Battle of the Marne in World War I.

1915: German zeppelin raids on London are the first example of strategic bombing by military aircraft.

1944: V-1 and V-2 rockets launched by Germany during World War II are the first intercontinental ballistic missiles; German Me-262 and British Meteor are the first military jet aircraft.

1945: U.S. bombings of the Japanese cities of Hiroshima and Nagasaki mark the first time nuclear weapons are delivered by air.

1947: U.S. test pilot Chuck Yeager breaks the sound barrier, paving the way for modern supersonic military aircraft.

1956: The United States first employs the U-2 spy plane for high-level reconnaissance.

1957: The Soviet Union launches Sputnik satellite, setting the stage for future deployment of satellites for military use.

1964: The United States employs missiles with multiple warheads.

1968: In relief of Khe Sanh during the Vietnam War, U.S. B-52's carry out the most concentrated bombing raid in military history.

1991: A U.N. coalition exhibits a full range of modern military aircraft to defeat Iraq during the Persian Gulf War.

the Soviets, although there was a perception of a so-called bomber gap, in which the Soviets had the advantage.

Air reconnaissance was also revolutionized during the Cold War by jet power and new designs. Planes with extremely high ceilings and long ranges gathered information on the enemy—one example was the U.S. U-2, which flew its first mission in 1956 and was able to fly above 70,000 feet. In 1960, a Soviet fighter plane shot down a U-2 piloted by Gary Powers over Soviet airspace, and a tense series of allegations between the United States and the Soviet Union followed. It was also a U-2 that photographed clear evidence of offensive Soviet missiles being built in Cuba in 1962. Later, satellites would replace such aircraft as the principal means of gathering intelligence.

Another innovation in military flight after World War II was the development of ballistic missiles capable of carrying nuclear warheads thousands of miles. By 1960, the debate over the bomber gap between the two superpowers had turned into a discussion over the missile gap. During the 1950's, America produced two classes of intercontinental ballistic missiles (ICBMs): the Titan and the Atlas. Both were designed to deliver a 1-megaton warhead over a distance of 5,000 miles. By 1960, such ICBMs could be launched from U.S. submarines.

Although the Soviet Union initially lagged behind the United States in missile production during the 1950's, it launched its first successful ICBM in Siberia in 1957. Soon afterward, the Soviets sent by rocket into Earth orbit two satellites, Sputnik 1 and Sputnik 2, the latter of which carried a live dog. During this period, the Soviets also began to fit their submarines with nuclear warheads with short initial ranges. By the early 1960's, a second generation of U.S. ICBMs, the Minuteman I and Titan II, were in production. The numbers of Soviet ICBMs soared during the 1960's, with series such as the SS-11, the SS-9, and the SS-13. By 1970, the Soviet Union's 1,299 ICBMs surpassed the U.S. total of 1,054. However, the United States retained superiority in numbers of bombers and submarine-launched ballistic missiles (SBLMs). The range of the U.S. Polaris missile, carried by nuclear submarines, increased from 1,375 to 2,850 miles during this period.

Cold warfare also promoted the development of the helicopter. Although helicopters appeared in World War II, they came into their own in the 1950's and 1960's, during the Korean War and Vietnam War. Used for a variety of needs, the helicopter was suited to the rugged terrain of many battle zones during this period. An example was the American UH-1 Huey, which served many functions: troop transport, evacuation of wounded, and attack on enemy ground troops. The Huey was part of the air cavalry created by the U.S. Army in Vietnam. The First Airmobile Cavalry Division, created by the United States in 1965, was capable of moving ten thousand troops into battle within a few hours. The Soviet Union began regular production of military helicopters in 1948, with many models of various sizes to follow.

Still another and more advanced form of Cold War military flight was the use of surveillance satellites. In 1957, after the Soviet Union launched Sputnik 1, the world's first satellite, into space, the United States began work on the Corona satellite, designed to snap photographs of selected territory at regular intervals from space. Although often unsuccessful, by 1972, the Corona series of satellites had provided more information about the Soviet Union than all previous surveillance flights by U-2 planes. By 1962, the Soviets had launched its first Cosmos satellite, larger than the Corona and with more cameras. During the 1970's and 1980's, satellite surveillance was improved as it was employed by more nations. Satellites helped to detect telemetry signals and to wage electronic warfare by jamming transmission signals. The administration of U.S. president Ronald Reagan called for the development of the Strategic Defense Initiative (SDI), a satellite missile defense system that could block incoming ICBMs.

Beyond the Cold War: 1990-Present

In 1990, at the beginning of Operation Desert Shield, the first major conflict since the decline of the Soviet Union, it appeared that U.S. military air power might be able to achieve victory substantially on its own. With cruise missiles launched from ships and submarines combined with a massive bombing campaign, tremendous damage was done to the Iraqi army of Saddam Hussein. Once again, new technology, such as the U.S. Air Force's stealth bomber, which could not be detected by Iraqi defenses, surfaced. Military aircraft could now be used effectively at night because of infrared viewing devices. In fact, the transportation of about 35,000 U.S. military personnel by air, most by commercial aircraft, was a massive undertaking necessary before the war could begin. Bombers hit Iraqi targets with smart bombs, which provided new and astounding levels of accuracy—the F-117A stealth fighter was one such aircraft. However, despite a massive air campaign by the United States and its allies, ground troops still proved necessary to dislodge the Iraqi army from Kuwait. For all of its advances since the Wright brothers' achievement in 1903, military flight still required careful integratation with other forms of military power to achieve its desired results.

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Missiles

Also known as: Arrows, bullets, rockets, ICBMs

Definition: Any type of aerial projectile delivered against a target, normally with a high trajectory and over greater distances than personal weapons. In modern times, the term "missile" usually refers exclusively to pilotless air vehicles carrying a warhead and powered by a rocket or jet engine.

Significance: Missiles provided two-thirds of the Triad, the combination of bombers, sea-launched missiles, and land-based missiles that the United States maintained to deliver a nuclear strike against the Soviet Union during the Cold War. In the late twentieth and early twenty-first centuries, the development of small yet sophisticated computers coupled with the desire within the United States to avoid risking the lives of air crew members led to an increased dependence on smaller tactical missiles to carry out military objectives.

Premodern Missiles

Air-delivered projectiles have been used since before the dawn of civilization. Although for thousand of years, armies depended primarily on hand-held weapons, such as swords and spears, kinetic-energy missiles in the form of arrows fired from bows and, later, bolts fired from crossbows had an auxiliary role on battlefields. Heavier projectiles were developed for use against fortifications and city walls. Roman armies employed artillery in the form of large engines that could hurl boulders at enemy fortifications. However, the birth of the modern missile came when gunpowder, a Chinese invention, was made to burn inside a tube that was closed at one end, causing the thrust to push out the other end and force the tube to lift. This use of missiles with their own propulsion, called rockets, slowly began to change warfare.

Pre-World War II Missiles

Early rocket-type missiles caused little physical destruction on the battlefield, but European armies began employing them in the late eighteenth century for illumination and psychological purposes. Military missiles remained mostly a curiosity until World War II. Missile development got its greatest boost in the early twentieth century from Dr. Robert H. Goddard, a physicist from Massachusetts, who began to experiment with liquid-fueled rockets. Although his experiments were largely ignored in the United States, his work became highly influential in Germany and became the basis for later German missile development.

World War II Missiles

Germany led the world in missile development during World War II. To make an effective weapon, missiles were fitted with warheads, which were bombs designed to explode either on impact or at a certain altitude. By 1943, Germany began to place more emphasis on so-called wonder weapons, high-tech weapons which would compensate for Germany's deficiencies in manpower and resources. Among these were missiles. Nazi leaders believed that missiles might be able to inflict enough physical and psychological damage on the British that they might sue for a separate peace.

The German V-1 rocket was essentially a pilotless jet aircraft that would be pointed in the general direction of London, and would fly until it ran out of fuel. It would then crash and explode. The V-1 was followed by the V-2, a much more sophisticated device. The V-2 rocket was a true liquid-fueled guided missile. London received strikes from these weapons in 1944 and 1945. Of more than 8,000 V-1's launched against London, fewer than 2,500 found their target. Only eleven V-2's exploded in England. Fortunately for the British, the Germans were never able to produce them in large enough numbers to make a real impact on the British war effort. Even more importantly, the Germans neglected research into nuclear weapons, which, if fitted to even a small number of V-2's, would have given Germany a means to inflict catastrophic damage on its enemies.

Post-World War II Missiles

After the war, both the United States and the Soviet Union became interested in German research into the field of missiles. Both nations began to expedite the movement of top German scientists to their own nations. The United States began its ballistic missile program under Wernher von Braun at Redstone Arsenal, outside of Huntsville, Alabama. Von Braun, a former Third Reich scientist who had developed the German V-1 and V-2, directed American missile research through the development of the intercontinental ballistic missile (ICBM) into the space program, including the Apollo missions. The United States became more focused on missile development when the Soviets launched the Sputnik 1 satellite in October, 1957, from a Soviet rocket. Sputnik showed the Americans that the Soviets had the technology to shoot a nuclear-tipped missile to the United States.

The Air Force's Strategic Air Command (SAC), which originally focused on using crewed bombers to deliver nuclear and conventional weapons to targets around the world, primarily in the Soviet Union, began in the 1950's to develop ICBMs to counter the Soviet threat in this area. The Air Force had to struggle against both the Army and the Navy to acquire the missile missions. The Army argued that missiles were essentially very long-range artillery, whereas the Navy thought missiles would best be launched from ships and naval aircraft. In the end, the Air Force got the mission to develop and field the largest missiles, the ICBMs, which would carry nuclear warheads from inside the United States to strike cities and military targets in the Soviet Union. The Navy received authority to develop and field sea-launched ballistic missiles (SLBMs) and other missile systems that would operate with the fleet. Eventually the Navy would build large submarines that functioned as platforms for launching ballistic missiles from the safety of the floor of the continental shelf. The Army received authority to develop and deploy intermediate-range ballistic missiles (IRBMs) and other missile systems that could be used on the battlefield.

U.S. ICBMs

The first major American ICBM was the Atlas, which the U.S. Air Force first fielded in 1958. An offshoot of the Atlas was the development of the Thor, an IRBM. Although the Atlas had the ability to strike targets in the Soviet Union, it needed several hours prior notice for launch and was vulnerable to a first strike. In the event the Soviet Union attacked the United States first, the Atlas site would be a priority target. In the event of a Soviet nuclear strike within a mile or more or of an Atlas launch site, the United States would be unable to launch its Atlas missiles.

As a response to this vulnerability, the U.S. Air Force developed and fielded in April, 1962, the first of the Titan series of ICBMs, which had a faster launch time, carried a larger payload, and were housed in protected underground silos. Throughout the life of the Titan system, including after the Titan missiles were removed from the strategic force in the 1980's, the missile had a secondary role in launching crewed spacecraft, such as the Gemini Program, and satellites into orbit. The Titans were soon joined by the Minuteman series, which first became operational in November, 1962. Unlike earlier missiles, the Minuteman missiles had a solid propellent and could be launched within a few minutes of receiving an emergency war launch order. The Minuteman III would carry up to three warheads per missile. After heated debate over basing systems, fifty Peacekeeper missiles, each of which had the capacity to carry up to ten warheads, were based in hardened Minutemen silos by 1988. The Minuteman IIIs and Peacekeepers would be the mainstay of the U.S. ICBM force through the end of the Cold War.

Missiles in the Soviet Union

After World War II, the Soviet Union placed great emphasis on missiles in their military establishment. Unlike the United States, the Soviets created a new branch of their armed forces, the Strategic Rocket Forces, for missiles, although early Soviet rockets had impressive payloads and intercontinental ability, their accuracy was poor. By the early 1960's, the Soviets placed more emphasis on IRBMs and medium-range ballistic missiles (MRBMs) to counter the American threat. The placing of 1,000-mile-range MRBMs and 2,000-mile-range IRBMs in 1961 in Cuba, from where they could strike most parts of the continental United States, led to the Cuban Missile Crisis in 1962.

In the 1980's, the Soviet decision to field their SS-20 missiles in Eastern Europe led the North Atlantic Treaty Organization (NATO) to allow American IRBMs into Western Europe. The U.S. Army fielded the Pershing missile while the U.S. Air Force fielded the ground-launched cruise missile (GLCM). These were tactical weapons and had for their targets areas of troop concentration and supply depots. The Intermediate Nuclear Force Treaty, signed in December, 1987, by U.S. president Ronald Reagan and Soviet premier Mikhail Gorbachev, required both nations to withdraw and destroy those missiles, the first such reduction in nuclear weapons.

Strategic Air Command

Throughout its existence, the SAC focused on its ability to deliver a devastating counterstrike against the Soviet Union after the Soviet Union had attacked the United States. This formed part of the strategy known as mutually assured destruction (MAD), whereby the United States and the Soviet Union were each discouraged from launching a first-strike nuclear attack against the other because of the ability of the other nation to inflict a major counterstrike that would cause an unacceptable level of damage to the nation that struck first. This ability to withstand a nuclear attack and maintain enough assets to strike back, thereby discouraging the Soviet Union from attempting a first strike, became known as deterrence. In order to provide a credible deterrent, the SAC physically and operationally adopted measures to allow it to function after receiving such an attack. This included burying Titan and Minuteman missile silos and surrounding them with steel-reinforced hardened concrete. Although the SAC maintained a large missile force, it never contemplated discontinuing the use of the crewed bomber because, while a bomber once launched could be recalled, a missile once launched could not be stopped.

Post-Cold War Developments

During the Gulf War, U.S. missiles played a prominent role. Although the Patriot missiles, which became an important defense against Iraqi Scud missiles, received most of the press, much of the strategic air campaign of January and February, 1991, depended on missiles. The Air Force's air-launched cruise missiles (ALCMs) and short-range attack missiles (SRAMs), combined with the Navy's Tomahawk land-attack missiles (ThANs), destroyed the Iraqi command and control networks before the United Nations ground offensive began.

After the collapse of the Warsaw Pact and of the Soviet Union, the U.S. Air Force began to implement a major reorganization. In 1992, most of the SAC was incorporated with most of Tactical Air Command to create the Air Combat Command. This arrangement lasted about one year, when the Air Force's ICBM units were again transferred to Space Command. The end of the Cold War led the United States to scale back its numbers of and reliance on ICBMs, and instead ALCMs became an increasingly important weapon, as shown by their widespread use during the NATO air war with Yugoslavia in 1999. With their increasingly sophisticated guidance systems, which allow targets as small as a square meter to be regularly hit without exposing air crews to danger, guided missiles have become increasingly vital to the United States to carry out military objectives.

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See also: Air Combat Command; Air force, U.S.; Wernher von Braun; Robert H. Goddard; Gulf War; Korean War; Rockets; Strategic Air Command; Tactical Air Command; World War I; World War II; Vietnam War

Billy Mitchell

Date: Born on December 29, 1879, in Nice, France; died on February 19, 1936, in New York, New York

Definition: Commanded the U.S. air effort in World War I and thereafter was an outspoken advocate of air power and of an independent U.S. air force.

Significance: Mitchell lobbied, cajoled, and bullied the U.S. governmental and military power structure to gain recognition of the role of air power in warfare.

William "Billy" Mitchell grew up in Milwaukee, Wisconsin, and in Washington, D.C. The son of a U.S. senator, he was deeply steeped in patriotism and military history. In 1898, at the outbreak of the Spanish-American War, he dropped out of George Washington University to join the U.S. Army and served in the aviation section of the Signal Corps. The armed forces were Mitchell's home and his love for the remainder of his life. Mitchell was an Army representative to a flight demonstration by Orville and Wilbur Wright, and he himself learned to fly in 1915. From 1917 to 1918, he commanded the Army Air Service of the U.S. Expeditionary Forces in Europe and was promoted to brigadier general in 1920.

Mitchell traveled widely, observed other countries' increasing interest in air power, and became a strong proponent for air power and for an independent Air Force. He worked hard to develop strategic doctrines that would utilize air power in the conduct of modern warfare and gathered many supporters. In 1921, the Army and the Navy held a demonstration of air power with a captured German battleship as the target. Mitchell's pilots sank the ship with heavy bombs, disregarding the rules set for the demonstration. Mitchell gained support in Congress but alienated his military colleagues by regularly and publicly criticizing the military's mismanagement of air power. At his 1925 court-martial, personally ordered by President Calvin Coolidge, he was found guilty of insubordination, reduced in rank to colonel, and suspended from active service for five years. Mitchell resigned a few months later and continued speaking out against the military command and for air power. His rank was posthumously restored, and he was decorated for his service.

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See also: Air Force, U.S.; Bombers; Fighter pilots; Military flight; World War I; World War II

Brigadier General Billy Mitchell was one of the earliest advocates of the use of aircraft by the U.S. military. (Library of Congress)

Model airplanes

Definition: Facsimiles ranging in size from a few inches to many feet in length intended to represent actual or imagined airplanes in reduced scale, for display or flying purposes.

Significance: Model airplanes were used, before full-scale airplanes had flown, to investigate the science of flight. Models are also used for aeronautical research and aerial reconnaissance. They provide youth with an aeronautical education, and many pilots have become interested in flying through modeling. Modeling is a passionately followed hobby worldwide, providing pleasure of both building and flying. For those who compete in regional, national, and world contests, flying model airplanes is a highly demanding sport.

Flying models take many forms. They can be unguided after launch and known as free-flight, or FF, models; constrained and controlled by wires and known as control-line, or C/L, models; or controlled remotely by radio signals and known as radio-control, or R/C, models. From an aerodynamics standpoint, models will always suffer from what is known as scale effect, obtaining smaller maximum lift coefficients and greater drag coefficients. However, wing loadings, or weight divided by wing area, are much lower, so landing speeds are much lower than for full-scale aircraft. Modern model engines are sufficiently light and powerful that it is possible to build a model that has more thrust than its weight and can climb straight up or even hover. Structurally, models profit from a different scale effect and are less likely to suffer in-flight or landing damage.

Free-Flight Models

Free-flight, or FF, models can be the least expensive flying models, the easiest to build from raw materials, and the easiest and safest to fly by oneself. However, they are the most demanding of trim and stability because of their "launch-and-pray" nature. The smallest and lightest models can be flown indoors or on very calm mornings or evenings.

Powered models are normally flown outside. They usually utilize a timer-controlled dethermalizer that tips up the leading edge of the horizontal stabilizer to prevent them from being lost if rising air and wind would otherwise take them out of sight. Contests with free-flight models usually involve trying to keep them aloft for the maximum amount of time for each of the different classes of models.

Control-Line Models

Control-line, or C/L, models are the next least expensive flying models and have the additional advantage that they cannot fly out of sight and be lost. They also provide tactile feedback to the flier, because they are flown on steel lines, mostly stranded stainless-steel cables, that range from about 30 feet to about 70 feet in length. The lines are attached to a control handle in the flier's hand that operates the elevator through a bellcrank. Manipulation of this handle grants the flier the option of using a full hemisphere of space, inverted or upright. Control-line flying has a unique dependence on surface winds, because the planes are connected to the ground through the flier. Inverted flight requires extra learning, because response to control handle movements is reversed.

Control-line models include sport/trainers, scale, stunt, carrier, speed, and race types. Scale control-liners feature engine power, retractable gear, "bombs," and other realistic details. Stunt models are optimized for aerobatics and use a symmetrical wing section that enables them to make inverted and upright maneuvers. They often use a flap on the trailing edge of the wing that is mechanically linked to the bellcrank, so that it deflects oppositely to the elevator and enhances the maximum lift available for abrupt maneuvering. Carrier models are judged on the difference between their maximum and minimum speeds and for their ability to grab a wire with their tail hook for landing. Speed models are used in contests, which are won by the fastest speeds, with either piston or jet power, for a specified number of laps. Racer-type models are flown with two or more fliers in the circle, to a specified number of laps and with mandatory pit stops. Combat contests require two fliers in the circle, each trying to cut the opponent's trailing streamer, often flying at speeds of more than 100 miles per hour.

Radio-Control Models

Radio-control, or R/C, models require a battery-powered miniature receiver with a separate channel for each servo. A servo is an electric motor that rotates a shaft one way or the other from the neutral position, based on the movement of a lever in the transmitter held by the flier. The number of channels utilized varies from two or three for trainers to six or more for sophisticated models that are determined to fully emulate their full-scale counterparts.

Radio-control models are the most popular form of model airplane flying, no doubt because of the challenge involved with flying them well and because of their good simulation of full-scale flight. They also require the most time to learn how to fly without crashing. They are the most expensive type of flying model and require the most sophisticated models. However, the best R/C models, both airplanes and helicopters, can perform all the same aerobatic maneuvers, and more, as can their full-scale counterparts.

The most difficult problem to overcome in first learning to fly R/C airplanes is that the airplane apparently responds differently whether it is going away or coming toward the flier. It is also difficult for the beginner to judge the landing approach and landing. In this, computer-based simulators can be of considerable assistance. Competitive R/C events include combat, precision aerobatics, and pylon races.

Power Plants

Gravity was the original power plant for both FF and R/C gliders. Twisted rubber strands were the next power plant, used until the 1930's, when the first miniature spark-ignition engines were commercially produced. In the 1940's, the much simpler and lighter glow-plug engine, which required a battery only for starting, appeared. Diesel and compressed-air engines are used in small models. Jet engines have been available since the 1940's. Electric motor engines are the newest type of power plant, providing quiet and clean power.

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See also: Aerodynamics; Experimental aircraft; Forces of flight; Tail designs; Testing; Wing designs

Monoplanes

Definition: Airplanes possessing only one primary lifting surface.

Significance: Monoplanes are less expensive to build, more efficient in flight, and are capable of higher speeds than two-winged biplanes. After their early structural problems were solved, monoplanes quickly became the favored configuration for transports (in the 1920's) and for light airplanes and fighter aircraft (in the 1930's).

Development

The earliest practical airplanes were biplanes, with low-powered engines and very large wing areas. The braced-wing biplane design was considered the lightest and strongest aircraft configuration, especially for the thin wing sections then thought to be necessary.

The first airplane to cross the English Channel, however, was Louis Blériot's wire-braced monoplane, the Blériot XI, on July 25, 1909, six years after the Wright brothers flew their first biplane at Kitty Hawk, North Carolina. In 1912, the streamlined Deperdussin monoplane established a world speed record of more than 100 miles per hour.

Biplanes continued to predominate during World War I, because their rapid climb to a fighting altitude and their maneuverability for fighting were favored over high speeds. However, a few monoplanes, such as the Fokker Eindecker, the first to have a machine gun synchronized to fire between propeller blades, were used. Early monoplane designers did not appreciate the twisting to which a wing is subjected in flight, and there were a number of structural failures due to the elimination of external bracing to reduce drag.

In 1927, the greater efficiency of the monoplane was decisively demonstrated by Charles A. Lindbergh's New

York-to-Paris flight in his Ryan monoplane, the *Spirit of St. Louis*. In the 1930's, the development of the Douglas DC-1 and DC-2 models, using the modern configuration of a single low wing, a retractable landing gear, streamlined engine cowlings, and flaps for good low-speed performance, instantly made all biplane transports obsolete. A DC-2 carrying passengers nearly won the 1934 London-to-Australia race against specialized racing machines. The military, requiring extra strength and maneuverability from its aircraft, took longer to be convinced of the monoplane's advantages and still maintained a few biplanes at the beginning of World War II in 1939.

The 1937 Piper J-3 Cub, a strut-braced, high-wing monoplane with an inexpensive four-cylinder opposed engine, was far less expensive to produce and fly than were biplanes with much more powerful radial engines. This configuration has dominated the lower end of light-plane flight ever since.

Design

In the traditional monoplane design, a single large wing is followed by a much smaller horizontal surface containing both a stabilizing surface and a pitch-control surface, or elevator. For pitch stability with this configuration, the airplane's center of gravity must be sufficiently forward that the horizontal tail generates a downward force, or negative lift. Pitch stability means that the aircraft will tend to maintain a constant nose attitude relative to the horizon, even when disturbed by atmospheric turbulence. However, a monoplane's wing can be made into a very efficient lifting surface, because it does not compete with another nearby lifting surface, as does a biplane's wing.

Different monoplane designs differ in their relative vertical locations of the wings on the fuselage. If the wing is mounted on top of the fuselage, as in high-wing aircraft, the critical upper surface of the wing is minimally disturbed by airflow around the fuselage. The placement of the primary lifting surface above the center of gravity also enhances lateral stability because of the pendulum effect, in which the airplane tends to return to wings-level flight if it is banked. High-wing aircraft give pilots and passengers a particularly good view of the ground but the upward and sideways views are typically restricted when the aircraft is banked.

The most efficient location for a monoplane's wing, from an aerodynamic standpoint, is considered to be in the middle of the fuselage. In this mid-wing configuration, the interference drag between the wing and the fuselage can be minimized. Therefore, many racing airplanes use this efficient design. The pilot typically must sit close to the center of gravity, about one-quarter or one-third of the way back from the leading edge of the wing to the trailing edge. The pilot's field of view is thus severely restricted, and the pilot's location obstructs any carry-through structure for the wing spar.

The low-wing airplane is favored for most high-speed airplanes, because the wing provides a good place to house retracted gear. To minimize interference drag, both the leading and trailing edges of the wing normally require rather elaborate fairings. To obtain lateral stability, the wing of a low-wing airplane must incorporate more of a dihedral angle, the upward tilt of the wingtips, than that of a high-wing airplane.

In the 1980's, a number of canard-type airplanes, efficient aircraft with a horizontal lifting surface in front of the main wing, were designed for both low- and high-speed flight. The low-speed canard-type aircraft are mainly those linked to Burt Rutan's very successful VariEze and later designs. Canard aircraft with two nearly equal wings, the dragonfly configuration, may be thought of as either two-surface monoplanes or biplanes with a great deal of stagger. High-speed military aircraft often use a canard for extra pitch control at high angles of attack. Propeller-powered canard aircraft normally use pusher propellers, which tend to be less efficient because they operate in the wake of the wing. A few three-surface aircraft, with both a canard surface and a conventional tail surface, have also been designed and flown; they have the advantage of placing the pilot and passengers ahead of the wing.

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rate, and glide rate contests. It also won the speed and efficiency contests at the 1923 National Air Races.

See also: Airplanes; Biplanes; Experimental aircraft; Charles A. Lindbergh; Burt Rutan; *Spirit of St. Louis*; Triplanes; Wing designs; World War I; Wright brothers

Montgolfier brothers

Joseph-Michel Montgolfier

Date: Born on August 26, 1740, in Vidalon-les-Annonay, Ardeche, France; died on June 26, 1810, in Balaruc-les-Bains, France

Jacques-Étienne Montgolfier

Date: Born on January 6, 1745, in Vidalon-les-Annonay, France; died on August 2, 1799, in Serrières, France

Definition: Aviation pioneers who first accomplished successful human flight.

Image Not Available

Significance: The Montgolfier brothers were pioneer developers of the hot-air balloon. Their work opened the way for exploration of the earth's upper atmosphere.

Joseph-Michel and Jacques-Étienne Montgolfier were two of sixteen children born to Pierre Montgolfier and his wife. Pierre's success in the paper industry provided the necessary finances for Joseph-Michel and Jacques-Étienne to obtain good educations and to conduct a variety of scientific experiments. Inspired by wood chips floating over a fire in the family fireplace, the two brothers theorized that when heated air was collected inside of a paper bag, the bag would rise. This discovery led to their invention of the first hot-air balloon in 1782.

On June 5, 1783, the Montgolfier brothers made the first public demonstration of their hot-air balloon at the marketplace in their hometown. The balloon was constructed from multiple sections of cloth and lined with paper that was coated with alum to provide a form of fireproofing. The sections were held together with approximately two thousand buttons. The fuel to heat the air inside the balloon was a mixture of straw and carded wool. Once released, the balloon stayed in the air for ten minutes, reached an altitude of about 6,560 feet, and traveled a distance of more than 1 mile.

On September 19, 1783, the Montgolfier brothers sent the first living creatures, a duck, a sheep, and a rooster, on a balloon flight in Versailles. Watched by King Louis XVI; his wife, Marie Antoinette; and some 130,000 spectators, the balloon stayed aloft for about 8 minutes, reached a height of 1,640 feet, and safely landed 2 miles from the point of departure. This successful exhibition made the Montgolfier brothers national figures, and a gold medal was issued in their honor.

In Paris, on November 21, 1783, the Montgolfier brothers conducted the first untethered human flight. It was manned by Jean-François Pilâtre de Rozier, a science teacher, and Marquis François-Laurent D'Arlandes. The balloon sailed over Paris for about 25 minutes and traveled approximately 7 miles from the launch site.

In later life, Joseph-Michel invented a type of parachute, a calorimeter, and a hydraulic ram and press. In 1807, he was made a knight of the Legion of Honor. Jacques-Étienne developed a process for producing a new type of paper called vellum. Both brothers were honored by the French Academy of Sciences.

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See also: Balloons; Buoyant aircraft; History of human flight; Hot-air balloons; Lighter-than-air craft

N

National Advisory Committee for Aeronautics

Date: From 1915 to 1958

Definition: A U.S. government organization formed to promote the scientific development of aircraft and flight.

Significance: The premier American research facility on aeronautics and rocketry, the National Advisory Committee for Aeronautics maintained U.S. leadership in aircraft development through the mid-twentieth century.

Established in 1915, the National Advisory Committee for Aeronautics (NACA) promoted the scientific advancement of aircraft at a time when U.S. technological prowess in the field was declining. Although the Wright brothers had pioneered powered flight in 1903, both private and government research in aircraft technology declined in the United States over the following decade. Although flight was considered by many Americans to be an impressive technical achievement, many others considered flight an often-dangerous passing fad. Unreliable engines and haphazard construction led to many deaths, and many people believed powered flight to be a science that was ahead of its time. During this period, various European designers emerged as the leaders in aerospace research, and the United States' early lead in aircraft development disappeared.

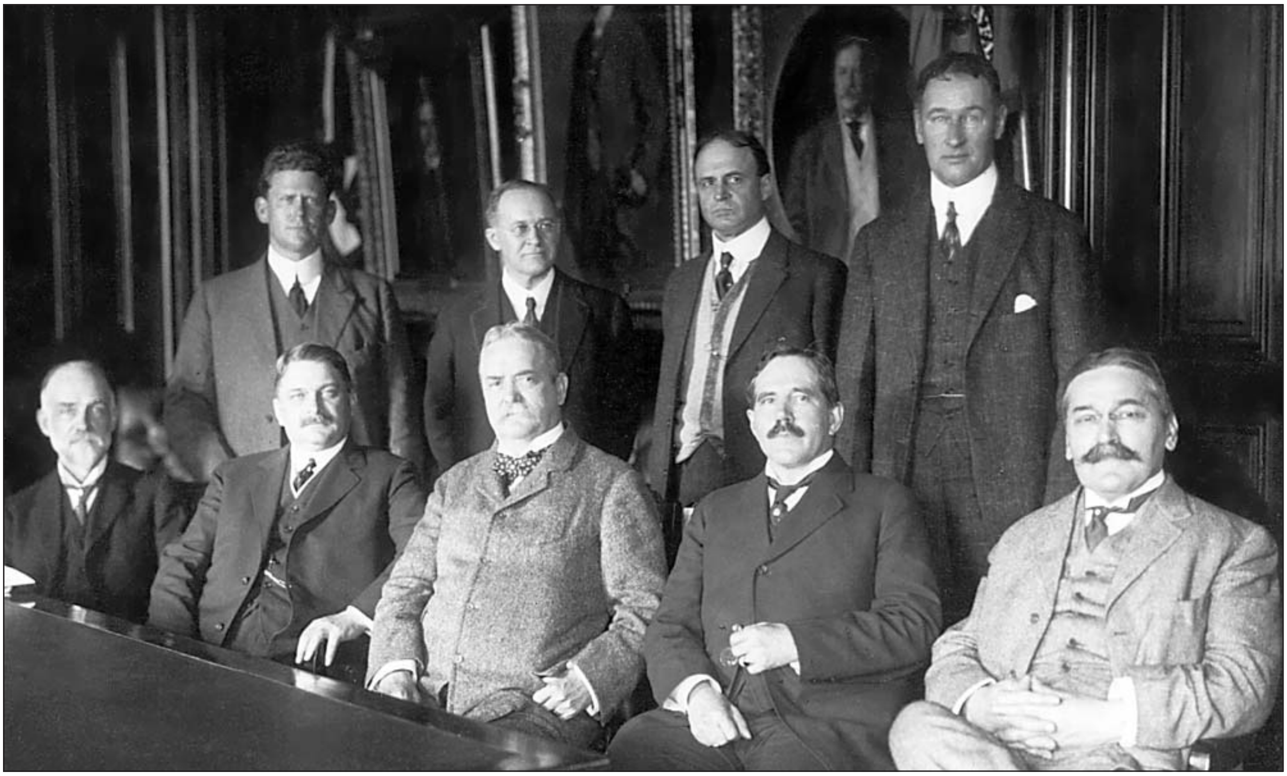
World War I

With the outbreak of World War I in 1914, the U.S. government, pondering the possibility of U.S. involvement in the war, came to the realization that the United States could not produce the advanced aircraft needed to wage modern warfare. Although prewar European and U.S. military planners had considered the use of aircraft merely as observation platforms, as the war progressed, airplanes were used for increasingly important tasks, such as air defense and bombing.

Under pressure to prepare the United States for a possible war, Congress established NACA as a branch of the Smithsonian Institute on March 3, 1915. The administration of President Woodrow Wilson, afraid that American citizens would consider NACA a purely military facility at a time of neutrality, added the proposal for NACA funds as a rider on the annual naval appropriations bill. NACA was originally limited to a $5,000 annual budget and twelve unpaid staffers who directed research projects at the Smithsonian and various university facilities. However, NACA's contributions to wartime research, most notably the development of the ubiquitous JN-4 Jenny aircraft, earned the institution a long-term future as an institution separate from the Smithsonian and the creation of a permanent research facility of its own. Constructed in the middle of swampy ground owned by the U.S. Army north of Norfolk, Virginia, NACA's first facility, the Samuel Langley Memorial Aeronautical Laboratory, known simply as "Langley," opened in 1920. The new laboratory boasted four buildings and a full-time staff of eleven.

The Interwar Years

In the post-World War I era, NACA grew at an extremely slow pace. Postwar disillusionment and pro-neutrality sentiments reduced the amount of military-related research that was conducted at Langley. Also, the low pay associated with government employment relative to that of the private sector, coupled with Langley's remote location, led many engineers to accept jobs elsewhere. Despite its limitations, however, NACA continued to make significant scientific breakthroughs. Although military research lagged, the number of civilian aircraft boomed in the 1920's, due to the large number of surplus military aircraft, interest generated by traveling air shows and wing-walkers, and the exploits of civilian pilots, such as Howard Hughes and Charles A. Lindbergh. Driven by the growth of the civilian aircraft market, NACA made several contributions to aircraft development and technology. For instance, NACA pioneered the use of specially trained test pilots. Although other institutions had used full-time pilots, NACA was the first to employ pilots with backgrounds in engineering to identify problems in the air as well as on the ground. Langley's labs also developed advanced wind tunnels that measured precise aircraft takeoff and landing speeds. By 1931, Langley boasted the largest wind tunnel in the United States, capable of conducting tests on full-sized aircraft instead of scale models. NACA's



The first meeting of the National Advisory Committee for Aeronautics on April 23, 1915. The committee promoted scientific advancement in aircraft from World War I until the onset of the space age in 1958. (NASA)

wind tunnels proved particularly valuable in the development of early airliners, planes too large for their manufacturers to test themselves. These aircraft, the Boeing 247 and Douglas DC-1, pioneered civilian air travel before World War II, and the development of these two planes formed the backbone of commercial air travel after the war.

NACA also developed an innovative aerodynamic engine cowl that greatly reduced drag on the early piston-powered aircraft. In the 1920's and 1930's, the biggest goal of aircraft designers was speed, and European aircraft designers opted for complex liquid-cooled engines to boost top speed. The NACA cowl, however, boosted speed by reducing drag, permitting U.S. manufacturers to use less complex and less expensive air-cooled engines. Although NACA grew slowly during the 1920's and 1930's, the organization's contributions during this period ensured its long-term future and greatly aided the U.S. war effort in World War II.

World War II

If World War I had provided the motivation for the creation of NACA, World War II proved the value of its research facilities. As it had in World War I, the United States began World War II with aircraft that were less capable than those of its enemies. NACA faced the task of improving the United States' air arm as quickly as possible. Toward this end, NACA expanded its presence and roles to aid the war effort. In addition to new facilities at Langley, NACA constructed new specialized laboratories in other parts of the country. In 1939, NACA opened a laboratory at the U.S. Army Air Corps base at Moffett Field, south of San Francisco, California. NACA's Moffett Field facility tapped into the pool of skilled engineers on the West Coast and was situated close to the region's developing aircraft industry. In 1940, the West Coast lab was renamed the Ames Aeronautical Research Laboratory in honor of NACA's long-time director. In the same year, NACA opened a propulsion research lab in Cleveland, Ohio, to support research in engine development in conjunction with the major engine manufacturers in the Midwest. In 1948, the Cleveland facility became the Lewis Flight Propulsion Laboratory.

The new laboratory and propulsion laboratories proved their worth by improving upon the new aircraft types introduced during the war. NACA wind tunnels allowed for improvements to new fighters, such as the P-38 Lightning, by solving serious dive-instability problems and boosted the speed of the P-51 Mustang by introducing a laminar flow airfoil that moved air over the wing at peak efficiency. NACA's participation in the development of Boeing's B-29 bomber, particularly in aerodynamic and wing-loading issues, helped to expedite an advanced aircraft design into an effective weapon in only three years. During the war, NACA laboratories improved the performance of eighteen different warplanes, stretching speed, bomb load, and endurance beyond the capability of their original designs.

NACA also branched into the field of rocketry during World War II. Although earlier rocket pioneers such as Robert H. Goddard conducted research on their own, the widespread use of rockets during the war attracted NACA attention, both in the development of its own rocket designs and in the improvement of Army and Navy projects. Although NACA concentrated on the military applications of rockets, as bombardment weapons or air-to-air ordnance, late in the war, the agency began research in ballistic missiles that paved the way for future work.

Postwar Contributions

Deserving of praise for its wartime contributions, NACA received some undeserved criticism when the United States turned to jet propulsion in the mid-1940's. NACA conducted initial research on jet engines in the mid-1930's, but found that contemporary manufacturing methods made the technology unfeasible. By World War II, however, British breakthroughs had made the jet a viable means of propulsion, and the British shared their innovation with their American allies. Instead of allowing NACA to develop the new engines, however, the U.S. Army gave General Electric, a private corporation, the development rights. Bell Aircraft received a contract to develop an airframe for the new jet engine, an airplane that eventually emerged as the XP-59. Bell, however, lacked NACA's research capability, and the XP-59 could not match the performance of its European rivals, the British Gloster Meteor and German Me-262 aircraft. Because NACA had had a hand in the development of so many of U.S. wartime aircraft, many Army and aviation observers incorrectly believed that NACA had developed the XP-59 and had failed in the task. However, NACA knew nothing about the XP-59 until 1943, a full year after the aircraft's first test flight.

Once involved in jet aircraft development, NACA's facilities proved invaluable in integrating captured German data into the U.S. Air Force's growing arsenal of jet warplanes. NACA wind tunnels provided aerodynamic data on swept-wing configurations that resulted in the advanced F-86 Sabre, the premier U.S. fighter of the Korean War. NACA's wind tunnels also suggested solutions to the problem of shock waves that formed on wingtips near speeds of Mach 1, the mythical sound barrier. Using the ballistic data of a .50-caliber machine gun bullet, NACA collaborated with Bell Aircraft to build the X-1, the first in a series of legendary experimental aircraft. On October 14, 1947, test pilot Charles E. "Chuck" Yeager took the X-1 beyond Mach 1 and became the first pilot to break the sound barrier.

As aircraft broke the sound barrier with increasing frequency throughout the 1950's, another problem, known as transonic drag, surfaced. Because subsonic aircraft shapes were inappropriate for supersonic flight, jet aircraft of the 1950's continually failed to meet speed and altitude expectations in supersonic flight. NACA's solution to transonic drag was to create a design element known as area ruling. Transonic drag occurred at the wings, where the mass of the airplane, the fuselage plus the wings, suddenly increased, and the air simply could not move out of the way quickly enough. Because airplane designers could not dispense with the craft's wings, they had to make the fuselage thinner. On aircraft designed with area ruling, the fuselage narrowed as the wings spread, resulting in an airplane with an hourglass or Coca-Cola-bottle shape. With this innovation, aircraft speeds continued to rise, and engineers could predict aircraft performance beyond the sound barrier.

NACA's early forays into rocketry beginning in World War II increased throughout the late 1940's and early 1950's. The United States acquired advanced rocket technology, along with jet propulsion, from the defeated Nazis, and began a series of rocket testing by several different agencies. The U.S. Army, having secured the services of the top German rocket scientist, Wernher von Braun, began rocket testing at the Redstone Arsenal in Alabama. At the same time, the U.S. Navy and the U.S. Air Force began their own rocket programs with the intent of developing nuclear delivery systems. In addition, the Smithsonian and the National Academy of Sciences developed rockets for scientific research.

NACA contributed to these military projects primarily by testing internal systems and lightweight materials. NACA's role in the U.S. rocket program became preeminent, however, after October 4, 1957, when the Soviet Union launched Sputnik 1, the first human-made Earth-orbiting satellite. Although Sputnik was a minor technical achievement, its launch created widespread public fears of Soviet atomic bombs raining down upon American cities from orbit, and the U.S. government demanded a response from its own rocket programs. The U.S. response to Sputnik, the first launch of the Navy's Vanguard rocket, embarrassingly exploded on the launch pad on December 6, 1957. One month later, a smaller Army rocket known as Explorer 1 finally put a small satellite into orbit.

The public demand for a response to Sputnik, coupled with the inefficient system of multiple rocket programs, generated the idea of a single space agency, which NACA, as a civilian agency with advanced research labs, was in the best position to lead. Many Americans, particularly in Congress, worried that a military-led project would create only rockets for military use. Congress also blamed the various military rocket projects for allowing the Soviets to take the lead in rocket technology. Therefore, on July 29, 1958, President Dwight D. Eisenhower signed the National Aeronautics and Space Act into law. The law merged NACA with the various military rocket programs, scientific rocket projects, and several other government laboratories into a new entity to run the U.S. space program. On October 1, 1958, the newly amalgamated institutions became the National Aeronautics and Space Administration (NASA).

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See also: Air shows; Crewed spaceflight; Experimental aircraft; Howard Hughes; Jet engines; Samuel Pierpont Langley; Charles A. Lindbergh; Military flight; National Aeronautics and Space Administration; Rockets; Sound barrier; Spaceflight; Sputnik; Supersonic aircraft; Test pilots; Uncrewed spaceflight; Wind tunnels; Wing-walking; World War I; World War II; X planes; Chuck Yeager

National Aeronautics and Space Administration

Date: Established on October 1, 1958

Definition: The civilian space agency and aeronautical research agency for the United States of America.

Significance: The National Aeronautics and Space Administration oversees all U.S. civilian space exploration activities and coordinates the U.S. involvement in international space coventures. It also is the primary U.S. agency for civilian government research in aeronautics.

Origins

The idea of a central agency for aeronautical research in the United States dates back to 1915, when an amendment to another bill created the National Advisory Committee for Aeronautics (NACA) to help the United States catch up with European countries in aeronautical research. NACA was primarily involved in aircraft design and testing. An aeronautical research center, later to be named the Langley Aeronautical Laboratory, was founded with NACA. In the years leading to World War II, additional aeronautical facilities were constructed at Moffett Field in California (later named the Ames Research Center) and at Lewis Field in Cleveland, Ohio. Rockets and space travel were of little interest to NACA until the 1950's. During the 1930's, however, rocketry experiments were being conducted at the Guggenheim Aeronautical Laboratory at the California Institute of Technology (GALCIT). During World War II, GALCIT became the Jet Propulsion Laboratory (JPL) and was under Army control. Besides developing missiles for the Army, such as the WAC Corporal, JPL also developed the Aerobee, a version of the WAC Corporal designed for civilian high-altitude research activities. After the war, the U.S. Army also created a separate missile unit, which eventually became the U.S. Army Ballistic Missile Agency (ABMA), near Huntsville, Alabama. During the early 1950's, the Navy and the Air Force began their own missile programs.

Each of the separate missile and rocket programs eventually began to develop rocket boosters with a goal of launching satellites into orbit around the earth. By the mid-1950's, the Air Force and the Army were both looking at possible lunar space probes, and JPL was considering the possibility of interplanetary space probes. The Air Force was also investigating rocket-propelled aircraft, an area of research that overlapped with NACA's mission. At this time, there was no central unified agency overseeing rocket development or space exploration. Multiple agencies, and even separate departments within each agency were working independently of one another, often duplicating efforts and competing with one another for resources. Possibly as a result of the fragmented approach to space exploration and rocket development, the United States appeared to lag slightly behind the Soviet Union in these areas during the 1950's. The Soviet Union's rocket development and space exploration activities were coordinated under one authority, largely working under the leadership of Sergei Korolev. A working group, called the Upper Atmospheric Rocket Research Panel (UARRP), consisting of representatives from the different U.S. agencies involved in space exploration, including NACA, was formed in the mid-1950's to address some of these concerns. In January, 1956, UARRP issued a report suggesting that all U.S. space-related activities be centralized in one agency. A later report suggested that civilian space exploration be formed into an agency separate from Department of Defense space activities.

Little real progress had been made in consolidating U.S. space efforts until the Soviet Union launched Sputnik 1 on October 4, 1957, and Sputnik 2 on November 3, 1957, with Sputnik 2 carrying a dog into space. The United States tried to respond with the Navy's Vanguard rockets, but the early Vanguards failed to launch a satellite. Finally, on January 31, 1958, the Army succeeded in launching Explorer 1, built by JPL, atop a modified intercontinental ballistic missile (ICBM) built by ABMA. The U.S. government finally began to take seriously the need for a unified effort at space exploration. On July 29, 1958, President Dwight D. Eisenhower signed into law the National Aeronautics and Space Act of 1958. This act dissolved NACA and created the National Aeronautics and Space Administration (NASA), effective October 1, 1958. NASA was responsible not only for aeronautical research, as NACA had been, but would also be the U.S. civilian space agency. NASA acquired all NACA facilities, including the Langley Research Center, the Lewis Research Center, and the Ames Research Center, along with two flight stations. On December 3, 1958, JPL was transferred to NASA. Much of ABMA was also transferred to NASA, becoming the Marshall Space Flight Center on July 1, 1960. Since that time, NASA has built numerous research centers and other stations throughout the country. Though space exploration gets most of the public attention, NASA has always remained active in aeronautical research, with several research centers devoted primarily to non-space-related activities.

Early Crewed Spaceflight

One of NASA's early goals was to launch a person into space. This goal was formally stated on October 7, 1958, shortly after NASA's formation. The first U.S. crewed spacecraft project was named Mercury. Prior to the Mercury project, two competing ideas for crewed spaceflight had existed. Wernher von Braun and many others believed that a crewed spacecraft should take off like an aircraft, fly into space, and land again like an aircraft. Such a spacecraft would be fully reusable, and would be an extension of well-proven flight technology. Preliminary work toward such a space plane had already begun. Like the Soviet Union's Korolev, many of the engineers in NASA were not willing to wait for the development of a safe and reliable space plane. Rather, they wanted to use modified ICBMs to launch a crewed capsule into space. Such an approach would yield results much faster. NASA engineers realized that the Soviet Union would likely beat the United States in sending a human into space if the United States were to wait to develop a method of flying a space plane into orbit. Thus the Mercury project aimed to launch a small capsule containing a human being atop a modified ICBM. Researchers at Ames showed that a nuclear warhead could safely survive reentry into the atmosphere with a blunted body. The Mercury capsule, therefore, would be shaped with a blunted bottom and use an ablative heat shield to prevent the capsule from burning up due to friction as it reentered Earth's atmosphere at the high speeds required for Earth orbit. Such a craft could not land as an aircraft, so it deployed a parachute and floated down to a landing in the ocean, called a splashdown. The first launch of a Mercury capsule was an uncrewed test flight on September 9, 1959. The first crewed launch was May 5, 1961, when Alan B. Shepard was launched into space atop a modified Redstone rocket. The Redstone, however, was not powerful enough to put the Mercury capsule into orbit. Rather, Shepard's flight, lasting only about fifteen minutes, was merely a suborbital ballistic trajectory. The first U.S. crewed spaceflight took place on February 20, 1962, when a modified Atlas missile carried a Mercury capsule containing John H. Glenn into orbit. The United States, however, did not beat the Soviet Union into space, for a modified ICBM had carried Yuri Gagarin into orbit around the Earth in a Vostok capsule on April 12, 1961.

With the Soviet Union beating the United States in sending a human into space, President John F. Kennedy consulted his science advisors for a goal that the United States might hope to accomplish ahead of the Soviet Union. That goal was for a U.S. crewed mission to the Moon within a decade. President Kennedy made this goal public in a speech on May 25, 1961, even before the United States had put a human into orbit. NASA had to scramble to accomplish this goal. The crewed lunar mission, called the Apollo Program, was born in November 1961. In order to launch a spacecraft to the Moon, NASA had to create the largest rocket ever known, eventually dubbed the Saturn V. Realizing that it would take a rocket bigger than they could build to launch a spacecraft to the Moon's surface and back, they opted to launch a spacecraft into orbit around the Moon. Astronauts would then descend to the lunar surface in a small landing craft, and then ascend to rendezvous with the orbiting spacecraft, which would carry them back to Earth. Such a mission would involve extended missions in space, and spacecraft rendezvous. None of this was at that time possible. Thus, as work progressed on the Apollo missions, NASA created the Gemini Program to develop the skills and test the procedures needed in the upcoming Apollo missions. The Gemini Program ran from December 7, 1961, until December 23, 1966, with the first crewed flight on March 23, 1965. While the Mercury capsules held just one astronaut, the Gemini capsules each had a crew of two astronauts. The first crewed Apollo spaceflight was Apollo 7, launched October 11, 1968. Apollo 7 was an Earth orbital test flight. The first lunar landing mission was Apollo 11, launched July 16, 1969, crewed by Edwin "Buzz" Aldrin and Neil Armstrong, both of whom walked on the surface of the Moon, and by Michael Collins, who piloted the command module that orbited the Moon during the landing mission. The last lunar mission was Apollo 17, launched December 7, 1972.

Crewed Spaceflight After the Moon

The last three scheduled Apollo missions to the Moon were cancelled. The hardware for these missions, however, was not wasted. The third stage of a Saturn V rocket was adapted to be used as a crewed space station called Skylab, launched May 14, 1973. Three Apollo capsules were used to ferry astronauts to and from Skylab from May 25, 1973, to February 8, 1974. Left in low-Earth orbit, Skylab eventually reentered the Earth's atmosphere and burned up on July 11, 1979, with some solid pieces striking the Indian Ocean and Australia.

The final Apollo mission was the Apollo-Soyuz Test Project. This program was a rendezvous mission between the U.S. Apollo spacecraft and a Soyuz spacecraft from the Soviet Union during July, 1975. This rendezvous mission was primarily a political mission, designed to show good will between the two superpowers. It was, however, one of the first space missions involving more than one nation. This project eventually became a model for later international space coventures.

One of the major drawbacks of the spacecraft used in the early days of the U.S. space program was that they could only be used one time. By the 1970's, the United States was no longer in a space race with the Soviet Union, so NASA took the time to investigate a reusable spacecraft, much as had been envisioned in the earliest days of space exploration. A compromise vehicle was eventually developed that would take off as a rocket, with strap-on solid rocket boosters and a discardable external fuel tank. The spacecraft would land, however, as a glider. Designed to transport satellites and equipment into orbit and to carry astronauts and equipment to a permanent space station, this partially reusable spacecraft was called the space shuttle. The first operational flight of a space shuttle was on April 12, 1981. The worst accident in NASA's history involved the explosion that destroyed the space shuttle *Challenger* on January 28, 1986, seventy-three seconds after launching, when the shuttle's external fuel tank ruptured after being penetrated by a plume of gas escaping from a failed solid-rocket joint seal. On July 27, 1995, the space shuttle *Atlantis* launched to rendezvous with the Russian space station Mir to exchange crew. Over the next three years, there were several more missions to Mir, fulfilling some of the hopes of the Apollo-Soyuz Test Project.

Beginning in 1998, the first elements of the International Space Station (ISS) were launched. This space station was a scaled-down version of the proposed space station Freedom authorized by President Ronald Reagan in 1985. The space shuttle is scheduled to have many dozens of flights through the 2000's, constructing the ISS and transporting crew and equipment to the station. The space shuttle missions to Mir and the ISS finally fulfill some of the original design plans of the space shuttle project.

Uncrewed Space Exploration

In addition to crewed spaceflight, NASA is responsible for most U.S. uncrewed space flights. Some of these missions, such as the Ranger Moon probes (1961-1965) and the Surveyor Moon landers (1966-1968) were precursors to crewed missions. Others, such as the Explorer series, which began as an Army project but was transferred to NASA after its formation, were scientific missions designed to study the Sun, Earth, and space environments. NASA has been a leader in interplanetary explorations, with spacecraft in the Mariner series that visited Mercury, Venus, and Mars. The Pioneer series of spacecraft were designed as small interplanetary spacecraft. Some were lunar flyby missions, others were placed into solar orbit to study the solar wind, several of which remained in operation for over thirty years. Pioneer 10 and Pioneer 11, launched in the early 1970's, were the first spacecraft to fly past Jupiter and achieve escape velocity to leave the solar system. They were joined by the two Voyager spacecraft as the only four spacecraft ever launched from Earth to leave the solar system. Voyager 1, launched September 5, 1977, flew past Jupiter and Saturn. Voyager 2, though launched on August 20, 1977, before Voyager 1, arrived at Jupiter and Saturn after Voyager 1 and continued on to pass Uranus in January, 1986, and Neptune in August, 1989. NASA launched the Galileo spacecraft to Jupiter on October 18, 1989, and the Cassini spacecraft to Saturn on October 15, 1997. On August 20 and September 9, 1975, NASA launched two Viking spacecraft to the planet Mars, both of which achieved the first successful surface landing missions on Mars. Starting on December 4, 1996, with the launch of the Pathfinder mission, NASA began a decade-long series of missions to study Mars. In addition to interplanetary missions, NASA has launched many astronomical satellites into orbit around Earth to study the universe. These satellites contained telescopes of various types to study the entire range of the electromagnetic spectrum. The most famous of these orbiting observatories is the Hubble Space Telescope, deployed from the space shuttle in April, 1990.

Aeronautical Research

When NASA was formed in 1958, it absorbed NACA, and was charged with not only space exploration but also aeronautics. Though most public attention, and much of NASA's budget, is directed toward space exploration activities, a major portion of NASA's activity has involved aeronautical research. Upon its formation, NASA inherited the Air Force X-15 project. The first X-15 rocket plane flew in 1959 as a NASA aircraft. X-15 flights continued until 1968. Other aeronautical research involved lifting-body aircraft designs, such as the X-24, the HL-10, and the M-2 aircraft of the 1950's. Such aircraft use the shape of the aircraft rather than wings to provide lift.

In 1975, NASA began the Aircraft Energy Efficiency Program, designed to increase flight efficiency and develop less-polluting aircraft engines. The new engine designs from this program were incorporated in Boeing's 767 and McDonnell Douglas's MD-80 commercial aircraft. Additional designs showed that wingtip winglets also increase efficiency, and many aircraft designed from the 1980's and later have included these winglets.

In addition to efficiency, NASA has also promoted aircraft safety. NASA conducts crash tests to design safety systems that maximize the likelihood of survival during an aircraft crash. NASA also works to develop improved guidance systems for both commercial and private aircraft. During the 1990's, NASA undertook a study at major commercial airports to determine the optimal spacing between arriving and departing aircraft. The Lewis Research Center has had a long history of studying icing on aircraft and ways of dealing with this problem, dating back to NACA days. During the 1970's, NASA developed fly-by-wire technology, whereby aircraft control could be done electronically rather than using mechanical means.

NASA has not limited itself to fixed-wing aircraft. The Ames facility oversees NASA's helicopter research. Ames was also the lead site for the XV-15, an experimental aircraft with tilting rotors designed as a hybrid between helicopters and traditional fixed-wing aircraft.

NASA also operates research aircraft designed to carry infrared and radar instruments to study the ground under the aircraft's flight path. Additional science aircraft include the Kuiper Airborne Observatory that flew from 1977 to 1995. The Kuiper was a modified C-141 aircraft carrying a 36-inch-diameter infrared telescope high above much of Earth's atmosphere anywhere it was needed in the world. The Kuiper is to be replaced with another airborne observatory called the Stratospheric Observatory for Infrared Astronomy (SOFIA), expected to begin operations in 2002. The SOFIA is a modified Boeing 747SP designed to carry a 2.5-meter reflecting telescope into the lower stratosphere. Unlike the Kuiper, which was entirely a NASA project, the SOFIA is to be jointly operated with the Deutschen Zentrum für Luft- und Raumfahrt (DLR), the German equivalent to NASA. SOFIA, like Kuiper before it, is operated out of NASA's Ames facility.

NASA Centers

Due to the complex and varied nature of NASA's mission, the agency has many research and operations centers, each with its own specialty. NASA headquarters in Washington, D.C., handles administrative duties. The Kennedy Space Center on Cape Canaveral, Florida, is NASA's primary launch facility, supported by the White Sands Test Facility at Las Cruces, New Mexico, and the Wallops Flight Facility on Wallops Island, Virginia. The Jet Propulsion Laboratory in Pasadena, California, is NASA's primary center for interplanetary spacecraft development and operations. The Johnson Space Center in Houston, Texas, coordinates all crewed spaceflight activities. The Goddard Space Flight Center in Greenbelt, Maryland, handles most Earth-orbiting satellites and oversees much of NASA's astronomical studies. Aeronautical research is performed at the NASA Ames Research Center (at Moffett Field, California), the Dryden Flight Research Center (at Edwards Air Force Base, California), Langley Research Center (at Hampton, Virginia), and the Glenn Research Center (at Lewis Field, Cleveland, Ohio). Ames is also the headquarters for NASA's astrobiology program, and Dryden supports space shuttle landings if the shuttle cannot land at Kennedy due to weather. The Marshall Space Flight Center (at Huntsville, Alabama) and the Stennis Space Center (in southern Mississippi) are the primary centers for rocket research and development.

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See also: Air Force, U.S.; Apollo Program; Neil Armstrong; Astronauts and cosmonauts; Crewed spaceflight; Gemini Program; John Glenn; Jet Propulsion Laboratory; Johnson Space Center; Mercury project; Military flight; Missiles; National Committee for Aeronautics; Orbiting; Rockets; Rocket propulsion; Satellites; Alan Shephard; Spaceflight; Uncrewed spaceflight; Uninhabited aerial vehicles; X planes

National Transportation Safety Board

Date: Created April 1, 1967

Definition: Independent U.S. agency responsible for the investigation of civil aviation, railroad, highway, marine, and pipeline accidents within the United States and for the issuing of safety recommendations designed to prevent future accidents.

Significance: The National Transportation Safety Board provides independent crash-site analysis and offers recommendations for improving the safety of all forms of transportation.

History

The National Transportation Safety Board (NTSB) was established by Congress in 1967 to investigate the causes of all transportation-related accidents involving aviation, railroads, highways, marine craft, or pipelines. Although the NTSB's funding appropriations came from the Department of Transportation (DOT), the NTSB functioned independently of the DOT. In 1975, Congress passed the Independent Safety Board Act, which formally severed all ties between the NTSB and DOT.

NTSB investigators operate twenty-four hours a day, seven days a week, investigating accidents within the United States as well as accidents involving U.S. crafts overseas. Once NTSB teams reach the crash site, they evaluate the evidence to determine the probable cause of the accident and issue safety recommendations to prevent a recurrence.

Since opening its doors in 1967, the NTSB has investigated more than 110,000 aviation accidents. Although the NTSB does not have the regulatory power to enforce its recommendations, approximately 82 percent of its 11,000 safety recommendations have been implemented by the Federal Aviation Adminstration (FAA).

Recommendations

The NTSB is responsible for investigating all civil aviation accidents in the United States. The number of civilian takeoffs and landings exceeded 63 million in 1997, and the number of passengers flying rose from 580 million in 1995 to 630 million in 1997. The safety of these commercial flights rests with the NTSB, which focuses on specific problems, such as operations, cabin safety, weather, and aircraft design, when issuing its recommendations for improved safety.

One of the principal recommendations in the area of operations involves the addition of ground proximity warning systems (GPWS) for aircraft equipped with ten or more seats. The recommendation was issued after an Eastern Air Lines Lockheed L-1011 crashed into the Florida Everglades on December 29, 1972 and a TWA Boeing 727 crashed into a mountain on its approach to Washington Dulles International Airport in Virginia on December 1, 1974. One hundred ninety-one people died in these two crashes, and, after thorough investigations of each, the NTSB determined that the cause of both accidents was "controlled flight into terrain," which could have been prevented if the aircraft had been equipped with warning systems. In 1975, the FAA implemented the NTSB recommendation that all large passenger aircraft be equipped with ground proximity warning systems that alert the crew if terrain is approaching, if the plane is descending too quickly, and if the landing gear is not functioning properly. In 1994, the original recommendation was expanded to include smaller aircraft capable of carrying as few as ten passengers.

A second area of concern for the NTSB involves fire safety. On several occasions, fires that started in aircraft lavatories or cargo areas have resulted in fatalities. In July, 1973, the NTSB recommended that airplanes be equipped with smoke detectors after a Boeing 707 crashed near Paris, France, after a fire started on board. After several more incidents, the NTSB recommended, and the FAA mandated, that automatic-discharge fire extinguishers be installed in all aircraft trash receptacles. Airline attendants are also required to routinely check the containers. After a fatal fire occurred on board an Air Canada flight that was forced to land at Cincinnati, the NTSB recommended that all lavatories be equipped with smoke alarms, that floor-level lighting be installed for passenger safety during an emergency evacuation, and that fire-blocking materials be used in all cabin and seat material. In addition, the NTSB recommended that all emergency slides be equipped with a heat-resistant coating to prevent injury to passengers during a postcrash evacuation. In 1981, after a fatal fire on board a Lockheed L-1011 out of Riyadh, Saudi Arabia, the NTSB issued a recommendation for aircraft modifications aimed at preventing the spread of fires from cargo areas to the cabin. Additional restrictions on the containment of cargo fires followed the crash of a South African Airways Boeing 747 that crashed into the Indian Ocean with the loss of all 160 people on board.

The most serious weather-related problem addressed by the NTSB involves wind shear. The first instance of NTSB involvement with the weather phenomena occurred in 1968, and since that time, the NTSB has issued more than sixty safety recommendations. The most serious crash involving wind shear occurred at Dallas-Fort Worth International Airport on August 2, 1986, when a Delta Air Lines Lockheed L-1011 crashed, killing 135 people on board. Investigators examined the data and suggested the need for additional pilot training specifically geared toward this type of weather condition and for the installation of low-level wind shear alert systems at all major airports. As a result, the terminal Doppler weather radar (TDWR) warns pilots and air traffic controllers allowing them to prevent possible disasters. Since 1985, only one wind shear-related accident has occurred, at Charlotte, North Carolina, where the TDWR system was not yet operational.

Another potential weather-related issue that the NTSB has investigated deals with icing. The accumulation of ice on airplanes has been a problem since the early days of aviation, but it was not until the crash of a USAir Fokker F-28 at New York's LaGuardia International Airport in 1976 that the NTSB issued specific recommendations concerning the measurement and forecasting of icing on airplanes and protection against it. The FAA implemented these recommendations. In 1994, the NTSB issued additional warnings about icing problems on the ATR-72 passenger planes, and the FAA ordered the modification of deicing systems the following year.

As the number of aircraft operating in limited airspace multiplied, midair collisions began to increase. As early as 1967, the NTSB advocated the development of a system designed to prevent such accidents. The proposed technology would be separate from the air traffic control system and would offer the earliest possible warning of a potential crash. In 1993, the FAA ordered that all aircraft used for transport be equipped with traffic alert and collision avoidance systems (TCAS). Mode C transponders, located near major airports, analyze the altitude of airplanes equipped with the device and alert air traffic controllers, who then warn the airplanes before a disaster occurs. Since the implementation of this recommendation, the number of near-midair collisions has dramatically decreased.

When evaluating the causes of crashes, the NTSB examines aircraft design and has revealed several areas where modifications were necessary. While investigating a crash that occurred when an American Airlines DC-10 attempted to take off from Dallas-Fort Worth International Airport on May 21, 1988, the NTSB discovered that the minimum specifications for the brake friction material were inadequate for a rejected takeoff that required more than twice the minimum amount of material to stop safely. As a result, the FAA increased the safety standard and ordered additional training for pilots to improve passenger safety during aborted takeoffs.

Another area of concern involves the length of airport runways. The FAA requires a 1,000-foot safety area at the end of runways for emergencies. Newer airports have allowed for plenty of room, but older airports frequently have sharp drops in terrain at the ends of runways. A 1994 crash at LaGuardia International Airport prompted investigators to recommend the use of soft-ground arresting systems to slow airplanes down in the event of an emergency. Arrestor-beds have prevented accidents at many airports, including John F. Kennedy International Airport in New York.

Always cognizant of the possibility of human error, the NTSB has advocated several changes that would improve the safety of passengers. One recommendation included cross-referencing pilots' licenses with the National Driver Register (NDR) to check for alcohol-related violations that could indicate a potential problem that would adversely affect a pilot's performance during flights. Since the late 1980's, the NTSB has also recommended random drug screening. Another area of particular concern involves the interaction of crew members. The NTSB found that on numerous occasions, because the pilot remains the final authority in the cockpit, other crew members were hesitant to warn the pilot of potential problems for fear of reprimand. On December 28, 1978, a United Air Lines DC-8 ran out of fuel and crashed on approach to Portland, Oregon, killing ten people, because the first officer had failed to communicate the problem to the pilot. The NTSB found that improved crew management would reduce potential fatalities, and the FAA ordered a crew management training program for all major airlines.

Aircraft design flaws account for many fatalities, and the NTSB has issued numerous recommendations based on their investigations of accidents caused by such flaws. In 1991, the NTSB examined the wreckage of an Atlantic Southeast Airlines EMB-120 that crashed in Georgia and found that excessive wear on the propeller-control unit had rendered the aircraft uncontrollable. After the NTSB issued its report, the FAA required the installation of a fail-safe device that prevents propellers from rotating too far. In its investigation of another crash in Georgia in 1995, the NTSB found that a small crack had developed in the aircraft's propeller, resulting from the improper installation of a propeller blade. As a result of this investigation, the NTSB advocated the use of ultrasonic inspection techniques to detect future problems. After the crash of a Turkish Airlines DC-10 near Paris, France, in 1974, the NTSB suggested the use of blowout pressure-relief doors to prevent a recurrence of an explosion that would buckle the cabin floor and damage flight controls. In 1989, the NTSB investigated a similar incident. On February 24 of that year, a United Air Lines Boeing 747 took off from Honolulu, Hawaii, bound for New Zealand. During the airplane's ascent, the lower cargo door flew off, but the modifications implemented as the result of the Turkish Airlines crash saved the 355 lives on board.

In addition to accidents caused by faulty airline design, the NTSB also investigates accidents involving structural fatigue and corrosion. On April 28, 1988, the NTSB investigated the structural failure of an Aloha Airlines Boeing 737-200 that lost a portion of its fuselage during takeoff from Hilo, Hawaii. The force of decompression during the accident resulted in one flight attendant being sucked out of the plane. After examining the aircraft, the NTSB recommended numerous changes in the structure and design of similar aircraft.

The NTSB offers additional recommendations in numerous areas, including the improved quality of off-wing escape slides, fuel-tank protection, and safety belts. In addition to airplane safety, the board is also interested in the safety of helicopters and investigates problems involving the in-flight loss of the main rotor control and the need for flight restrictions during adverse weather conditions. More recently, the NTSB has worked with the National Aeronautics and Space Administration (NASA) to determine the survivability of space orbiters. The NTSB was involved in the investigation of the 1986 space shuttle *Challenger* explosion. NTSB investigators also located a flaw in a crashed Titan 34D military launch vehicle, enabling the problem to be addressed before another accident occurred.

Over the past four decades, the National Transportation Safety Board has gained a reputation for its fair and impartial analysis of crash sites. The recommendations made by the board have been implemented with a high degree of success. Many lives have been saved, and the board continues to improve the safety conditions on commercial aircraft, earning the confidence of the traveling public. With only four hundred employees, the agency provides an invaluable service.

Cynthia Clark Northrup

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See also: Accident investigation; Airline industry, U.S.; Emergency procedures; Federal Aviation Administration; Midair collisions; National Aeronautics and Space Administration; Runway collisions; Safety issues; Space shuttle

Navy pilots, U.S.

Date: Beginning in 1910

Definition: Aviators who are part of the United States Navy, who fly combat as well as search and rescue missions around the world.

Significance: The addition of aviation into the United States Navy provides greater flexibility and an extension of air power globally.

U.S. Naval Test Pilot School

At the end of World War II, aviation entered a period of rapid change. The development of new technology required extensive evaluation of experimental aircraft involving test flights. Although Navy pilots participated in the testing process, the military offered no formal training program. In 1945, Commander Thomas F. Connolly, assistant flight test officer at the Naval Air Station at Patuxent River, Maryland, and Commander Sydney Sherby, his chief project engineer, recognized the need for additional pilot training and recommended a curriculum. Navy pilots would receive instruction in aerodynamics, procedures for aircraft performance testing, evaluation of aircraft stability and control characteristics, miscellaneous tests and trials, actual in-flight performance testing, and standardized flight test reporting during thirty-seven hours of classroom instruction. Commander C. E. Giese, the flight test officer, approved the proposed training and appointed Sherby as the officer-in-charge of the U.S. Naval Test Pilot School. Sherby conducted several classes during the next two years, and by 1947 the Chief of Naval Operations approved a request to establish a nine-month school. Funding appropriations allowed for the purchase of seven aircraft used for training purposes including a PB4Y-2 Privateer, an F6F-5 Hellcat, an XNQ-1, an F7F-3 Tigercat, an F8F-1 Bearcat, a PBY-6A, and an SNB-1. In 1948, Sherby and Connolly compiled the lecture material into a textbook, *Airplane Aerodynamics*, which the U.S. Navy continues to use in its training program. Since 1950, advances in technology have resulted in the addition of curriculum in three separate areas: Fixed Wing, Rotary Wing, and Airborne Systems. Due to increased course content, the length of the school has been increased from nine to eleven months. Alan Shepard and John Glenn are two of the most famous graduates of the U.S. Naval Test Pilot School.

Civilians seeking a career as a Navy pilot must have a B.A. or B.S. degree, pass the Aviation Selection Test Battery exam, and have twenty-twenty vision and normal depth and color perception. Only U.S. citizens between the ages of 19 and 26 qualify for a commission. Once candidates are accepted, they attend a thirteen-week course at Officer Candidate School (OCS) at the Naval Air Station in Pensacola, Florida. An additional six-week indoctrination program completes the training program. Pilots are then promoted to the rank of ensign and receive basic and advanced pilot training. The service obligation for Navy pilots is eight years of active duty if designated for Naval Aviation (Jets) and seven years if designated Naval Aviation (Props/Helos). All pilots must then remain on Ready Reserve status.

Blue Angels

At the end of World War II, interest in all military activity declined dramatically. In an effort to garner public support for the continuation of naval aviation, Admiral Chester W. Nimitz, the chief of naval operations, formed a flight demonstration team that became known as the Blue Angels. The first flight demonstration, lead by Commander Tony Less, occurred in 1946 at the Naval Air Station in Jacksonville, Florida, with the pilots flying Grumman F-6F Hellcats. The following year the Blue Angels flew the Grumman F-8F Bearcat and adopted the famous diamond formation that became the trademark of the precision flying team. When war broke out again in 1950, the Blue Angels, flying Grumman F-9F Panther jets, joined United Nations forces in Korea. In 1951, the squadron returned to the United States and reported to the naval air station at Corpus Christi, Texas, where new Panther F-9F5's awaited them. After spending three years in Texas, the Blue Angels made one final move to their new headquarters at the Naval Air Station at Pensacola, Florida. Since 1954, the Blue Angels have flown in the swept-wing Grumman F-9F9 Cougar, the F-11F Tiger, the McDonnell Douglas F-4 Phantom II, and the McDonnell Douglas A-4F Skyhawk II. After 1986, the Navy Flight Demonstration Squadron has flown

McDonnell Douglas F/A-18 Hornets, a plane that functions as both a fighter and an attack aircraft. Each year, the Blue Angels perform at air shows around the country and since 1946, over 260 million Americans have witnessed the precision flying of these naval aviators.

World War II Navy Aces

The era of flight for the U.S. Navy began in 1910, but combat missions remained under the direction of the United States Air Service during World War I. Navy pilots did not fly combat missions during this war so none of them qualified as an ace. During World War II, the importance of naval aviation increased dramatically. As the United States recovered from the loss at Pearl Harbor, naval ships sailed toward the South Pacific equipped with F-4F Wildcats. In 1942, the Navy pilots experienced difficulty against the Japanese Zeros, but even though they remained outnumbered, several Navy pilots scored an impressive number of kills. Edward "Butch" O'Hare received a Medal of Honor after shooting down seven Japanese aircraft in his F-4F. Stanley W. "Swede" Vejtasa, during the Battle of Santa Cruz, destroyed two Japanese Vals headed for the USS *Enterprise*. He also downed five more low-flying torpedo planes before running out of ammunition. Although the *Enterprise* sustained two hits by Japanese bombs, the ship remained afloat. Navy pilots destroyed over 150 Japanese planes in this one battle. Some Navy pilots flew both F-4F Wildcats and F-6F Hellcats after the new planes arrived in the Pacific during the last part of 1943. Lieutenant Elbert McCuskey, a Navy Cross recipient, scored thirteen confirmed kills flying the Hellcat and the Wildcat planes. Once the Hellcats arrived, Navy pilots gained a technological advantage over the Japanese fliers and the number of kills increased as the United States military fought battles for the Marshall and Marianas Islands.

Alexander Vraciu, a remarkable Navy pilot who ended World War II as the fourth highest ace, received his wings in August, 1942. Assigned to the USS *Wolverine*, Vraciu shot down his first plane over Wake Island in October, 1943. By January, he had shot down a total of five enemy aircraft. During the next six months, he destroyed seven additional Japanese planes and sank a Japanese merchant ship with a direct hit to the stern. On June 19, 1944, Vraciu joined other Navy pilots in a battle over the Marianas Islands. Twenty-five miles west of his home ship, the USS *Lexington*, Vraciu spotted twenty-five bombers. Although he managed to shoot down six planes within eight minutes, the remaining Japanese planes continued directly toward the ship. Vraciu destroyed another bomber, this time at a range of two hundred feet. While dodging the debris, he realized that to continue pursuing the Japanese required chasing them into the antiaircraft fire from his own ship. He downed several more bombers before chasing a bomber headed directly for the *Lexington*. Vraciu put his plane in a steep dive to catch the enemy and destroyed the plane just in time. Almost shot down by his own ship, Vraciu returned with six confirmed kills for that one mission, and by the following day, the number of enemy aircraft that he had destroyed totaled nineteen. After the Battle of the Philippine Sea, Vraciu transferred to the Patuxent River facility, where he spent the remainder of the war as a test pilot. After the war, Vraciu commanded the VF-51 squadron.

The list of Navy aces during World War II is lengthy. Commander David McCampbell, a native of Alabama, remained the Navy's top ace, with thirty-four confirmed kills during one tour of duty, nine of them in one battle. He commanded a squadron off the USS *Essex* and participated in the Battle of the Philippine Sea as well as Leyte Gulf. During his career, which lasted until 1964, McCampbell received the Congressional Medal of Honor, the Navy Cross, the Silver Star medal, the Legion of Merit, and the Distinguished Flying Cross.

Cecil E. Harris maintains the position of the second highest-ranking Navy ace, with twenty-four confirmed kills. He served on the USS *Intrepid* in the South Pacific and fought against the dreaded Japanese kamikazes. A teacher from South Dakota, Harris returned to his former occupation after the war with the Navy Cross, the Distinguished Flying Cross, a Silver Star, and two Gold Stars.

Eugene Valencia earned the position of third highest-ranking Navy ace during World War II with twenty-three confirmed kills. Flying a Hellcat F-6F, Valencia and his squadron, commonly referred to as the Flying Circus, mowed down Japanese kamikaze pilots in record numbers. During one mission over the island of Okinawa, Valencia downed six Japanese planes, while his division returned to their ship that day with a total of fourteen kills. Other notable Navy aces are Comelius N. Nooy, Patrick D. Fleming, Douglas Baker, Ira Cassius Kepford, Charles R. Stimpson, Arthur R. Hawkins, John L. Wirth, George Duncan, Roy Rushing, John Strane, Wendell V. Twelves, James Shirley, Daniel A. Carmichael Jr., Roger Hedrick, William J. Masoner, Jr., Hamilton McWhorter III, and P. L. Kirkwood, who all had twelve or more kills. Navy aces with fewer kills, ranging from seven to eleven, include Frederick E. Bakutis, John T. Blackburn, James B. French, William A. Dean, Jr., Donald E. Runyon, Stanley W. "Swede" Vejtasa, Harris A. Mitchell, Whitney Feightner, Ralph E. Elliott, and Edward "Butch" O'Hare.

Navy Aces of Korea and Vietnam

Since the majority of battles in the South Pacific during World War II involved Navy aircraft, the number of Navy aces is the highest during this period. During the Korean War, most of the flying missions remained under the control of the U.S. Air Force. On occasion Navy pilots flew into combat situations but only one achieved the distinction of being called an ace. Lieutenant Guy Bordelon of the V-3 Squadron flew F4U's over Korea and managed to down five planes, the minimum number of kills to qualify as an ace. Bordelon flew night missions over North Korea to destroy depots of aviation fuel and other supplies. Air Force jets flew too fast to harass the prop-driven North Korean planes, so Bordelon was assigned to a Marine base for that purpose. He managed to score five kills in three weeks and then rejoined his squadron on the USS *Princeton* as the Navy's first prop ace in Korea.

As in Korea, Navy pilots saw limited combat action during the Vietnam conflict. Only two Navy pilots during this period achieved the status of ace. On May 10, 1972, Lieutenant Randy "Duke" Cunningham and Lieutenant Junior Grade Willy Driscoll engaged enemy MiGs, including one flown by Colonel Toon, North Vietnam's deadliest pilot with thirteen confirmed kills. Cunningham and Driscoll managed to achieve a triple kill before returning, with heavy damage, to their base. The previous day, the two pilots had destroyed two MiGs.

As technology has advanced the number of Navy Aces has declined. Computer-guided missiles and armed, unmanned aerial vehicles account for many of the kills previously made by pilots. World War II will always remain the era of the Navy ace.

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See also: Blue Angels; Hornet; Kamikaze missions; Korean War; Military flight; Rescue aircraft; Test pilots; Vietnam War; World War II

Ninety-nines

Also known as: International Organization of Women Pilots

Date: Founded on November 2, 1929, at Curtiss Field, Valley Stream, Long Island, New York

Definition: An international club of more than 6,000 licensed women pilots from about thirty-five countries, with its headquarters in Oklahoma City

Significance: In 1929, ninety-nine female aviation pioneers banded together to provide one another with moral support and to promote aviation. Since that time, the mission of the Ninety-nines has evolved "to promote world fellowship through flight, to provide networking and scholarship opportunities for women and aviation education in the community and to preserve the unique history of women in aviation."

History

The Ninety-nines owe their beginnings to an air race, and they have been involved in air racing ever since. At the start of the 1929 Women's Air Derby, from Santa Monica, California, to Cleveland, Ohio, the first airplane race in which women were permitted to compete, humorist Will Rogers remarked that it looked like a "powder puff derby." Twenty licensed women pilots competed in the grueling nine-day race, flying fragile, unstable aircraft with unreliable engines.

After the race, Amelia Earhart, Gladys O'Donnell, Ruth Nichols, Blanche Noyes, Phoebe Omlie, and Louise Thaden gathered under the grandstand to plan the formation of an association of women pilots. Louise Thaden, winner of the race and holder of numerous flying records, served as secretary, and Blanche Noyes was treasurer. Opal Kunz served as acting president until Amelia Earhart was elected in 1931. The organization's name, the Ninety-nines, was taken from its ninety-nine charter members.

In addition to the U.S. pilots, the original ninety-nine included Thea Rasche from Germany; Jessie Keith-Miller, from Australia; and Lady Mary Heath, from Ireland. Members came from all walks of life and included socialites, test pilots, nurses, housewives, and barnstormers.

Powder Puff Derby

The Ninety-nines are often identified with the Powder Puff Derby, officially known as the All-Woman Transcontinental Air Race. The first race, in the summer of 1947, was flown from Palm Springs, California, to Tampa, Florida, where the Florida chapter of the Ninety-nines was staging the Florida All-Woman Air Show.

Although only one of the two planes entered in the race actually finished, the 1947 Powder Puff Derby was the first of more than thirty annual derbies, which became so popular that the number of entrants had to be limited and qualifications raised. Government officials, celebrities, costumed comic strip characters, and aviation leaders participated in the Powder Puff Derbies as racers, workers, and contributors.

The Powder Puff Derby became an aviation icon, but the All-Woman Transcontinental Air Race Board decided that the 1976 race would be the last. Fuel shortages loomed, airspace was becoming more restricted, and costs were escalating. The 2,926-mile-long 1976 race stretched from Sacramento, California, to Wilmington, Delaware, with two hundred aircraft from all over the world competing. Encouraged by the Smithsonian Institution, a final commemorative race was flown in 1977, retracing the original route.

The members of the Ninety-nines continue to represent diverse occupations and interests, with a love of flying as their bond. For many members, flying is a hobby, but because of their mutual support and encouragement, an increasing number are enjoying productive aviation careers.

Organization

The headquarters of the International Organization of Women Pilots, located located at Will Rogers Airport in Oklahoma City, Oklahoma, is run by an executive director and staff. Officers and the board of directors, who are elected every two years, volunteer their services. The president appoints committee chairs, who coordinate the group's many activities. The local chapters and sections throughout the world are the soul and strength of the Ninety-nines. Their members work together to fulfill the organization's mission.

Membership in the Ninety-nines is open to any female pilot who is licensed by the laws of her country. There is a special membership category for female student pilots. Husbands and significant others of Ninety-nines are affectionately known as Forty-nine-and-one-halfs. Members keep informed and in touch with an international bimonthly magazine, an annual directory, chapter and section newsletters, and an e-mail service.

Scholarships

The Amelia Earhart Memorial Scholarship fund is a living tribute to the Ninety-nines' first elected president and inspirational leader. Established in 1940 by Betty Gillies and Alma Harwood, it has helped many hundreds of women reach their career goals by helping to pay for new flight ratings.

Contributions to the scholarship fund are invested and managed by a board of trustees, and awards are made from the earnings. Individual chapters and sections award their own scholarships and also contribute to the Amelia Earhart Memorial Scholarship fund. The first award of $150 was given to Patricia Gladney in 1941. As the fund has prospered into the twenty-first century, ten to twenty scholarships of many thousands of dollars each are presented at the international convention each July. From time to time, special research scholar grants are also awarded.

United Parcel Service was the first air carrier to participate in the awards in 1992. Since then, companies have awarded training that leads to employment in the airline cockpit for the young women.

Activities

One of the Ninety-nines' highest priorities has always been the promotion of aviation safety. The Ninety-nines host most of the Federal Aviation Administration (FAA) safety seminars that are held throughout the country and conduct survival and flying companion courses, fear-of-flying clinics, and aerospace workshops for teachers. Ninety-nines volunteer their skills and airplanes for rescue missions, transporting patients, blood, organs, animals, and supplies.

Ninety-nines introduce young people to aviation by visiting schools, taking youngsters on flights and airport tours. They serve as judges and coaches for the National Intercollegiate Flying Association meets and for international proficiency competitions. They sponsor, direct, and compete in air races and rallies throughout the world.

Since 1935, Ninety-nines have, with the blessings of federal and local governments, volunteered their time and energy to paint airport names and other helpful information on rooftops and airport taxiways. In the days before pilots were able to make use of the electronic navigation aids that currently exist, airmarking was an important source of directional information. Ninety-nines continue to provide the vital service of painting markers and compass roses on airport surfaces so that pilots and mechanics can check the accuracy of aircraft compasses.

Historical Preservation

The Amelia Earhart Birthplace Museum, a cottage overlooking the Missouri River in Atchison, Kansas, has been restored and preserved by the Ninety-nines and the city of Atchison. A National Historic Site, the home was built in 1861 and is open to the public. Led by charter member Fay Gillis Wells, the Ninety-nines and the city of Atchison also cooperated to create the International Forest of Friendship in Atchison.

In July, 1999, the 99's Museum of Women Pilots was dedicated on the second floor of the International Headquarters Building in Oklahoma City. It secures and displays papers, personal items, and artifacts that highlight the accomplishments of women in aviation from 1910 to the present.

Ursula Malluvius Davidson

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See also: Air shows; Amelia Earhart; Federal Aviation Administration; Safety issues; Training and education; Women and flight

Northwest Airlines

Date: Founded on September 1, 1926

Definition: A worldwide commercial airline with one of the largest route structures of any U.S. airline.

Significance: Northwest Airlines, founded in 1926, was a pioneer of the North America-Asia air route. Through the acquisition of the domestic carrier, Republic Airlines, in 1986 and a long-term alliance with KLM Royal Dutch Airlines signed in 1997, Northwest entered the twenty-first century offering truly global service.

As was true for many U.S. airlines, Northwest Airways began as a mail carrier. In 1926, it inaugurated mail service between Minneapolis, Minnesota, and Chicago, Illinois. It began passenger service in the following year, carrying a total of 106 passengers in 1927, mostly on a route between Chicago and Minneapolis with intermediate stops. It even became an international carrier when, in 1928, it instituted service to Winnipeg, Manitoba. The service was stopped after three months due to opposition from the Canadian government, but in 1931 it was resumed in a fashion, with flights that actually landed just south of the Canadian border, connecting with a Canadian plane for the last few miles. In 1935, this restriction was lifted and Northwest flew regularly into Canada.

By 1934, the airline had changed its name to Northwest Airlines and passenger service had become a major source of revenue. It expanded its service to the West Coast, serving Seattle, Washington, and cities along a northern route to the west of Minneapolis. In 1939, Northwest Airlines introduced the remarkably able DC-3 aircraft. The Northwest DC-3 carried twenty-one passengers and attained a speed of 140 miles per hour. In the same year, Northwest employed its first stewardess to serve passengers on the DC-3. An interesting record was celebrated in 1999, when a Northwest stewardess, Connie Walker, hired only eighteen years after the introduction of stewardess passenger service, retired at age seventy after forty-two years of service.

Northwest Airlines became a publicly traded company in 1941, when common stock was first made available to the public. It remained on the open stock market until 1989, when it was purchased by Wings Holdings for $3.5 billion.

During World War II, the airline became engaged in defense work for the U.S. government. In the postwar years, the airline began using four-engine planes, beginning with the unpressurized DC-4. At this time, the airline expanded its service to become a transcontinental carrier, initiating flights from the Midwest to New York and to Anchorage. Soon after, it began service to Asia, serving Tokyo, Seoul, Shanghai, Manila, and Okinawa. Starting in 1948, Northwest painted the tails of its aircraft red, the distinctive insignia of the airline that endures into the twenty-first century.

In 1949, Northwest scheduled the giant, two-deck, four-engine Boeing Stratocruiser on its long-distance flights across the United States and to Asia. Ten years later, it introduced jet service to Asia, flying long-range DC-8's to Tokyo and beyond. Flights to Asia were somewhat dependent on the political situation in each country. Flights to Shanghai had to stop in 1949 when China experienced its communist revolution, and Seoul had to be dropped a year later due to hostilities in Korea. Flights to Seoul were reinstituted after the Korean War, but it was not until 1984 that flights to Shanghai were reintroduced. In 1996, an alliance was announced with Air China, the national airline, greatly facilitating travel to and within China.

Travel to Asia, including extensive flights devoted all or mostly to freight, became a major part of Northwest Airlines' business. The company even went so far as to purchase an entire island, Shemya Island in the Aleutian chain, in order to have a useful stop on the route to Asia. Another important development was the introduction of polar flights, which originally followed a New York-Anchorage-Tokyo route, considerably reducing the travel time between the U.S. East Coast and Asia.

In the 1960's, the airline introduced pressurized aircraft, including the DC-6 workhorse and the unusual and elegantly designed Lockheed Constellation, allowing for more comfortable flights over the Rockies and other mountain chains. These craft were soon replaced with jets such as the 707 and the DC-8. Greatly increased capacity came in the 1970's with the introduction of wide-body jets, including both 747's and DC-10's. During this period, Northwest remained unique among U.S. airlines in attempting to be both a local carrier and an international one, concentrating its foreign ports in Asia. Only TWA made a similar attempt, concentrating on European destinations.

The 1980's saw several mergers and consolidations among U.S. airlines. Hughes Airwest, Southern Airlines, and North Central Airlines combined to form a new company called Republic Airlines. Northwest acquired Republic Airlines in 1986, adding its many short-hop routes to Northwest's domestic network and making it one of the largest U.S. airlines.

The next development of this kind occurred in 1991, when Northwest reached an agreement to become partnered with KLM Royal Dutch Airlines. Together, the two airlines offered service to virtually the entire world, with Northwest adding the extensive KLM network of European ports, as well as cities in Eastern Europe, the Caribbean, South America, Africa, and Southeast Asia. This arrangement having been found to be mutually beneficial, the two airlines signed a long-term agreement of partnership in 1997.

The early 1990's saw some troubled periods involving restructuring of the airline's route systems and changes in its hub design, as well as financial restructuring. Later problems included a pilots' strike in 1998, which caused the entire airline to cease operations for three weeks.

By the end of the twentieth century, Northwest Airlines was involved with a complex combination of favorable alliances with other airlines, including Continental, Alaska, Mesaba, Hawaiian, American Eagle, America West, Big Sky, and Horizon in the United States. It was also teamed with several foreign carriers in addition to KLM, such as Malaysian, Japan Air System, Alitalia, Jet Airways of India, Pacific Island Aviation, Braathens, CebuPacific, Cyprus, Garuda Indonesian, and Kenya Airways. With these in place, Northwest serves a total of about 750 cities in 120 different countries on seven continents.

Paul Hodge

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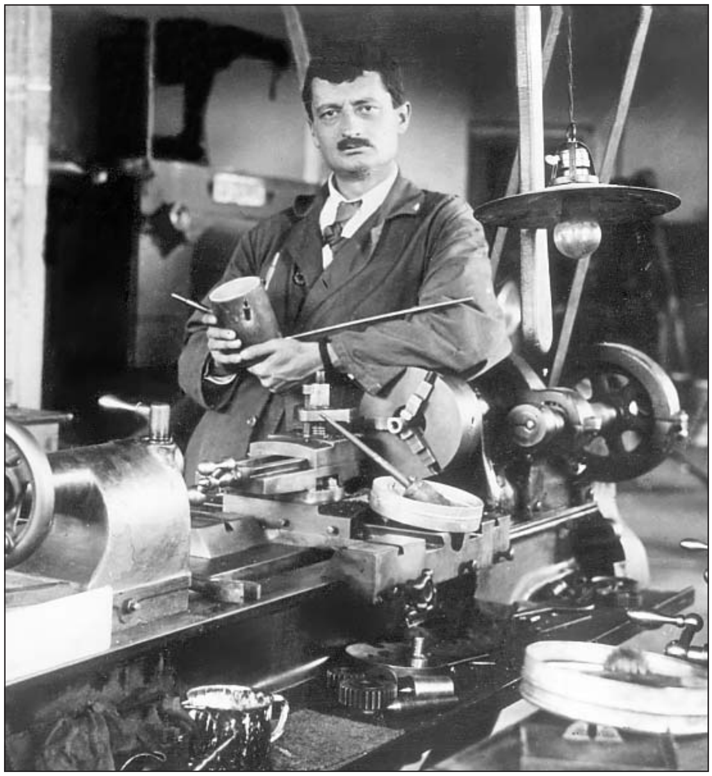
See also: Air carriers; Airline industry, U.S.; Airmail delivery; Alitalia; Continental Airlines; Flight attendants; Food service; Jumbojets; KLM

Hermann Oberth

Date: Born on June 25, 1894, in Hermannstadt, Siebenbergen, Transylvania; died on December 28, 1989; in Nürnberg, Germany

Definition: An early pioneer of the physical principles of spaceflight and designer of some of the first liquid fuel rockets.

Significance: Oberth's calculations proved that spaceflight was possible with multistage liquid-fueled rockets. Many of his visions, such as the space telescope, space suits, and reuseable space vehicles, have been realized.



Hermann Oberth first proved that multistage rockets could make spaceflight possible. (Library of Congress)

As a youth, Hermann Julius Oberth became interested in rockets after reading Jules Verne's novel *Autour de la lune* (1870; *From the Earth to the Moon . . . and a Trip Around It*, 1873). His later thesis *Die Rackete zu den Planetenräumen* (1923; the rocket into interplanetary space) was rejected at Heidelberg University, but when it was published as a book in 1923, it sold out two editions and attracted interest all over Germany.

To support his growing family, Oberth taught mathematics, physics, and chemistry at a grade school in Mediasch, Siebenburgen. In 1927, he helped found the Verein für Raumschiffahrt (VfR), Germany's first society for space travel, becoming its president in 1929. He went on lecture tours defending the scientific possibility of spaceflight. In collaboration with Rudolf Nebel and Wernher von Braun, who was then a student, he built and tested liquid fuel propulsion systems for rockets, using liquid oxygen and gasoline.

In 1936, the German army opened the famous installation at Peenemünde to develop ballistic missiles. At Peenemünde, Oberth and von Braun helped develop the so-called Vergeltungswaffen, or "revenge weapons," the V-1 and V-2 rockets. In 1941, Oberth took up residence at Peenemünde under the alias Felix Hann. He patented the fuel pump used in liquid fuel rockets and also helped develop an ammonium nitrate-propelled antiaircraft rocket.

After a period of incarceration at the end of World War II, Oberth returned to rocket research in Germany and Italy, and published the book *Menschen im Weltraum* (1954; *Man into Space*, 1957), which contained novel ideas for propulsion systems. In 1955, he went to Huntsville, Alabama, where he joined von Braun, who now headed the U.S. rocket program. In 1958, Oberth returned to the town of Feucht, Germany, where he wrote prolifically on technical and philosophical subjects and moved into retirement. He died in 1989 at the age of ninety-five at a hospital in Nürnberg, Germany.

John R. Phillips

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See also: Wernher von Braun; Missiles; Rocket propulsion; Rockets; Spaceflight

Orbiting

Definition: Sustained repetitive motion about a gravitating body, generally consisting of closed circles or ellipses.

Significance: Orbiting is the type of motion exhibited by both natural and artificial satellites.

The Laws of Motion

Isaac Newton in 1684 published three laws of motion that put its study on a firm scientific basis for the first time.

The first law states that a body at rest will remain at rest, and a body in motion will remain in motion in a straight line at constant speed, unless acted on by an outside force. Sometimes referred to as the law of inertia, this law first articulated the principle that motion, not rest, is the natural state of objects. Contrary to commonsense observation, and to the beliefs of many philosophers prior to 1684, a force is not necessary to keep objects moving; rather, a force is necessary to bring them to a halt once they are moving.

The second law states that the application of a force to an object will cause it to accelerate in the direction of the force, with the magnitude of the acceleration equal to the strength of the force divided by the mass of the object. Acceleration is defined as a change in velocity; velocity covers both speed and direction of motion. An acceleration can be a change in speed in a constant direction, or it can be a change in direction of motion at constant speed, or it can be a simultaneous change in both speed and direction. An airplane increasing its speed from 100 to 200 miles per hour is accelerating. So is an airplane banking in a tight circle to the left at a constant 100 miles per hour.

The third law states that for every action, that is, a force exerted by one body on a second, there will be an equal and opposite reaction, that is, a diametrically opposite force exerted on the first body by the second.

In addition to the three laws of motion, Newton also discovered the law of gravitation, which states that any two objects will attract each other with a force which is proportional to the product of their masses divided by the square of the distance between their centers. The gravitational attraction of Earth and an object is the force of weight.

Free Fall

Objects solely under the influence of gravity are said to be in free fall. In such a situation, weight is the only force acting on the object and the law of gravitation states that the direction of this force is toward the center of Earth. From the second law, it follows that the object will accelerate toward the center of Earth. If the object is initially at rest or in pure vertical motion, then the resultant acceleration will be a change in speed only: an object traveling vertically upward will slow to a halt and then begin to travel downward at an ever-increasing rate, or if initially traveling vertically downward, will simply increase its downward speed.

An object traveling horizontally will also accelerate downward, but in this case the acceleration will include a change in direction. The initial horizontal velocity will accumulate a downward component in addition to the initial horizontal component, and the combination of the two will result in a curved path. The object will travel on a parabola. In both of these two cases, the force is the same—the object's weight does not change—and the acceleration is the same. The effect of the acceleration is different because of the different initial velocities of the two situations.

Orbiting

The force of gravity extends to infinity and cannot be canceled or screened. At altitudes where Earth's atmosphere is too thin to exert the aerodynamic forces of lift and drag, the motion of an object is governed solely by the force of gravity: it is in free fall. Such is the case for the Moon. It accelerates toward the center of Earth, but because its initial velocity is horizontal, the acceleration results in a curved trajectory. Because the gravitational force decreases with distance, the curvature of the trajectory is shallow and the path of the Moon does not bend enough to intersect the surface of Earth. Instead of falling toward Earth, the Moon falls around Earth and circles it repeatedly. The horizontal velocity and downward acceleration are delicately matched to give the Moon a trajectory which is almost a perfect circle.

Three laws of planetary motion were discovered by Johannes Kepler in the years between 1601 and 1618. The first law expresses the discovery that contrary to all previous expectation, the orbits of the planets are ellipses instead of circles. The Sun occupies a special position at one focus of the ellipse, placing it offset from the geometric center. As a result, the distance from planet to Sun changes from a minimum (perihelion) to a maximum (aphelion) and back to a minimum as the planet completes an orbit. The orbit lies entirely in one plane that contains the center of the Sun.

The second law expresses Kepler's discovery that the speed of a planet varies along its orbit, being greatest at perihelion and smallest at aphelion. The variation of the speed is such that a line drawn from the Sun to the planet will sweep out equal areas in equal times.

The third law expresses Kepler's discovery that the size of an orbit is related to the time a planet takes to complete one orbit, called the period. The size of an orbit is indicated by the average distance (mean radius) of the planet from the Sun. The cube of the mean radius divided by the square of the period is the same for all planets.

Newton's demonstration that all three laws follow mathematically from the three laws of motion and law of gravitation was a magnificent scientific triumph and marks the beginning of the modern scientific age.

Earth Orbit

Kepler's three laws apply to satellites in Earth orbit with minor changes. The closest approach of a satellite to Earth is called perigee. The most distant point is called apogee. The orbits are still ellipses with Earth at one focus, and they lie in a plane that contains the center of Earth. The cube of the mean radius of the orbit divided by the square of the period is a constant for all satellites, but is not the same constant that is associated with orbit around the Sun.

Ellipses vary from near-circular to very long and narrow. The degree of narrowing is referred to as the eccentricity. A circle is considered to be an ellipse of zero eccentricity. As ellipses get longer and narrower, the eccentricity approaches one.

The plane of the ellipse may be tilted with respect to the equator. The angle between the plane of the orbit and the plane of the equator is the inclination zero. Inclinations from 0 to 90 degrees are associated with satellites orbiting Earth counterclockwise as seen from a vantage point over the North Pole. Inclinations from 90 to 180 degrees are associated with satellites orbiting clockwise as seen from above the North Pole.

Positive inclination orbits are called prograde. Negative inclination orbits are called retrograde. Prograde orbits are easier to attain because the counterclockwise rotation of Earth adds a free contribution to the velocity of the satellite. Satellites destined for retrograde orbit must launch to the west against the rotation of Earth, making orbit harder to achieve.

Inclinations near 90 degrees are referred to as polar orbits. Satellites in polar orbit will eventually pass over every spot on Earth, making them extremely useful for scientific, remote sensing, and photographic missions.

A satellite in low-Earth orbit has an orbital period of just over ninety minutes. As altitude decreases, orbital period increases. At an altitude of 35,780 kilometers (22,360 miles) the orbital period is exactly twenty-four hours. A satellite in circular equatorial orbit (zero eccentricity, zero inclination) at this altitude will travel along its orbit at exactly the same rate as Earth turns beneath it. The satellite appears to have a fixed position in the sky as seen from Earth. These geostationary orbits are particularly advantageous for communications satellites. Since satellites in these orbits never change their apparent position, no antenna tracking is necessary and the satellites are always available since they never go below the horizon.

Earth Orbit Decay

Ideally, orbits are perfect ellipses which never change. In reality, complications due to the irregular shape of Earth, aerodynamic drag from the thin residual air at orbital altitudes, and the extra gravitational tug of the Sun and Moon continually change the shape and size of satellite orbits.

For low-Earth orbits, the predominant effect is aerodynamic drag. Drag is a dissipative force which converts an object's energy of motion into heat. Ordinarily, it slows things down, but as a satellite loses kinetic energy, it drops closer to Earth. When this happens, gravitational potential energy is converted into kinetic energy and a satellite gains more kinetic energy this way than it loses due to drag. The paradoxical result is that a satellite actually ends up going faster (albeit at a lower altitude) due to the drag. Since drag increases with speed, so does the loss of altitude, and eventually the satellite reenters the atmosphere. The resulting high speeds through dense air create a powerful shock wave in front of the satellite, which compresses and heats the air to the point of incandescence. The satellite burns up like a meteor.

At higher altitudes, aerodynamic drag is negligible and the change in size, shape, and orientation of the orbit due to the irregular shape of Earth and the extra gravitational tug of the Sun and Moon predominate. These orbital changes can be measured with such accuracy that they can be used to refine knowledge of the shape of Earth and the distribution of mass within its interior. Geology now looks to the motion of objects in the sky to find out what is buried in the ground beneath.

Escape Orbits

The apogee height of a satellite increases as the total energy of the satellite increases. If the total energy is great enough, apogee height becomes infinite and the satellite is on an escape orbit. The eccentricity of an escape orbit is greater than 1 and the orbit is an open curve called a hyperbola rather than a closed ellipse. The minimum velocity required to put a satellite on an escape trajectory is called the local escape velocity. For low-Earth orbit, local escape velocity is about 11 kilometers per second (7 miles per second). Satellites with this velocity or greater will leave Earth forever and become artificial planets, satellites of the Sun.

The Solar System and Beyond

Kepler's third law may be rephrased as the principle that the cube of the mean orbital radius divided by the square of the orbital period equals a constant value multiplied by the mass of the gravitating object at the focus of the orbit. For Earth orbits, this formula gives the mass of Earth. For the solar system, it gives the mass of the Sun. The principle can be used to determine the mass of any object in the universe which has detectable satellites whose orbital radius and period can be measured. It is thus that astronomers know the mass of distant objects ranging from tiny asteroids to immense galaxies.

Billy R. Smith, Jr.

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See also: Apollo Program; Crewed spaceflight; Forces of flight; Gemini Program; Gravity; Mercury project; Microgravity; National Aeronautics and Space Administration; Satellites; Spaceflight; Uncrewed spaceflight

Osprey helicopter

Also known as: Bell-Boeing V-22, MV-22, CV-22, HV-22

Definition: A tilt-rotor aircraft designed for military applications.

Significance: The Osprey was the first tilt-rotor aircraft ever to be designed, built, and put into production.

Tilt-Rotor Aircraft

The Osprey is a tilt-rotor aircraft, a hybrid of a helicopter and fixed-wing aircraft. Its unique design allows it to take off and land vertically and hover, like a helicopter, and to fly at high forward speeds, like a turboprop airplane. The Osprey weighs 33,140 pounds and can carry almost 20,000 pounds of cargo. Its top speed is 340 knots and its maximum range is 700 miles. From nose to tail, the Osprey measures more than 57 feet. With its 38-foot-diameter rotors, it is almost 84 feet wide.

The Osprey, built under a team agreement between Bell Helicopter Textron and the Boeing Company, is the first tilt-rotor aircraft ever to be approved for production. There are three variants on the basic V-22 design: the MV-22, the CV-22, and the HV-22. The MV-22 was built for the U.S. Marine Corps as a replacement for its aging CH-46 Sea Knight helicopters, which performed combat-assault and assault-support missions. The CV-22 is built for U.S. Air Force long-range, special-operations missions. The U.S. Navy's version, the HV-22, is intended for combat search and rescue, special operations, and logistics support.

The MV-22 was temporarily grounded in 2000 following a crash that killed nineteen Marines; flights were resumed after an investigation found that the helicopter had descended too quickly. Its future with the Marine Corps was placed in doubt.

In forward flight, the Osprey looks like a fixed-wing aircraft with very large propellers attached to the nacelles located at the wingtips. The nacelles contain the turboshaft engines and transmissions that provide power to the rotors. In the event of an engine failure, an interconnect shaft between the two nacelles allows one engine to power both rotors. The Osprey is unique compared to propeller-driven aircraft or helicopters because its nacelles are designed to pivot. When the nacelles are pivoted such that the rotors are pointed up like those of a helicopter, the Osprey can take off and land vertically or hover. In cruise flight, when the rotors are in their horizontal position, they provide propulsive force like propellers, while the wings provide the lift necessary to keep the aircraft aloft.

Evolution of the Osprey

Although helicopters have superior performance for vertical takeoff and landing (VTOL) and hovering flight, they are limited in forward speed. A typical helicopter has a cruise speed of less than 150 knots, which is far more slow than that of many propeller-driven, fixed-wing aircraft. In order to achieve speeds approaching those of fixed-wing aircraft, aircraft designers since the 1950's have investigated concepts for aircraft that can hover, take off, and land vertically and achieve high forward speeds.

In December, 1954, the Model 1-G, built by the Transcendental Aircraft Company, became the first tilt-rotor aircraft ever successfully to perform a transition from hover to forward flight. Before being lost in an accident, the Model 1-G flew more than twenty hours in more than one hundred flights. The Model 1-G was followed by the Model 2, which was tested in 1956 and 1957. Despite these accomplishments, the Air Force, which was supporting tilt-rotor development, chose to shift its support to the Bell Helicopter Company, which completed the first of two XV-3 prototypes in 1955.

In 1973, under contract to the National Aeronautics and Space Administration (NASA) and the Army, Bell Helicopter, by now a subsidiary of Textron, began the development of the XV-15 as a tilt-rotor technology demonstrator aircraft. The XV-15 made its first flight in May, 1977, and performed its first conversion in July, 1979. The two XV-15 aircraft built under this program have flown hundreds of research and demonstration flights and continue to be flown. The unprecedented success of the XV-15 contributed directly to the development of the V-22 Osprey.

Osprey Flight Regimes

Unlike helicopters and fixed-wing aircraft, the Osprey must operate in three flight regimes, cruise, hover, and transition. In cruising flight, it is flown in a manner similar to that of fixed-wing aircraft. Fixed control surfaces on the aircraft allow the pilot to change the aircraft's attitude. A large elevator on the horizontal tail controls pitch; flaperons, which operate both as flaps and ailerons, on the wings control roll; and rudders on the twin vertical tails control yaw. In order to increase the forward speed of the aircraft, the pilot increases the pitch angle of the rotor blades, thereby increasing the thrust.

Image Not Available

V-22A Osprey Characteristics

Primary Function: Vertical takeoff and landing (VTOL) aircraft
Builder: Bell-Boeing
Propulsion: Two pivoting Rolls Royce/Allison AE1107C engines
Main Rotor Diameter: 38 feet
Blades per Rotor: 3
Maximum Gross Weight: 60,500 pounds
Service Ceiling: 25,000 feet
Cruise Speed: 272 knots
Armament: Provisions for two .50-caliber cabin guns

Source: Data taken from (www.chinfo.navy.mil/navpalib/factfile/aircraft/air-v22a.html), June 6, 2001.

In hovering flight, the Osprey's fixed control surfaces are not effective, because the aircraft has no forward velocity. Therefore, all of the control must come from the rotors. Collective pitch changes are obtained by changing the pitch angle of all rotor blades on one rotor by the same amount. To increase the altitude of the aircraft, the pilot increases the collective pitch on both rotors by the same amount. Roll is obtained with differential collective pitch, which involves increasing the collective pitch on one rotor while decreasing the collective pitch on the other. Changing pitch angle of each rotor blade in a sinusoidal pattern during each revolution effects cyclic pitch changes on a rotor. Unlike collective pitch, cyclic pitch does not change the total thrust produced by the rotor but does produce a movement about an axis perpendicular to a line between the points where the largest and smallest pitch angles are obtained. Control of the aircraft pitch in hover is obtained by changing the cyclic pitch of both rotors by the same amount. Yaw control is obtained by using differential cyclic pitch.

During the transition flight regime, the Osprey changes from being an aircraft that is controlled like a helicopter to one that is controlled like a propeller-driven, fixed-wing aircraft. Through control system software, which relies primarily on measurement of forward speed, the pilot's control of the aircraft is gradually transitioned between the helicopter flight regime and the cruise flight regime. Once the cruise flight regime has been attained, with the rotors in their horizontal position, the rotation speed of the rotors is changed from its helicopter mode value of 397 revolutions per minute to a cruise value of 332 revolutions per minute.

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See also: Helicopters; Military flight; Rescue aircraft; Rotorcraft; Vertical takeoff and landing

Overbooking

Definition: The degree to which an airline will allow more reservations for a flight to be made than there are seats on an airplane.

Significance: Because airlines sell a perishable product, and an empty seat at departure time is gone forever, overbooking is the airlines' attempt to balance the number of passengers with the reservations of those who do not fly, no-shows, so that every possible seat is filled.

Reasons for Overbooking

Airlines face the dilemma of providing scheduled transportation services to the traveling public, whose demand for transportation is variable. During vacation periods, more passengers will fly to vacation destinations. During the beginning or end of any weekday, business passengers can be expected between business destinations. During a convention, air traffic to the convention's location is predictable. The challenge that all airlines face is to maximize the sale of seats during those times when demand for transportation is high.

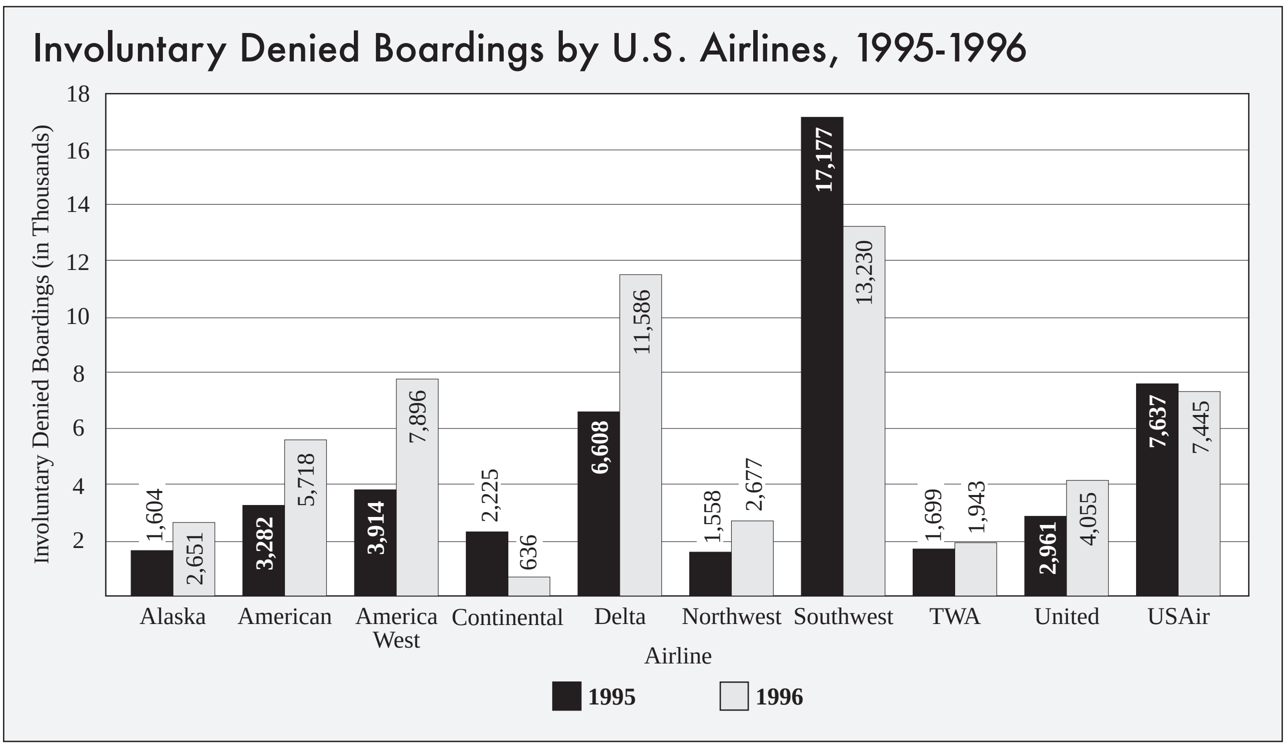
To determine the number of reservations that an airline will authorize to sell above the actual number of existing airplane seats, historical data of past departures are considered. These data include the number of passengers on similar flights during past time periods. Elaborate mathematical and statistical computer programs calculate these variables to predict as closely as possible the demand for seats.

The number of reservations that are then allowed to be sold is called the authorization level. On the average, the authorization level is set ninety days before departure, which is approximately how far in advance passengers typically begin to make reservations. Prior to the day of departure, authorization levels may be changed from their original estimates to take into account cancellations or changes that passengers have made to travel on other flights. On the day of departure, airline personnel initiate overbooking procedures for those flights that have more reservations than seats.

Overbooking planning assumes that all passengers holding reservations will show up for the flight. The first step is to determine by how many reservations a flight is overbooked. The second step is to arrange alternate flights for the extra passengers, preferably on the same airline. Other airline departures that are reasonably close to the flight's departure may also be considered. The third step is to establish what the airline will offer to motivate passengers to volunteer to give up their seats. Most airlines offer two kinds of voluntary compensation, as it is called. Voluntary compensation can be a voucher, in the form of either a dollar amount that can be applied to another trip or an outright free trip at a later date.

Every passenger who checks in for the flight is told that the flight is oversold and informed of the voluntary compensation and alternate flights. If passengers are interested in volunteering to give up their seats, the airline personnel enters these data into the computer, so that the gate agents know who and how many volunteers have been generated. If all the seats are taken prior to departure, passengers to whom seats cannot be assigned are considered potentially to be involuntarily denied boarding. Other computer entries are made so that the gate agents know to whom they owe a seat. If passengers to whom seats cannot be assigned wish to volunteer, they may do so.

As the departure time approaches, it is the objective of overbooking planning that the number of volunteers will exceed the number of involuntary passengers. At thirty minutes prior to departure, those passengers with reservations who have not as yet purchased tickets may be cancelled from the flight. At twenty minutes prior to departure, the seats of those passengers who have not checked in for their reserved seat assignments are released. These entries establish the actual situation of the overbooking. Often the cancelled reservations and the released reserved seats free enough seats to accommodate the passengers who require seats. If they do not, other



Source: Data taken from U.S. Department of Transportation.

computer entries are made to give the seats of volunteers to those who still require them. If, after that step, all passengers have been accommodated, the volunteers are notified that their seats were taken. Either the gate agents or other designated agents then arrange the alternate flights and issue the voluntary compensation.

If, however, there still remain passengers who will be left behind, these passengers are due what is called involuntary denied boarding compensation. This type of compensation may be the same as the voluntary compensation that had been previously offered or some other form of compensation, depending on how soon the airline can get the passengers to their destination. If the airline can get the passengers to their destination within one hour, no compensation is due. However, the voluntary compensation is usually offered. If the airline can get the passengers to their destination within two hours, they are due 100 percent of the value of their one-way ticket or $200, whichever is less. If the two-hour time frame is not possible, they are due 200 percent of the value of their one-way ticket or $400, whichever is less. Airlines are obliged to provide payment on the day or within twenty-four hours of the denied boarding.

After the aircraft departs, the numbers of volunteer and involuntarily denied passengers are communicated to the departments that set authorization levels for their consideration and analysis.

Overbooking is both an emotional and a financial issue. No passenger wants to be left behind, and every airline wants to fill every seat. Although every attempt is made on the part of the airlines to accurately predict and analyze actual passenger numbers, the fact that customers make reservations and do not show up for their flights remains a sensitive issue.

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See also: Air carriers; Airline industry, U.S.; Boarding procedures; Ticketing

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Pan Am World Airways

Date: First regularly scheduled service on October 28, 1927; ceased operations on December 11, 1991

Definition: One of the largest and most successful airlines in history until 1991.

Significance: Pan Am was, for a time, the largest, most successful airline in the world and the chosen instrument of the U.S. State Department in international air transportation, establishing routes throughout Central and South America and across the Atlantic and Pacific Oceans.

Early History

Pan American World Airways began as the vision of one man, Juan Terry Trippe, a Yale University graduate who had learned to fly during World War I. Trippe was convinced that the future of commercial aviation lay in international air transportation with operational guarantees furnished by governments in the form of airmail contracts. He founded what was to become Pan American Airways by outmaneuvering other companies in acquiring a mail contract and exclusive landing rights in Cuba. To accomplish this feat, he used political and financial connections cultivated in his undergraduate days at Yale.

Thus, what would become one of the largest and most successful airlines in history began operations with a 90-mile route from Key West, Florida, to Havana, Cuba. Throughout the airline's history, Trippe repeatedly applied the lessons he learned in obtaining this route. He ruthlessly used political, family, and financial ties to expand Pan Am. With the assistance of the U.S. State Department and the U.S. Post Office, he negotiated landing rights throughout the Caribbean, Central America, and South America. Whenever possible, these landing rights were exclusive, in effect prohibiting other airlines from operating in these countries.

Pan Am, under Trippe's leadership, expanded by winning every airmail contract offered through the U.S. Post Office in Central and South America. By November, 1930, the airline was operating to Buenos Aires, Argentina. In fewer than four years, the original 90-mile route had been expanded to one of more than 13,000 miles.

Acquisitions and Mergers

When Pan Am found it impossible to operate within a foreign country or found an established airline already operating, it simply bought controlling interest in the operating airline and continued to operate it as a subsidiary. Thus, airlines such as Compania Mexicana de Aviacion became part of the Pan Am empire in 1929. Pan Am also joined with the W. R. Grace steamship line to form PANAGRA to operate along the west coast of South America. In a 1930 hostile takeover allegedly sanctioned by the U.S. postmaster general, Pan Am acquired the New York, Rio, Buenos Aires Line (NYRBA), which had established a route along the east coast of South America. At the same time, Pan Am established a Brazilian subsidiary, Panair do Brazil, in order to comply with prior agreements between Brazil and NYRBA. Pan Am gained controlling interest in the Colombian airline SCADTA in a secret agreement of which even the governments of Columbia and the United States were unaware. Pan Am did not limit its grasp to Central and South America, however, purchasing two small airlines in Alaska and an interest in China National Airways. Trippe's dream for Pan Am had expanded across both the Atlantic and Pacific Oceans.

Two major obstacles stood in the way of this expansion. The first was the technology of existing aircraft, which were, in their range and payload, inadequate for long, transoceanic flights. The second impediment was international relations. European countries, particularly Great Britain, were unwilling to grant Pan Am landing rights in their territory until their national airlines were capable of competing. Trippe, in typical fashion, placed Pan Am in the position to overcome both of these difficulties.

Aircraft Technology

Pan Am worked closely with manufacturers to develop aircraft capable of servicing the developing transoceanic routes. Although Pan Am's first aircraft had been the Fokker Trimotor, it was soon apparent that more advanced designs were required. Pan Am began to rely heavily on the designs of Russian American aeronautical engineer Igor Sikorsky, who produced large flying boats. Pan Am decided that the flying boat was the most appropriate design for their operation, because many of the countries to which they were operating had no major airports. Virtually all, however, had adequate areas for waterborne operations. Sikorsky designed multiengined flying boats that could carry up to forty-two passengers at 140 miles per hour. These aircraft serviced the routes throughout Central and South America and conducted proving runs across the Atlantic and Pacific Oceans.

Pan Am also hired aviation pioneer Charles A. Lindbergh as a technical consultant. Much of Lindbergh's expertise went into the development of the advanced designs that soon appeared, such as the famous Pan Am Clippers built by Sikorsky, Martin, and Boeing. The range and payload of these aircraft were in direct response to Pan Am's operational needs. These designs culminated in the Boeing 314, considered the ultimate development of the flying boat. With suitable aircraft, Pan Am began to pursue expansion across both the Atlantic and Pacific. The major problem remaining was the resistance of foreign governments to Pan Am's encroachment. Lindbergh, who played the role of goodwill ambassador, made a number of transatlantic and transpacific proving flights for the airline.

International Relations

Although Pan Am's immediate goal was transatlantic service, major difficulties remained in negotiating agreements with European governments. Great Britain was especially reluctant to allow Pan Am access until British Imperial Airways was capable of flying comparable routes. On February 22, 1937, a reciprocal agreement was reached, and Pan Am's transatlantic service finally began on July 8, 1939. Unfortunately, Britain was soon at war. The difficulties in negotiating reciprocal agreements with European nations had caused Pan Am to pursue expansion across the Pacific. Taking maximum advantage of U.S. State Department concerns about Japanese expansion and fortification of its possessions in the Pacific, Pan Am worked closely with the U.S. Navy to establish a series of bases from Hawaii to Midway, Guam, and the Philippine Islands. Pan Am's service to Hong Kong began on November 22, 1935. As the United States became inevitably drawn into World War II, the State Department began to utilize the services of Pan Am more openly. On November 2, 1940, a subsidiary of Pan Am, the Pan American Airport Corporation, contracted to construct bases across Central America. These bases were designed to allow the ferrying of aircraft to North Africa to supply the Allied forces there. Pan Am also contracted to fly a regular service across the Atlantic to Cairo, Egypt, in support of British troops. Another subsidiary, Pan Am-Africa, constructed a series of bases across Africa. Pan Am began scheduled service to Khartoum in July, 1941. Pan Am continued to increase operations throughout the war years, emerging from the war as the world's dominant international airline. However, the war also introduced an element of competition into Pan Am's monopoly, and a shift in the political winds spelled trouble for the airline.

Postwar Difficulties

Pan Am enjoyed unparalleled success during the 1930's. International passenger traffic increased from approximately 44,000 in 1930 to more than 246,000 by 1939. Mail rates in the Pacific were increased significantly beginning in 1939, primarily due to the recommendation of the Navy. By 1942, Pan Am had a gross income of $109,000,000 and a staff of 88,000.

World War II introduced competition for Pan Am in the form of Trans World Airlines (TWA) and American Airlines. These hitherto domestic operators were awarded international routes in support of the war effort. These awards were particularly troubling to Pan Am, because they included the lucrative transatlantic route on which Pan Am had expended so much effort and expense. By war's end, although Pan Am remained the major transatlantic carrier with more than 15,000 flights, American and TWA had also become major international carriers. Both airlines had garnered significant international experience: TWA had made 10,000 transatlantic crossings, and American had made 5,000.

In addition to international competition, Pan Am had other problems. With only four domestic terminals and no domestic routes, the company was not positioned to benefit from the dramatic increase in domestic air traffic caused by the war. Although Pan Am had lost its exclusivity in international operations, it was unable to expand domestically to contend with its new international competitors. Additional concerns arose as early as 1943, with the Roosevelt administration's call for an international open-skies policy to be enacted after the war. This would open international operations to a number of airlines and further threaten Pan Am's position of primacy. Roosevelt chose not to recognize any one airline as the chosen instrument of the United States and invited bids from airlines interested in establishing international routes. Two Atlantic and three Pacific routes were opened for competitive bidding.

Pan Am attempted unsuccessfully to use political pressure to forestall Roosevelt's efforts, and was confirmed on its routes to London, continuing to Calcutta, India. Although this confirmation in effect allowed Pan Am to fly around the world, with its Atlantic and Pacific routes meeting at Calcutta, both TWA and American were confirmed in their transatlantic routes. Roosevelt's death did not improve Pan Am's government relations; his successor, President Harry S. Truman awarded routes to Central and South America to Braniff and Eastern. In 1945, National, American, and Chicago and Southern were awarded routes that ventured into Pan Am's prewar empire. Northwest Airlines was allowed to compete with Pan Am in the Pacific, connecting with TWA to form an around-the-world service. Finally, United Air Lines was granted a San Francisco-to-Hawaii route that actually duplicated the route pioneered by Pan Am in the 1930's.

The Jet Age

Despite the changes that eroded Pan Am's position of dominance, Pan Am remained a very successful airline. Under Trippe's guidance, it was poised to enter the jet age. Trippe negotiated with a number of manufacturers to develop a jet transport that would adequately service long-haul routes, and Pan Am placed the largest aircraft order ever made, totaling $265,000,000 and including twenty Boeing 707's and twenty-five Douglas DC-8's. On October 19, 1958, Pan Am officially launched the jet age of transatlantic travel, with its first jet flight carrying 111 passengers at a speed of 475 miles per hour. This tremendous gamble paid off, and the aircraft dominated the transatlantic route. However, Pan Am's lack of domestic routes would cause the airline increasing difficulties.

Trippe's final major decision was to purchase the wide-body Boeing 747. In April, 1966, Pan Am announced the purchase of twenty-five Boeing 747's at a cost exceeding one-half billion dollars. Pan Am made its first 747 flight in January, 1970. By this time, Trippe had retired as Pan Am president and had been replaced by a succession of leaders who were unable to continue the pattern of innovation and success Trippe had carried out for forty-three years. Economic factors, a slowdown in passenger growth, and politically motivated decisions by the Johnson administration to increase competition in the Pacific had a dire effect on Pan Am. In addition, the airline experienced a series of crashes that destroyed eleven aircraft and resulted in numerous fatalities.

The seemingly invincible airline's hard times grew worse. Attempts to merge with other major airlines were unsuccessful. In just three years, Pan Am lost more than $120 million, and its debt exceeded $1 billion. In 1974, Pan Am was denied a government subsidy. As the airline struggled to survive, employment was reduced to 27,000, and a number of international routes were relinquished to TWA. In an attempt to establish a domestic route structure, Pan Am acquired National Airlines at a cost of $374 million; however, the purchase only intensified the airline's problems. By 1980, Pan Am was losing more than one million dollars a day, and the first quarter of 1981 saw a record loss of $118.8 million. The company's New York headquarters were sold, as were other resources, and orders for new aircraft were cancelled. In 1985, the employees went on strike, and Pan Am sold its Pacific routes to United.

On December 21, 1988, the final catastrophe occurred. A terrorist bomb destroyed Pan Am Flight 103 over Lockerbie, Scotland. This tragedy, coupled with the Iraqi invasion of Kuwait in 1990, sealed Pan Am's fate. Most remaining assets and aircraft were sold to Delta Air Lines. Pan American World Airways ceased to exist on December 11, 1991.

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See also: Air carriers; Airline industry, U.S.; Airmail delivery; Commercial flight; Jumbojets; Mergers; Igor Sikorsky; Terrorism; Trans World Airlines; United Air Lines

Paper airplanes

Definition: Paper folded and creased into the shapes of airplanes.

Significance: Learning to fold and fly a paper airplane is a basic study of aerodynamics.

History of Paper Airplanes

Human experimentation with flying did not begin with the Wright brothers. People have been fascinated by flight since ancient times. The first flying devices made from paper were kites, constructed by the Chinese around 1 C.E. Even Leonardo da Vinci tried to devise a way for humans to fly. It is said he used parchment folded into winged flyers during his experiments. At the beginning of the twenty-first century, paper airplanes were used as a common technique to study aerodynamics. During World War I, flying paper airplanes became a popular activity with children. In the 1940's, the General Mills Company offered a series of fourteen paper model warplanes.

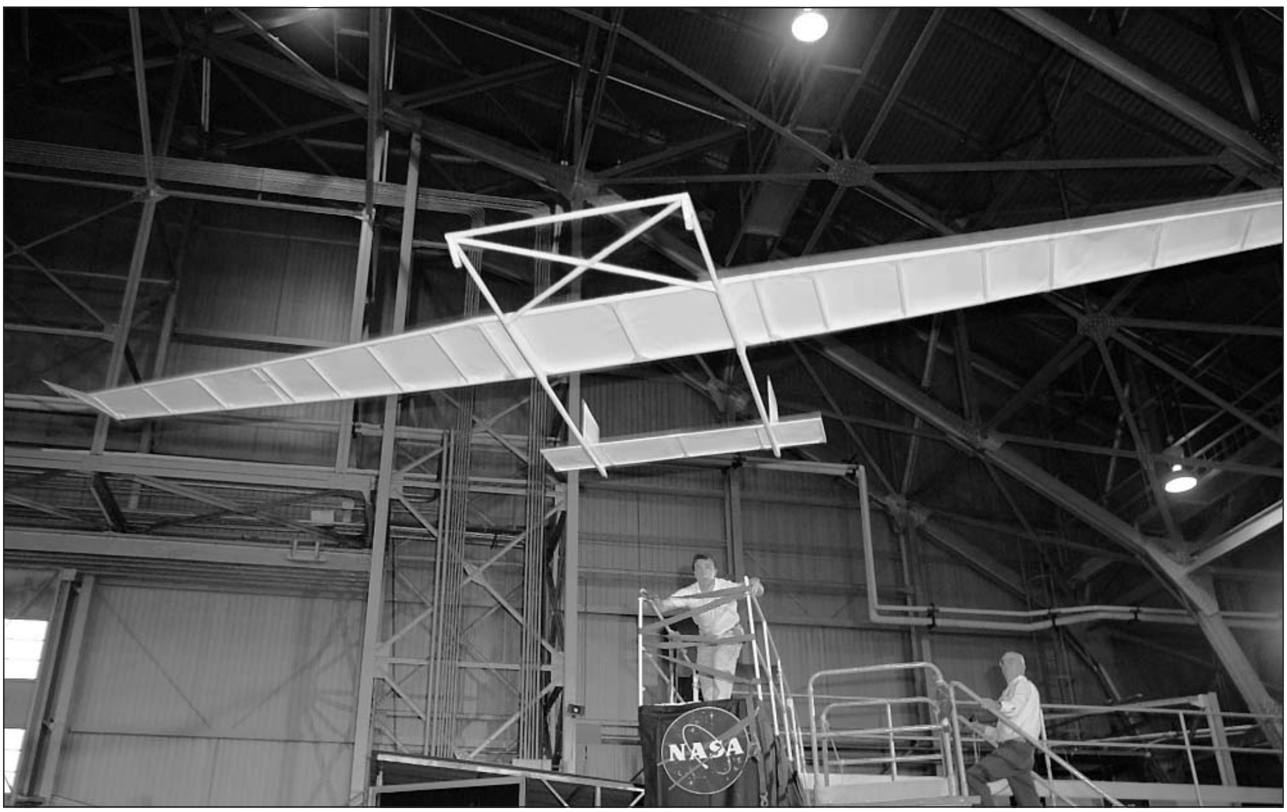
How Airplanes Fly

The wings of an airplane share a shape with those of insects, bats, and birds, called an airfoil. An airfoil is curved on top and flat on the bottom. Air rushing over the wing travels faster than the current going under the flat bottom of the plane. The eighteenth century Swiss scientist Daniel Bernoulli discovered that when air speeds up, its pressure is reduced. When air slows down, its pressure is increased. Therefore, the slower air going over the wing pushes down, which is known as weight, or gravity. The faster air under the wing pushes upward. This tug-of-war between opposing forces is what causes lift. During level flight, lift and weight pull equally. If lift pulls harder, the plane will rise. If weight pulls more, the plane will fall.

The center of lift on a paper airplane is the point at which lift seems to be working. The center of gravity is the balance point of the plane, the point at which gravity seems to be working. On paper airplanes, the center of gravity needs to coincide with the center of lift. If the center of lift is in front of or behind the center of gravity, the nose of the plane will pitch up or down accordingly.

Another set of opposing forces present during flight are drag and thrust. These two forces are what pull the plane forward or back. Real planes get their thrust from a propeller or engine. Paper airplanes get their thrust from being launched or thrown by a person. A throw gives a plane its initial speed, and gravity pulls it along.

When a plane flies level, drag is what pulls it back. Most of drag comes from air resistance. As a plane flies, air sticks to it, creating turbulence, or resistance to motion. If the nose of a plane points down, gravity will add thrust and the plane will crash. Any surface not parallel to the flow of air adds drag. Sharp creases and accurate folding will reduce drag and increase time aloft. Lift also contributes to drag by pulling up and a little back. A typical paper airplane's drag is one fifth of its weight.



This paper airplane, constructed in 1992, broke the world record for size. (NASA)

Differences in wing loading, the specific amount of weight a standard size area of the wing lifts in flight, will create difference in speeds. Wing loading is how many pounds per square foot the wing is lifting. The larger the wing area, the less wing loading and more slowly the plane will glide.

Building a Stable Craft

Another factor that affects flight is stability, which helps an airplane return to steady flight after a bad throw or a strong gust of wind. There are three basic types of stability: pitch, directional, and spiral.

Pitch stability keeps the airplane flying at a constant speed. If the nose of a plane pitches up, the plane will slow down. If it pitches down, the speed will increase. There is a small distance along the length of a plane where it must balance to provide optimum pitch stability. On a paper airplane, this distance is less than one inch long. If the balance point is too far forward, the plane will dive; too far back, and it will spin out of control.

Directional stability can be maintained by creating a fin on the back of the plane to counteract the tendency to spin. On most paper airplanes, the body acts as the fin. If most of the plane's body is behind the balance point, it will be directionally stable. Bending the wing tips up will add to its stability.

Spiral stability is when the plane flies straight and smooth. A spirally unstable plane will circle, turning tighter and tighter, until it spins into a dive. To correct a spirally unstable plane, the wings, as viewed from the nose, should be bent up slightly so that they make a Y shape with the body.

Flying Techniques

Getting a good flight out of a paper airplane requires a good throw. To get the most out of a throw, the plane should be held on the bottom near the front, using the forefinger and thumb. How a plane is thrown depends on the type of flying intended. The types of flying include slow flight, fast flight, and high (world record) flight.

Slow flight is achieved by holding the plane in front of the shoulder and pushing the plane forward and slightly downward. For fast flying, the plane should be held in front of the shoulder for short flights and above the shoulder for long flights. The high throw is mainly used for competition and is achieved by throwing the plane straight up as hard as possible. If done properly, the plane will spiral up, level off, and glide slowly forward.

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See also: Aerodynamics; Airfoils; Airplanes; Flying Wing; Forces of flight; Model airplanes; Tail designs; Wing designs

Parachutes

Definition: Large, umbrella-like devices attached to people or other objects by ropes called shrouds and used to slow down falls to the ground from aircraft or any other great height.

Significance: Parachutes are the best known devices for emergency escape and descent from endangered aircraft. Their other uses include deploying paratroops; distributing airborne food, supplies, weapons, and assault or other vehicles; decelerating aircraft for landing; recovering space vehicles; and skydiving, or sport parachuting.

Development

A parachute is a very light, flexible device which is intended to retard the passage of an object through Earth's atmosphere to the ground. Parachutes resemble huge umbrellas. They are most frequently used to slow the fall of a human or of other valuable objects from high-flying aircraft or from any other great height, most often ensuring a safe landing. The term "parachute" derives from a French term which means to protect one from a fall or a bad tumble.

The theory of the parachute is credited to the fifteenth century Italian genius Leonardo da Vinci. However, the first practical application of a parachute occurred in the late eighteenth century. At that time, parachutes were used for exhibition purposes in France to allow aeronauts quick descent from gas-filled balloons. By the beginning of World War I, this use had evolved into the application of parachutes as life-saving devices for emergency jumps from damaged aircraft. By the 1920's, parachutes had become familiar devices with widespread military uses, including the dropping of airborne troops (paratroopers), weapons, vehicles, and supplies. Parachutes have developed many additional uses related to peacetime aircraft recovery and to spaceflight.

Operation

Parachute operation is based upon several simple principles of physics. Two forces act on falling objects. These are gravity (or Earth's gravitational force) and air resistance. Gravity pulls any object initially suspended in the atmosphere downward, toward Earth's surface. Air resistance, due to particles of matter in the air, slows a falling object's movement. The pull of gravity is so much stronger than air resistance that the downward speed of a falling object, whether a rock or a human, is only slowed very slightly.

With two objects of the same weight, air resistance is much greater for the one which has the larger surface area. This is because objects of the same weight with large, flat surfaces, such as clay saucers, offer greater areas of resistance to the air than those with small surfaces, such as a clay brick of the same weight as the saucer. Therefore, when an object is shaped like a saucer, it falls more slowly than a sphere of the same weight.

Design and Construction

Parachutes designed for human use are all oblate hemispheres 2 to 3 feet across when open, and of weights ranging between 22 and 30 pounds. Parachutes used to drop cargo are often 100 feet across or larger, and heavier. Parachutes used to decelerate aircraft or spacecraft for landing and recovery are even larger than this. They are also most often used in assembled groups of three or more parachutes. The most common parachute used by humans is the seat pack model associated with a seat in an aircraft. The other kinds of parachutes attach directly to the chest or the back of a wearer.

All parachutes are worn on harnesses. Each parachute harness is made up of a group of straps fitting around the shoulders and the legs of a parachutist. The parachute harness straps connect parachute and parachutist, also supporting the parachutist during descent to the ground. Straps called risers are attached to the shoulder portions of the parachute harnesses to hold the lines, called shrouds, that attach to the parachute canopy. The canopy is the umbrella-like part of the parachute. A rip cord is also attached to a harness strap, usually on the parachutist's left side. It terminates in a ring that the parachutist pulls soon after jumping. Pulling a rip cord causes the parachute canopy and its shrouds to leave their enclosing pack. This process is accomplished by the ejection of a small parachute from the pack. The small chute opens and pulls the larger one out after it. As each canopy leaves the pack, air enters it and causes it to open. All parachutes are carefully folded before insertion into their carry packs. This careful treatment makes sure that the parachute will open properly when the rip cord is pulled by a parachutist.

The initial opening of the canopy can slow down the descent through the air so quickly that the parachutist is jerked sharply upward in "opening shock." To reduce the extent of this opening shock and to stabilize the parachutist's descent, manufacturers use several canopy modifications that lead to a planned canopy air porosity. Often, ribbon canopy material, having planned holes (slots), is used. These slots allow enough airflow through the canopy to reduce air resistance and minimize opening shock. They also help to minimize parachutist sway and maximize comfort during the descent. Another type, the vortex-ring parachute, is composed of four sections that rotate during the descent, functioning like a helicopter rotor to produce maximum parachute stability.

A parachute is most often made of one type of material, usually nylon, silk, cotton, rayon, or a plastic film, although mixed materials are used in some cases. The fiber is turned into cloth for canopies, cord for shrouds, and webbing for harnesses. The most important parachute construction factors include proper air porosity, adequate material strength, good aerodynamic behavior, the lightest weight possible, and easy operation. The materials experimented with and used increase as new fabrication techniques, new artificial polymers, and new fabrics develop.

Parachute Jumping and Parachute Uses

Parachutes are decelerators (or air brakes) that allow parachutists to descend toward Earth at rates of 9 to 11 miles per hour, depending on the parachutist's weight and the canopy's diameter. All parachute jumps made from under 500 feet above ground level are very dangerous because this height does not allow enough distance and time for complete parachute opening. Even safe jumps can lead to parachutists landing with great force, due to the excessive rate of

Nylon in Parachute Construction

Nylon is a synthetic polymer widely used for brush bristles, molded items, and textiles such as those from which parachutes are made. Characterized by great strength, toughness, and elasticity, nylon 66 was developed in the 1930's by scientists working for E.I. du Pont de Nemours & Company. It is made by polymerizing two chemicals called adipic acid and hexamethylenediamine. Another good nylon, nylon-3, is a similar polymer made from an amino acid called 3-aminopropanoate. Nylons are insoluble in water and most other solvents, and nylon 66 melts at 263 degrees Celsius.

To make nylon textile fibers, chips of the nylon polymer, a tough, whitish solid, are melted and pushed through holes in devices called spinnerets. The filaments are then partly solidified by air blown over them. The diameter of the solid filament is controlled by changing the rates at which molten nylon is pumped into a spinneret and at which filaments are pulled away from them. Strong filaments much thinner than those of natural textile fibers can be made from nylon. Nylon can be made to look like silk or can resemble fibers such as cotton. It can be dyed in liquid or filament forms, and its tensile strength is higher than that of wool, silk, rayon, or cotton. A nylon rope or thread can hold up three times as much weight as a steel cable of the same weight.

their decelerated fall, and spraining their ankles or breaking bones. This is most often true of jumps over rough terrain. Winds also add to landing dangers, because they engender sideways parachute motion through the air. The addition of this motion to air-braked fall speed causes some landings to seem like jumps from fast-moving automobiles and can cause similar injuries. It is therefore crucial that the parachutist be well trained in how to control a parachute. The other skills needed include a well-honed ability to judge the current wind speed, the altitude, the direction of sideways motion, and potential ground speed. Parachute jumping, or skydiving, nonetheless has become a popular sport that has a great many enthusiasts in Europe and America.

In skydiving, a slow-moving aircraft, cruising at a 2-mile altitude, is used as a jumping platform and skydivers often perform stunts while falling. Sport parachutes are unlike those used for simple descent. Many safety features are removed for ease in maneuvering. Also, the sport parachutes are often designed to be rotated by a control that regulates the direction of air passing through the canopy. In addition, skydivers do not pull their rip cords quickly after leaving the plane. Rather, they use an altimeter, which notes the rate of descent and indicates the last instant when the parachute can be opened safely.

In addition to the classical application of parachutes as devices to carry humans, parachutes are used to deploy paratroops in military assaults; to distribute supplies from aircraft; to slow, as needed, the rates of descent of bombs or flares; to decelerate jet airplanes during their landing; and to recover space vehicles and weather or flight recorders.

Sanford S. Singer

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See also: Forces of flight; Gravity; Military flight; Skydiving; Spaceflight

Parasailing

Definition: A recreational activity that allows a participant wearing a harness attached to a round parachute to be towed into the air behind an automobile or boat.

Significance: Parasailing is a popular form of recreational flight.

The inventor of parasailing was Pierre Lemoigne of France. In 1961, Lemoigne altered the design of a round parachute to ascend when towed behind an automobile. Parachutists referred to this method of lift as parascending. The development of parascending was triggered from a need of parachute instructors to lower the cost of training a new parachute trainee. Also, parascending allowed the instructor to tow the trainee to a specific altitude, one that would be a suitable dropping height from which the trainee would be released to make a landing on the ground. As this training method became popular, advancements in parascending led Lemoigne to the water. A boat was introduced as the towing vehicle in late 1961 and that introduction led to the renaming of parascending to parasailing.

Beach Method

With increased awareness of parasailing, more individuals were willing to participate not as parachute trainees but as ticket holders for a ride. Parasail concessions began offering rides at beachfront resorts. The parasailing rides offered to vacationers also created safety issues.

Injuries and deaths were connected to parasailing rides in the 1960's as a result of the combination of inexperienced parasail participants and inexperienced concessionaires' flight crews. A participant would be given instructions about the parasail and information on how a person would lift off the ground. The execution of the launch had two elements. First, the participant ran down the beach behind the boat. Second, the boat accelerated as the participant ran until lift was created. After the person was in the air and ready to end the ride, the descent began. The participant was visually instructed to pull certain lines on the parasail to land on the beach.

The beach method of launching and recovering a parasailer may look simplistic on paper, but it is simple only in theory. Injuries, including abrasions, cuts, and broken bones, occurred on launch and recovery. Some parasailers even died. These types of injuries occurred when participants were dragged through the sand during the launch or recovery procedure.

Platform Method

Although accidents occurred using the beach method of parasailing, the recreational sport increased in popularity as the activity evolved the platform method of launch and recovery. In 1971, Mark McCulloch designed a stationary parasail platform. The platform was positioned in a body of water to allow for the launch and recovery of the parasailer. Although platform parasailing was safer for participants, it was more costly to operate than the beach parasailing method because a five-member crew was needed to operate the ride. The beach method needed only a two-member crew for the launch and recovery operation.

Winchboat Method

Two years following the development of the platform method, the winchboat method evolved from it. The platform would no longer be stationary in the water, but was attached to the back of a boat so that it would move. This method allowed the concessionaire to have fewer crew members to operate the ride. By the 1990's, improvements in equipment, crew-member training, and participant awareness had made winchboat parasailing a safe aeronautical activity.

Parasailing has grown to capture the hearts of vacationers everywhere, which has led to an increased demand for the sport. This would not have happened if the beach resorts had not embraced it. Since the 1960's, concessionaires who offer parasail rides to their customers have forced the parasail manufacturers to improve the equipment and the training given to the buyers of the equipment. This has provided a safer environment for both parasailers and ride operators.

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See also: Hang gliding and paragliding; Heavier-than-air craft; Parachutes; Safety issues; Skydiving

Passenger regulations

Definition: Government-imposed rules to govern passenger behavior, consumer financial transactions, access to transportation by persons with disabilities, and treatment of victims and relatives after accidents.

Significance: Passenger regulations assist in the safe, secure, and efficient operation of air transportation and generally address three areas: safety and passenger behavior, such as compliance with crew commands, noninterference with performance of flight and cabin operations, and abiding by regulations of smoking and electronic and communications equipment use; consumer financial issues such as fares, fair advertising, refunds, and overbooking; and access to transportation by persons with disabilities.

Underlying Reasons for Passenger Regulations

Passenger regulations have been promulgated over the years to address different problems and the changing needs of both planes and people. Thus, passenger regulations have many origins and are under the jurisdiction of several different government offices. Generally, however, these regulations serve three purposes.

First and foremost is the need for passenger regulations to help ensure the safe operation of aircraft and to aid the crew in the event of an emergency. These passenger regulations generally restrict rights and freedoms that citizens might otherwise have if they were not in an airplane or airport. Such regulations aid in the safe operation of the aircraft and airlines and are found in the Federal Aviation Regulations (FARs), which are part of the U.S. Code of Federal Regulations (CFR). Implementation of these regulations and enforcement are the jobs of the Federal Aviation Administration (FAA). Regulations have the effect of law, and if passengers fail to comply and thereby endanger the safe operation of the aircraft or airport, they can be subject to legal enforcement action, including fines and imprisonment.

Examples of passenger regulations and restrictions of passenger behavior include compliance with orders of the crew regarding seat belt and tray table usage, baggage stowage, no smoking, emergency exit seating restrictions, and other emergency preparations. Passenger interference with air crew duties and engaging in behavior which endangers or harms the plane crew or other passengers, now commonly referred to as air rage, are also prohibited and punishable by fine or imprisonment. Regulations imposing age and physical capability restrictions on who can sit in an emergency exit row were added in response to disasters in which evacuation was hampered by persons unable or unwilling to open emergency exits. The requirements imposed by the Aviation Disaster Family Assistance Act of 1996 sought to remedy abuses and provide more information and assistance to families of crash victims. The act sets forth the obligations of airlines and others in the event of a plane crash, and gives passengers and victims' families rights to information and property after an accident.

The second major body of passenger regulations concerns economic issues. Somewhat like a codification of fair business practices, these passenger regulations are also in the Code of Federal Regulations but are under the jurisdiction of the Department of Transportation Consumer Protection Division. These passenger regulations give passengers some rights to prompt refunds, access to lower fares if available, compensation and substitute transportation arrangements or prompt refund if involuntarily bumped because of overbooking, and the right to have the class and type of service purchased, such as first or business class, and jet aircraft if the ticket was purchased on a jet service flight.

The third major area of passenger regulations guarantees access to and reasonable accommodation in air transportation to persons with disabilities. These regulations forbid airlines to have a policy of denying handicapped persons access to planes and require the airlines to make reasonable accommodations for aids such as wheelchairs, guide dogs and assistance animals, and certain medical equipment. Codified in federal law, the Department of Transportation Consumer Protection Division has oversight, but other federal laws also protect discrimination against persons with disabilities and give other legal remedies to persons with disabilities wrongly denied access to air, as well as any other, public transportation service.

Areas Not Covered by Passenger Regulations

Perhaps the biggest problems that frustrate and confuse passengers and airlines, and cause a great amount of air rage, are issues which are not covered by passenger regulations. In purchases of comparably priced or even less expensive consumer goods or services, consumer protection laws provide customers with warranties and product and service protection guarantees. However, even though airline tickets are more expensive than most other consumer goods and services, the U.S. Congress and the airlines have resisted comparable consumer protection regulations for airline passengers. Airline passengers may be left without remedies for poor service and other complaints, such as failure of airlines to provide passengers timely and truthful information about their flights. The issues typically involve canceled or delayed flights and the provision of hotel rooms, food, and other amenities when a flight is delayed or canceled. Other airline rules address rebooking on the same or another carrier after a flight cancellation or delay, the numbers and size of carry-on and checked luggage, and recovery and temporary assistance in the event of lost or delayed bags. Even though these issues are covered in each airline's rules, these rules are not government regulations and do not have the same force and effect. Furthermore, airline rules are not typically enforced by the federal government, although the Department of Transportation Aviation Consumer Protection Division does accept complaints and publishes a report about the number and nature of complaints against airlines.

The airlines' rules are, however, legally part of the airline's contract of carriage, or the tariff, which governs the terms of a ticket purchase. Failure of a carrier to abide by its own rules is a tariff violation, but passengers rarely bring such a legal action because the costs of doing so usually far outweigh the possible award for a violation of the contract of carriage. Airlines must make their contract of carriage available to any passenger who requests it. An airline's rules are to be available at the airline's airport facility and by mail upon request, and they can be accessed on the World Wide Web.

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See also: Air rage; Airline industry, U.S.; Federal Aviation Administration; Safety issues

Pearl Harbor, Hawaii, bombing

Date: December 7, 1941

Definition: Aerial attacks conducted by Japanese aircraft above on the U.S. fleet at Pearl Harbor, Oahu, Hawaii.

Significance: The Japanese attack on Pearl Harbor left two-thirds of the U.S. military aircraft stationed there destroyed or disabled and killed more than 2,400 servicemen. The Pearl Harbor bombing immediately drew the United States into World War II and opened up the Pacific theater of war.

Background

The Pearl Harbor attack represented the culmination of a decade of deteriorating relations between the United States and Japan over the status of China and the security of Southeast Asia. Since the early 1900's, Japanese military leaders had been gradually expanding their territory within the Asian mainland, as military extremists had overrun the northernmost Chinese province of Manchuria in 1931 without consent of the Japanese civil government. Upheavals within the infrastructure of the Japanese government became an ongoing and constant occurrence, most notably evidenced by repeated attempts by the civil government to exert more control over the previously independent Japanese military. Japanese generals began to resent receiving armed forces orders from bureaucrats rather than directly from the emperor, as had been the tradition.

Many Japanese military leaders felt that Nazi Germany's 1940 defeat of France, Britain, and the Netherlands had left Japanese territories in Southeast Asia exposed to invasion. As Japan joined Germany in the Axis alliance, many Japanese military leaders focused on the ambitious goal of establishing an empire that would be immune to economic sanctions, such as the oil embargo by which the United States was attempting to curtail Japan's expansion into China. As both the United States and Japan publicly established positions from which they could not retreat without loss of international prestige, Japanese generals plotted to attack Pearl Harbor as a preemptive strike to gain command of the western Pacific.

Although the Japanese had formally declared war on China in 1937 and the nations of Europe had launched

The Japanese bombing of the U.S. Naval Base at Pearl Harbor, on the island of Oahu, Hawaii, on December 7, 1941, brought the United States into World War II. (Digital Stock)

World War II in September of 1939, the United States had remained uninvolved in both conflicts. The American public, previously divided over U.S. entry into World War II, rallied together after the bombing of Pearl Harbor in commitment toward victory over Japan and its Axis partners. The aviation industry then received considerable focus as it became obvious that victory would come to whichever side controlled the skies.

U.S. Entry into World War II

On Sunday, December 7, 1941, 7:50 A.M., Japanese carrier-borne aircraft attacked Pearl Harbor, prompting the entry of the United States into World War II. In fewer than two hours, 365 Japanese aircraft flying from 33 warships and auxiliary craft temporarily crippled the U.S. Pacific fleet. After the smoke cleared, fewer than 80 of the 231 operational aircraft assigned to the Hawaiian Air Force were flyable.

In two successive waves, Japanese bombers, torpedo planes, and fighters either sunk or disabled eighteen U.S. ships. Commander Mitsuo Fuchida sent the coded messages “To, To, To” and “Tora, Tora, Tora,” telling the Japanese fleet that a complete surprise attack had been accomplished.

More than 200 U.S. aircraft, most of them still grounded, were either destroyed or heavily damaged, along with six land air bases. Seven of the Pacific fleet’s nine battleships were lined up unsuspectingly in the harbor along “Battleship Row,” on the Northeast shore of Ford Island. The battleships USS *West Virginia*, USS *California*, and USS *Nevada* were sunk in shallow water, the USS *Oklahoma* was capsized, and the USS *Arizona* became a nonfunctional wreck, with 1,177 crew members killed. U.S. losses included 2,117 Navy and Marine Corps dead, 218 Army dead, and 68 civilians dead, in addition to 1,300 wounded and 1,000 temporarily missing in the resulting chaos. Five minutes after the first Japanese bomb landed, U.S. antiaircraft fire began to register hits, although many American shells actually fell on Honolulu, where civilians initially assumed them to be Japanese bombs. U.S. Army Air Corps pilots managed to get a few fighters into the air and shoot down twelve enemy planes before the second wave of Japanese warcraft entered the area at 8:40 A.M. Japanese losses included only 55 casualties, 5 midget submarines that had attempted simultaneously to enter Pearl Harbor and launch torpedoes, and 29 of the 365 planes that made the attack.

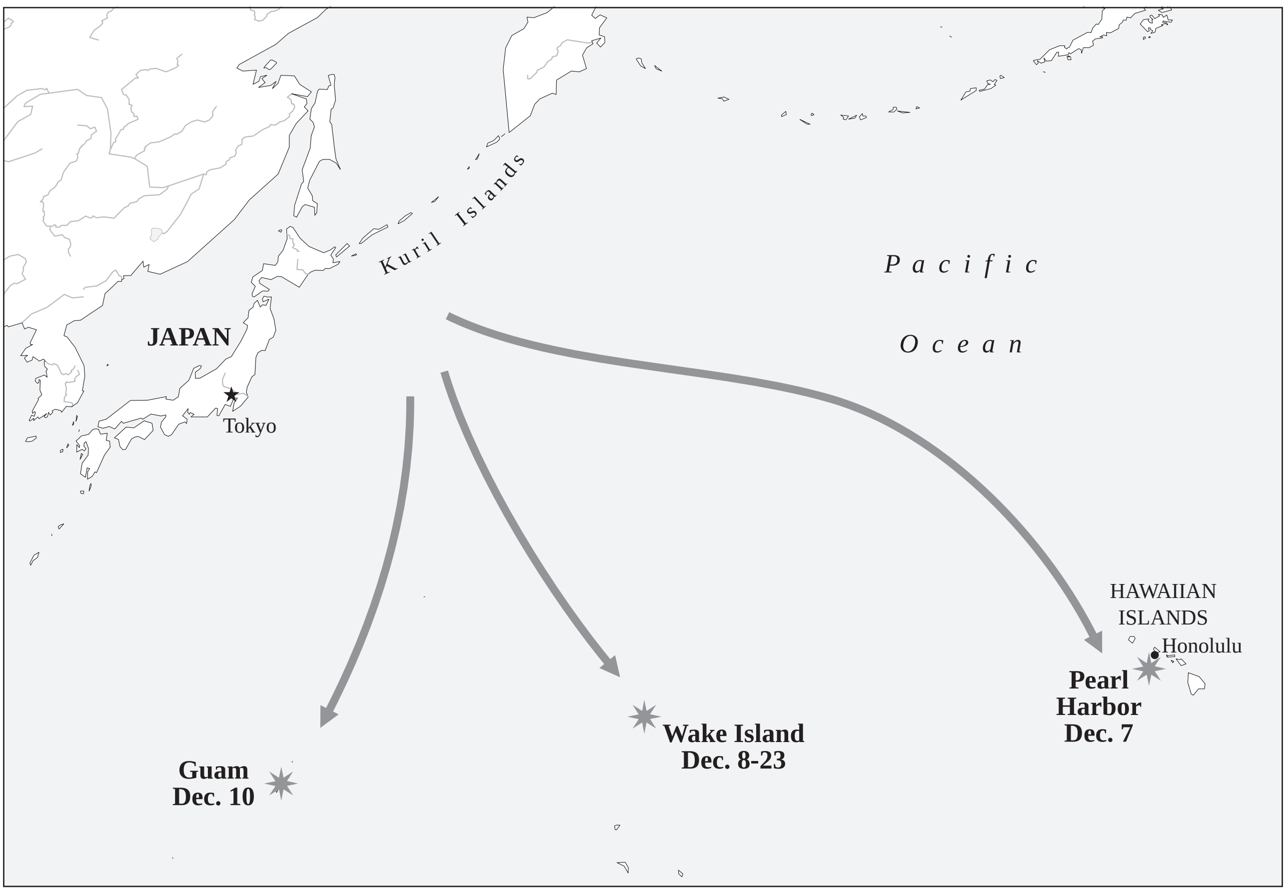
Japanese Air Strategy

Immediately after General Hideki Tojo took on the premiership of the Japanese empire in October, 1941, other military leaders warned him that only the U.S. Navy had the power to block Japanese expansion into Asia. The plan to cripple the U.S. Pacific fleet in one massive blow was deliberately masked behind false statements by Japanese representatives that implied their hope for continued peace with America. Japan was aware at the time of the bombing that Pearl Harbor functioned as a base to more than 75 U.S. warships, including battleships, cruisers, destroyers, submarines, and auxiliaries. What Japan did not know at the time, however, was that all U.S. aircraft carriers, essentially floating platforms from which air operations at sea were launched, were not then stationed in Hawaii, and that these carriers would later prove crucial to U.S. success in the Pacific.

The Japanese attack was devised and commanded by Admiral Isoroku Yamamoto, commander in chief of the Japanese combined fleet and one of Japan's stronger air power advocates. Although personally opposed to war with the United States at the time, Yamamoto knew that the success of the Pearl Harbor bombing was dependent upon a quick and silent attack. The U.S. military was not totally surprised by the possibility of a Japanese attack in the Pacific, although the bombing was essentially a complete shock to American civilians. However, U.S. leaders were embarrassingly caught off guard by Japan's unexpected ability to quickly achieve such a long-range air strike.

On November 26, six Japanese aircraft carriers, two battleships, three cruisers, eleven destroyers, and several tankers, carrying a total of 365 combat aircraft, had departed in secret from the Kuril Islands under the command of Vice Admiral Chuichi Nagumo. Their launching position 275 miles north of Hawaii was reached at 6:00 A.M. on December 7. By 7:55 A.M., the first of two waves of Japanese planes struck Pearl Harbor, bom-

Japanese Attacks on Pearl Harbor and the Central Pacific, December, 1941



barding airfields and battleships moored at the concrete quays.

The Pearl Harbor bombing was just one of a series of Japanese strikes throughout the Far East. Almost simultaneously, Japanese naval and air forces attacked Wake Island, Guam, British Malaya, Singapore, the Dutch East Indies, Burma, Thailand, and the Philippine Islands, destroying many U.S. land-based combat aircraft in the Pacific. Japanese troops later occupied Siam with the consent of that government.

Japan's clear intention in attacking Pearl Harbor was to disable the U.S. fleet and reduce opposition against their war of conquest across the eastern Pacific. After Pearl Harbor, Japanese ambassadors publicly accused the United States of standing in the way of their "new order in East Asia." The destruction of Allied sea power in the Pacific would win Japan access to Malaya, the East Indies, and other Southeast Asian areas, which all had supplies of raw materials the Japanese felt would ensure their success in future World War II battles.

U.S. Retaliatory Strategy

The Pearl Harbor bombing was described the following day by President Franklin D. Roosevelt as "a date which will live in infamy." Two and one-half hours after the surprise attack, Japan declared war on the United States and Great Britain. The following morning, Roosevelt called on the U.S. Congress formally to declare war on Japan. On the afternoon of December 8, 1941, the United States, Canada, and Great Britain declared war on Japan, and on the next day, China declared war on the Axis powers. On December 11, Germany and Italy, bound by treaty to Japan, declared war on the United States. World War II had become a global conflict. Although Honolulu was the only U.S. city to be attacked, the U.S. Army proclaimed martial law in fear of an invasion attempt, the act of which was later found to be unconstitutional by the Supreme Court. Not until October, 1944, was the civil government of the United States officially restored.

Because the United States had expected any potential Japanese aggression first to take place in the Philippines or Southeast Asia, no U.S. aircraft carriers were in port in Pearl Harbor on December 7, 1941. These carriers would later prove crucial to U.S. military success in the Pacific. Although the Pearl Harbor bombing was initially a tremendous success for the Japanese, it enraged a vast majority of Americans enough to show immediate public support for entry into World War II. Also significant was the fact that the Japanese had failed to destroy the vast oil supply adjacent to Pearl Harbor, thus leaving a significant fuel supply for American ships and planes.

Although many Japanese-Americans and persons of Japanese birth were interned, a vast majority of Asian-Americans worked peaceably on the plantations and on construction projects. Many Hawaiian-born Japanese-American troops achieved a notable combat record in Italy during the war.

Aircraft Development

Historians often note that nothing speeds up the development of machinery and technology in the aviation industry faster than war or even the threat of war. At the time of the bombing, the U.S. Army Air Force had only 1,100 combat-ready aircraft. By 1944, the Army Air Force had nearly 80,000 combat aircraft in sixteen separate air forces stationed around the world. U.S. airplane technology went through more changes immediately following the initial events of World War II than during the previous two decades of peace. The best piston-engine fighters developed during World War II were able to reach speeds of 460 miles per hour, nearly twice the speed of previous biplanes. The B-29 was America's most effective combat aircraft against both land- and sea-based antiaircraft guns and enemy fighters in the sky. As piston-engine planes reached their full potential, jet-propelled aircraft began to be developed. The economy of the aviation industry turned into a war machine, utilizing manpower and materials at record levels, as the Allied and Axis powers raced against time and each other.

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See also: Air force, U.S.; Aircraft carriers; Antiaircraft fire; Navy pilots, U.S.; Kamikaze missions; Military flight; Superfortress; World War II

Auguste Piccard

Date: Born on January 28, 1884, in Basel, Switzerland; died on March 24, 1962, in Lausanne, Switzerland

Definition: Physicist noted for explorations in both the upper atmosphere and in the ocean.

Significance: Piccard pioneered the development of pressurized airtight compartments. His design became the basis for such structures in modern airplanes.

Auguste Piccard was among the most prominent members of a family devoted to scholarship. His father, Jules Piccard, was a professor of chemistry at the University of Basel. Auguste's twin, Jean, earned a degree in chemistry and eventually held positions at several universities.

Piccard early developed a fascination for science. As a child, he was interested in the biology of the oceans; eventually this led him to design a ship to study ocean depths. Piccard enrolled in the Swiss Federal Institute of Technology in Zurich, studying physics. In 1904, he published his first scientific paper.

In 1910, Piccard was awarded a degree in mechanics from the institute, becoming a member of its faculty. He soon developed a gauge for measuring air pressure, and participated in his first balloon ride into the lower atmosphere. In 1914, he was awarded a doctorate by the institute.

Piccard's research during this period dealt with the study of cosmic rays. His appointment as a professor of applied physics at the University of Brussels in 1922 provided him with the opportunity to combine his expertise in mechanics and engineering with such study. A major difficulty in the observation of cosmic rays was caused by their absorption by the atmosphere. Piccard reasoned that if one could travel into the upper reaches of the atmosphere, interference could be negated. The low atmospheric pressure at such heights, however, had proven fatal to those who had made such attempts. With funding provided by the Belgian government, Piccard designed a pressurized, airtight cabin in a balloon, which would allow penetration into the stratosphere.

On May 27, 1931, Piccard and his assistant Paul Kipfer reached an altitude of 51,762 feet. Unable to release enough hydrogen to land, Piccard and Kipfer waited until sundown, when the cooler temperature allowed the balloon to land on an Austrian glacier; altogether, they were in the air approximately seventeen hours. On August 18, 1932, Piccard and Max Cosyns made a second ascent into the stratosphere in a redesigned cabin, reaching a height of 61,221 feet.

In the late 1930's, Piccard began the design of a bathyscaphe (a navigable submersible) that could be used to study the ocean depths. Interrupted by World War II, Piccard did not complete his design until 1948. In 1953, Piccard, accompanied by his son Jacques, made a dive to a depth of over 10,000 feet. Piccard retired from the University of Brussels in 1954, returning to Switzerland, where he died in 1962.

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See also: Aerodynamics; Balloons; Buoyant aircraft; Heavier-than-air craft; High-altitude flight; History of human flight; Lighter-than-air craft

Pilots and copilots

Definition: Pilots are the men and women in command of flying aircraft. Helping pilots are their assistants, copilots, also known as first officers.

Significance: Pilots and copilots are the people who take an aircraft where it needs to go. Whether amateur or professional, they must demonstrate their mastery of the skills needed to fly an aircraft and obtain licensing before they are allowed to fly solo. The pilot and copilot are responsible not only for their own safety but also the safety of their passengers, of others flying near them, and those on the ground beneath them.

The majority of pilots are hard-working men and women who work in an office in the sky. It is a mobile, dynamic working environment. Although the skills necessary to pilot a plane are many and the responsibilities great, with proper training almost anyone can learn to fly.

Requirements

For those aspiring to the professional track, there are many different jobs in the aviation industry, such as military pilots, charter pilots, and flight instructors. There are also jobs flying the bush in Alaska and Canada; fish spotting off the coast all around North America; towing gliders and aerial signs; or flying sightseers and photographers.

Pilots do not have to be perfect specimens of health. Some pilots fly challenged by shortcomings such as impaired hearing, paralysis, and even the loss of a limb. However, those who fly must meet certain minimum health standards. For example, they must be able to see and they must have normal cardiovascular function. Although some medical situations will prevent people from working as professional pilots, many can still fly their own aircraft.

As a private pilot, there is some relief from the pressure of medical examinations. A working airline transport pilot, for instance, must undergo a complete flight physical every six months. Professional pilots under a Commercial Pilot Certificate have a physical examination by an authorized medical examiner once each year. Private pilots are required to undergo a physical once every three years before their fortieth birthday and once every two years after they turn forty.

Pilots are not required to have college degrees. However, professional piloting positions on the high end of the scale require individuals to have completed their baccalaureate degree or, in some cases, a graduate degree. For a Private Pilot Certificate, the only educational requirement is that one be able to read, speak, and understand the English language. An applicant for the private pilot license must be seventeen years of age for certification by the Federal Aviation Administration (FAA).

The equivalent of a high school education will provide the required background to develop the skills and knowledge required in becoming a private pilot. After private pilot certification, if a pilot decides to pursue advanced ratings and a commercial pilot's license, formal study in the fields of aviation, math, and physics will be helpful, but not required. The military services require a college degree of pilot candidates. In the airline industry, baccalaureate degrees are preferred but may not be required, depending on the pilot situation. Fluctuations in the pool of available pilots may also affect the minimum education requirements for professional pilots; in times of pilot shortage, college degree requirements may be waived, while in times of pilot abundance, requirements become more stringent.

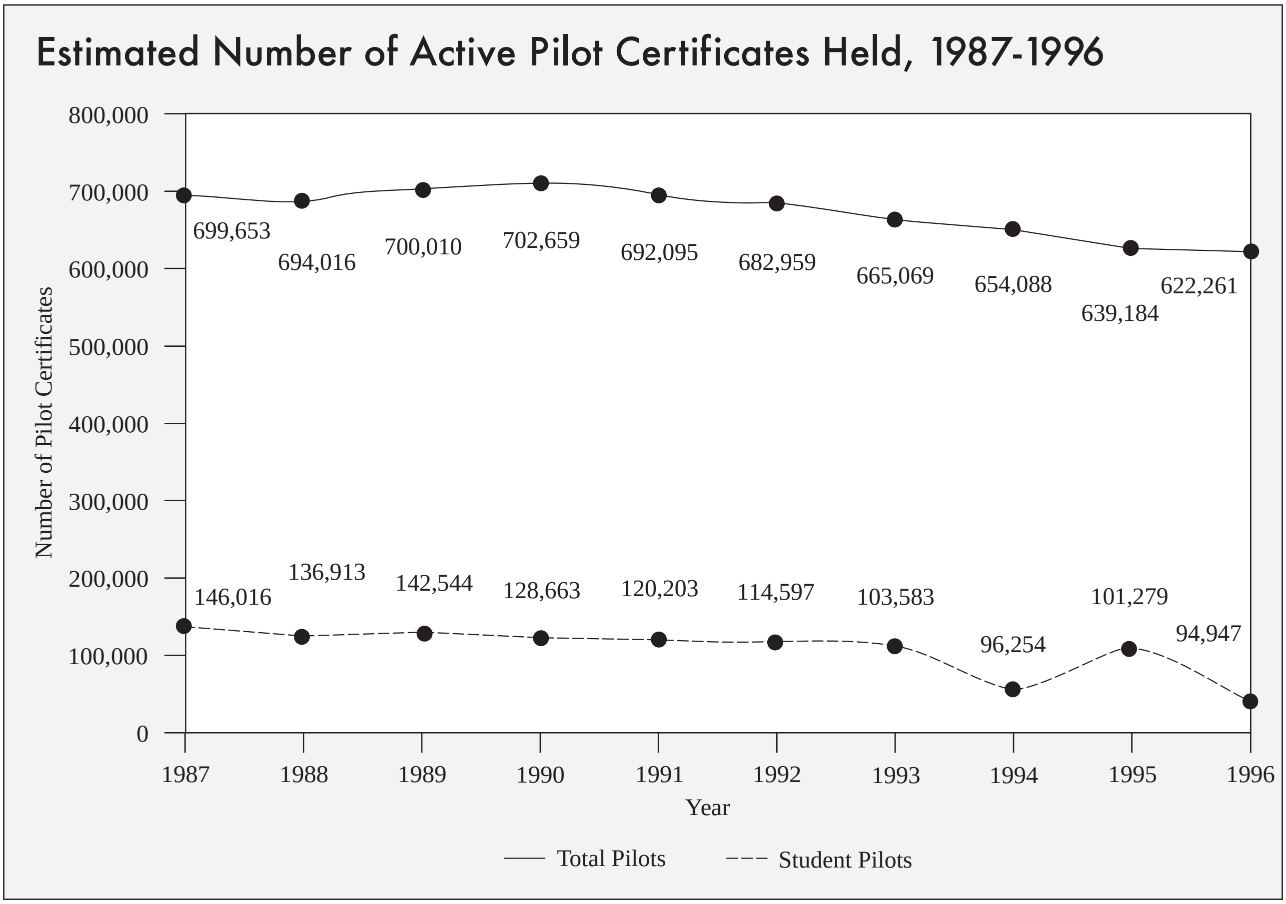
Becoming a Private Pilot

The first step in becoming a pilot is taking flying lessons. These rather simple lessons culminate in a written test, an oral test, and a flight check that allows the student to fly as a private pilot. The Private Pilot Certificate allows one to fly throughout U.S. airspace, with a few exceptions.

The first step in the process is to find a good flight instructor at a smaller airport. It is far preferable to fly at a smaller airport than at one used by the airlines and other larger aircraft. With less traffic, the student pilot and the flight instructor can devote more time to teaching and learning than waiting for a takeoff clearance.

After meeting a flight instructor for the first time, the new student will be able to go flying on an introductory ride. This is an important flight, in that it allows the potential student to taste the flavor of flight without becoming too financially committed. Upon completion of the first flight, the student can then start thinking about consigning more time and funds to the process of obtaining a pilot certificate.

The investment of time and money required for a pilot certificate will vary. The requirement in terms of flight experience is only forty hours, according to the FAA. Typically, an average student is going to spend about fifty



Source: Federal Aviation Administration, *Statistical Handbook of Aviation*, 1996.

hours flying for a private license. Of this, approximately half will be with a flight instructor while the other half will be alone, or solo.

Regarding the costs, as of 2001 in the United States, typical two-seat training aircraft rented in the range of $50 to $65 an hour. Therefore, fifty hours of private pilot training curriculum would entail rental costs ranging from $2,500 to $3,250. Flight instructor fees also vary. A young flight instructor, just starting out in the industry, may charge a fee of $15 per hour. A more established flight instructor may charge a fee approaching $50 per hour. The combined rental and instructional fees, therefore, can run from approximately $2,900 to $4,500. To this must be added flight check fees, incidentals, and supplies.

During the course of training, the student will fly the first ten to twenty hours with the flight instructor. During this time, the student learns the rudiments of flying and the flight instructor makes certain the neophyte has learned enough to stay out of trouble while flying alone.

Solo is the pivotal point in a new pilot's life. The first solo occurs at some time in the first twenty hours of flight training. After soloing, the student will fly in the local area for practice, becoming more comfortable with the airplane and flying.

After this solo practice, the instructor will again join the student for cross-country (X-C) training. In other words, the student will learn how to fly from one airport to another. The instructor will teach the student how to read charts, use navigational tools, and find the way from one place on the earth to the next. After proving proficient in these tasks, the student will fly ten hours of solo cross-country flights.

After completing the solo X-C requirements, the student is back with the flight instructor for the final preparations for the private pilot check ride. During this final phase of training, the student will learn rudimentary instrument flying skills, advanced stalls, and other maneuvers.

The test has written, oral, and flight elements. The written test is taken first. When this portion is passed, the student meets the designated examiner for a two-hour talk about flying. After passing the oral portion of the flight check, the student and examiner will climb into the airplane and fly. At the completion of the flight, the paperwork is completed and a license issued. Now comes the next monumental flight in the career of a pilot: flying with passengers.

After obtaining a Private Pilot Certificate, the new pilot may stop there or continue training. One step would be to work on obtaining Instrument Rating, certification that allows the pilot to fly without reference to the outside world. This is the most practical rating in that when the weather is not perfect, the instrument-rated pilot can take off and fly through the clouds. Another rating is the Commercial Pilot Certificate, which allows the pilot to work as a professional pilot. A Multiengine Rating allows operation of an airplane with more than one engine.

The highest pilot certificate, which comes after attaining a total of 1,500 hours of experience, is the Airline Transport Pilot Certificate, or ATP. Pilots who hold the ATP are usually working pilots who will eventually go on to become professional airline pilots.

Airline Pilots

Aviators include everyone on the aircraft who has a job to do. Members of the crew perform their duties in one of two areas, the cockpit or the cabin. Personnel in the cabin include the flight or cabin attendants. Members of the cockpit crew include the pilot, the first officer or copilot, and if the aircraft requires a flight engineer, the second officer.

Flight engineers and copilots usually are younger aviators building time and experience on the way to the captain's seat. The usual career path for an airline pilot begins with flying smaller aircraft in the charter business or as a flight instructor. After gaining experience and logging flight time to increase competitiveness, the next step is application to a commuter airline. Commuter airlines fly smaller aircraft that carry between twenty and fifty passengers. The young pilot begins as a first officer under the eye of an experienced captain. The new pilot will serve in this capacity for two or three years.

Advancement to captain requires additional training and examinations, and certification to act as the pilot-in-command. Service as a commuter captain continues for another period of time in which skills and knowledge are further developed. This makes the pilot more marketable to the large air carriers.

Airline pilots often say that they have the best job in the world. Those who achieve a position with a major airline work approximately twelve to fifteen days a month. For the few days they work, they enjoy good pay and benefits. In 2001, salaries for jumbojet captains were in the $150,000 to $300,000 range. Of course, pilots do not begin at that pay scale. The beginning flight instructor, working toward the goal of becoming an airline captain, may realize an annual salary of $12,000 to $25,000. Charter and corporate pilots fare better than flight instructors. A few charter jobs command higher pay than does flight instructing, whereas some corporate pilot salaries rival that of the airline captain.

Corporate Pilots

Pilots wanting greater security than that provided by flying charter flights, but who desire to avoid the rigidity of an airline position, often opt for employment with a corporate flight department. In this industry, pilots can find a company of the proper size to fit their requirements, such as a specific location or type of aircraft. The company may own only one aircraft, or it could operate a fleet of executive jets.

Like other positions in aviation, corporate aviation has advantages and disadvantages. On the plus side, pilots may fly into more varied destinations, avoiding the boredom of flying the same route over and over, as in airline flying. Corporate pilots tend to fly one or two aircraft of the same make, enabling them to become intimately familiar with their aircraft. An advantage or disadvantage, depending on the individual, is the ability to return home at night, or stay out on the road. Single pilots tend to request overnight trips while older, more established pilots may seek the short, out-and-in hops.

Military Pilots

Flying tactical jets is probably one of the most exciting jobs in the world for an aviation enthusiast. Military pilots may eventually become airline pilots, but for the time being, these young men and women are flying the most advanced fighters in the inventory.

All military pilots are college graduates, although they need not have studied aeronautical engineering or acquired degrees in aviation. After graduation, the prospective military pilot attends Officer Candidate School, a course of study lasting approximately twelve weeks. Upon graduation and commissioning in their respective branch of service, they receive orders to flight training.

Flight training takes one to two years, depending on the branch of service. New flight students go through primary flight training, where they gain their first introduction to airplanes. Unlike their civilian counterparts in the airlines, military pilots can start out in training knowing absolutely nothing about aviation. After primary training, students step up to more complex aircraft in intermediate training. Finally, in advanced training, they fly highly sophisticated jet trainers. When the training is complete, newly winged aviators go on to train in the tactical aircraft to which they have orders. At completion of training in a particular aircraft and weapons systems, they are posted to stations in defense of the country.

Flight Instructors

Flight instruction, or teaching others to fly, is the most important job in aviation. As with the teaching profession in general, the financial rewards may be less than deserved, yet many instructors realize rewards that go far beyond the financial. A flight instructor has some of the greatest responsibilities in the aviation industry.

Flight instructors are often young fliers just starting their aviation careers. They use flight instructing positions to develop themselves as aviators while building experience and logging flight time. This group of pilots is an enthusiastic lot, eager to learn, eager to teach, impatient to get on with their flying careers. That creates the possible drawback of younger flight instructors. Sometimes they are too eager to begin careers with airlines and will leave students in the middle of their training to take a more prestigious flying job elsewhere. Older flight instructors, on the other hand, may be content to stay where they are, enjoying the experience of passing their knowledge on by training new pilots.

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See also: Airline industry, U.S.; Airplanes; Commercial flight; Federal Aviation Administration; Marine pilots, U.S.; Military flight; Navy pilots, U.S.; Test pilots; Training and education

Piper aircraft

Definition: Piper aircraft are small airplanes intended for the general aviation market. Many are owned by amateur pilots who fly as a hobby.

Significance: The term Piper has become synonymous with small personal aircraft. Thousands of pilots, both amateur and professional, enjoyed their first flying experience in a Piper Cub, a small single-engine fixed-wing aircraft.

Beginning in the early 1930's, the Piper Aircraft Corporation aggressively promoted low-cost amateur aviation as a way to increase aircraft sales. As a result, thousands of people obtained pilots' licenses. Many of those people eventually bought airplanes. Between 1935 and 1984, Piper Aircraft built and sold over 77,000 airplanes.

In addition, Piper aircraft have proven to be well designed and highly useful in a variety of settings. Pipers were used extensively as trainers during World War II, with approximately 80 percent of all U.S. military pilots beginning their flight training in Piper L-4's. Pipers were also used in both the European and Pacific combat theaters as reconnaissance aircraft, where their small size and agility made them almost impossible to shoot down. The Pipers were able to fly so low and slow that fighter aircraft could not pursue them safely.

Early History

The Piper Aircraft company took its name from a most unlikely founder. William T. Piper has gone down in history as "the Henry Ford of aviation," but acquired the title almost by accident. Piper, born January 18, 1881, in Knapps Creek, New York, apparently had little interest in aviation prior to purchasing $400 worth of stock in the Taylor Brothers aircraft company in the 1920's. Piper, a Harvard graduate, had worked in the construction industry in Texas and as an oil company executive in Pennsylvania prior to becoming active in Taylor Brothers. Historians of the Piper company describe Piper as being pushed by civic leaders in Bradford, Pennsylvania, in 1929 to serve on the board of Taylor Brothers to help protect the city's investment. Bradford city officials had invested $50,000 in Taylor Brothers as an inducement to the firm to set up its aircraft manufacturing facility in their town. The local oil industry was in decline, and city officials were trying to attract new businesses to town to provide jobs for area workers.

At the time, Taylor manufactured a two-seater airplane known as the Chummy. The Chummy sold for $4,000, a price that William Piper considered too high. Taylor was aiming for the luxury market; Piper believed the path to financial success lay in designing and building a plane that anyone could buy. Taylor wanted to develop planes that would sell for $10,000 or more, while Piper wanted to go in the other direction. Piper was quoted as saying he wanted the airplane to become as accessible to the average person as the automobile.

Piper was convinced that an economical personal aircraft could be built using the assembly line techniques pioneered in the auto industry. He used salvaged materials from Ferris wheels and other scrap to create the jigs and fixtures necessary for mass production and pushed to develop a plane that could sell for under $1,000. A myth persists that the original Piper Cubs sold for $999. This is not quite true, but it is close: in 1931, the company began marketing the E-2 Cub, an inexpensive, small, easy-to-fly aircraft that sold for many years for only $1,350.

Piper's salesmen promoted flying by inviting would-be pilots first to Bradford and later to Lock Haven to take flying lessons for only $1 an hour. Every potential licensed pilot was seen as a potential customer. Piper employees were also encouraged to take advantage of the inexpensive lessons, with the result that at one time one out of every ninety people in town was a licensed pilot. A novice to aviation himself prior to becoming involved with Taylor Brothers, William Piper earned his private pilot's license several years after taking control of the company. Although some accounts describe him as learning to fly at the age of 60, he was actually slightly younger, in his early fifties.

Piper in the 1930's

In 1932, Piper hired a young aeronautical engineer, Walter Jamouneau. Jamouneau produced a fictitious resume claiming a degree from Rutgers University, but Piper hired him anyway. Jamouneau's credentials may have been dubious, but his engineering talents were not. He eliminated the E-2's boxy silhouette, giving it a more rounded profile and streamlined appearance. These design changes became a source of friction between Piper and Gilbert Taylor. In the end, Piper modified the E-2 Cub to the point where it became known as the J-2, after Jamouneau. In 1937, the J-3 Cub appeared. This was the plane that changed the face of general aviation.

At the same time that Piper and Taylor clashed over aircraft designs and the company's direction, the effects of the economic depression beginning in 1929 were being felt. The initial capital raised through the sale of stock was exhausted, Taylor was in debt to the bank for $15,000, and no new investors could be found. Taylor Brothers was forced into bankruptcy. No one bid on the company's assets. Piper acquired them for $761 and gave a half interest to Taylor.

As the company struggled to survive the Great Depression of the 1930's and to market the Cub, the friction between Piper and Taylor increased. Piper eventually bought out Taylor's interest in exchange for payments of $250 per month for three years and the promise to maintain the payments on Taylor's life insurance.

In 1937, the company suffered a disastrous fire at the Bradford plant. Debris soaked with highly flammable aircraft dope in the paint room ignited. The source of the fire was later traced to sparks from an electric drill. The plant was a total loss. The building had been uninsured. Money was tight, so Piper decided to do a public stock offering to raise the money necessary to rebuild. At the same time, due to a lackluster response from the city of Bradford toward helping with rebuilding, Piper decided to move the assembly plant. A company salesman told Piper about a former textile mill located next to an airstrip that was available in Lock Haven, so that was where Piper moved. It would remain the main Piper manufacturing facility for almost fifty years. The company name was changed to Piper Aircraft at the time of the move.

World War II

As the political situation in Europe worsened in the late 1930's, U.S. president Franklin D. Roosevelt pushed for the creation of the Civilian Pilot Training program. He and his advisors feared that in the event of war, the United States would not have enough trained pilots ready. Piper Cubs became the most common airplane used for flying lessons, with four out of five new pilots being trained in them. Thousands of American military pilots first learned to fly in a Piper, including future astronaut and senator John Glenn.

When the United States entered World War II in 1941, many military men were at first skeptical of the value of small aircraft outside of pilot training facilities. As the war progressed, however, doubters were won over. The Piper L-4, the military version of the J-4 Coupe, was used for reconnaissance in Europe and Asia. In addition to serving as scouts, Pipers were used to drop supplies such as food, ammunition, and blood plasma to ground troops. William Piper, Jr., later noted that turning Piper Cubs into military aircraft was easy—all that was required was a drab coat of camouflage paint and a J-4 became an L-4.

Postwar Years

Following the war, a boom in personal aviation occurred. Piper produced 8,000 Piper Cubs and Super Cruisers to meet pent-up demand. Competing companies, such as Beech and Cessna, also increased production. For a few years it seemed as though companies could not manufacture small airplanes fast enough to satisfy the market in general aviation. It has been estimated that over three dozen new aircraft manufacturing companies entered the market between 1945 and 1947. Piper established an assembly plant in Ponca City, Oklahoma. Then, just as quickly as the boom had appeared, it vanished. By 1948, sales numbers were dropping and the companies that had emerged to compete with Piper only two or three years earlier began vanishing as quickly as they had been formed.

William T. Piper, Jr., recognized the flying public wanted a different type of airplane than the original Piper Cub. The Cub was ideal for sport flying, that is, for short excursions leaving and returning to the same airport, and for training student pilots. As a two-seater, however, the Cub was simply too small for any distance flying. Piper Aircraft Corporation had acquired Consolidated Vultee's Stinson Aircraft division in 1948. The Stinson assets included a design study for a twin-engine, four-passenger airplane. Piper waited four years, and in 1952 came out with the prototype for the Apache. The prototype had a twin-fintail design which performed poorly in flight testing. It was replaced with a more conventional tail, and went into full production shortly thereafter. Piper began delivering Apaches, which handled well even in stormy weather, in March, 1954.

Beginning in 1960, the Apache was replaced by the Aztec, an aircraft with more powerful engines than its predecessor. The Aztec B had seating for six, and subsequent models introduced improvements such as fuel injection and turbocharging. Piper stopped production of the Aztec in 1984. By the 1960's, the corporate executive market was supplanting personal aviation. Piper responded with the Navajo, Mohave, and Cheyenne aircraft. Fully pressurized, the Cheyenne IV was capable of cruising at 400 miles per hour at an altitude of 40,000 feet. Although Piper is best known for its passenger aircraft, the company also developed the Pawnee PA-25, an airplane designed for use in crop dusting.

William T. Piper, Sr., died in 1970, shortly after a hostile corporate takeover of the Piper Aircraft Corporation in 1969. The Piper family lost direct control of the company, but Piper aircraft continue to be manufactured. Plagued by a variety of management woes and financial problems, Piper Aircraft almost shut down in the 1990's. In 1995, Piper became an employee-owned company and managed to regain some of its lost market share. Now known as New Piper Aircraft, Piper today manufactures a variety of small airplanes, including a single-engine turboprop, the Malibu Meridian, and the twin-engine Saratoga. Still, even today, the name Piper continues to evoke the image of the original bright yellow Piper Cub, the small plane that for many generations of fliers symbolized personal aviation.

Nancy Farm Mannikko

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See also: Aeronautical engineering; Airplanes; Beechcraft; Cessna Aircraft Company; Manufacturers; Pilots and copilots; World War II

Wiley Post

Date: Born on November 22, 1898, in Grand Saline, Texas; died on August 15, 1935, near Point Barrow, Alaska

Definition: A famous and colorful aviator of the 1920's and 1930's.

Significance: Post twice held speed records for trans-global flights, discovered the jet stream, and worked to develop the first pressure suit for stratospheric flight.

During the 1920's, Wiley Post worked in the Oklahoma oil fields. After losing his left eye in an oil-field accident, which led him to adopt his signature eye patch, he used money from an insurance settlement to buy his first airplane. He then performed as a parachute jumper and barnstormer. In 1925, the American humorist Will Rogers hired Post to fly to a rodeo, and the two became lifelong friends. During the late 1920's, Post, flying a TravelAir biplane, was the personal pilot for wealthy Oklahoma oilmen F. C. Hall and Powell Briscoe. Hall bought for Post's personal use a Lockheed Vega 5-C, which Post named *Winnie Mae*, after his daughter.

In the Vega, a streamlined, single-engine plane known for its ruggedness and airworthiness, Post won the 1930 National Air Derby, a Los Angeles-to-Chicago race that made him a national figure. Although the plane's cruise speed was 140 miles per hour, Post's winning time approached 200 miles per hour.

In 1931, Post flew around the world in the *Winnie Mae* with Australian-American aviator Harold Gatty. Traveling a northern route of some 15,000 miles, they set a world record of eight days and sixteen hours, breaking the speed record of twenty-one days set in 1929 by the German airship the *Graf Zeppelin*. Post received the Distinguished Flying Cross in 1932. In July, 1933, Post, flying alone with navigational instruments and an automatic pilot, reduced the time to seven days and eighteen hours, an achievement that earned him the solo record for around-the-world flight and the Harmon International Trophy.

Post took up the challenge of high-altitude flight in 1934, funded by Frank Phillips of the Phillips Petroleum Company. The *Winnie Mae* could not be pressurized, so Post asked the B. F. Goodrich Company to help him devise

Image Not Available

a pressurized flying suit made of rubberized parachute material, with pigskin gloves, a helmet made of plastic and aluminum, and a liquid-oxygen breathing system. Post first used the suit in a September, 1934, flight over Chicago, in which he also used a supercharger on *Winnie Mae*'s engine to set an unofficial height record of 50,000 feet.

In his high-altitude test flights, Post was the first flier to encounter the jet stream, which he used to his advantage in a May, 1935, flight from Burbank, California, to Cleveland, Ohio. At times, the ground speed on this flight approached 250 miles per hour, and the average ground speed was about 179 miles per hour. However, he failed in four attempts at making a stratospheric flight across the entire continental United States.

Ever the visionary innovator, Post predicted the development of supersonic transports and even space travel. He conducted secret experiments in a high-altitude chamber owned by the U.S. Army and researched the biological rhythms related to pilot fatigue.

In 1935, Post explored flight routes from the West Coast of the United States to Russia. With funding from U.S. airlines, he combined the parts of two planes: the wings of a Lockheed Explorer and the fuselage of a Lockheed Orion. Pontoons were necessary to land in Alaskan and Siberian lakes, and when the desired pontoons did not arrive, Post used a heavier set from a much larger plane.

In July, 1935, Post and Rogers left Seattle, Washington, in this heavy plane, further weighted down with fishing and hunting equipment. Lost in bad weather, they landed in a lagoon near Point Barrow, Alaska. When they tried to take off, the engine failed, and the plane plunged back into the lagoon, killing both men. Post's famous *Winnie Mae* was subsequently sold by his widow to the Smithsonian Institution.

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See also: High-altitude flight; Record flights; Transglobal flight; *Winnie Mae*

Ludwig Prandtl

Date: Born on February 4, 1875, in Freising, Germany; died on August 15, 1953, in Göttingen, West Germany

Definition: Considered the father of modern fluid mechanics.

Significance: Prandtl's boundary layer equation became fundamental to the study of fluid mechanics. His contributions to turbulence theory include the mathematical foundations for modern wing theory. Although untrained in mathematics, Prandtl was nevertheless able to simplify complex mathematical concepts explaining certain physical phenomena.

Ludwig Prandtl was born in Freising, Germany, in 1875, and studied mechanical engineering in Munich, Germany. After receiving his doctorate from the Munich Technische Hochschule in 1900, Prandtl worked at a factory in Nürnberg, Germany, before becoming professor of mechanics at the Technische Schule in Hannover. In 1904, German mathematician Felix Klein encouraged Prandtl to accept the position of professor of applied mechanics at the University of Göttingen, where Prandtl remained for almost a half-century. Because of Prandtl's groundbreaking work in fluid mechanics, Göttingen developed into an internationally renowned center of aerodynamic research.

Prandtl's 1904 discovery of the boundary layer resolved the issue of fluid friction. Prior to Prandtl's work, scientists had been unable to understand or explain the frictional forces of viscous fluids, especially water and air. Through experiments with a small water tunnel, Prandtl proved the existence of a boundary layer in fluids flowing around a solid structure, such as water in a pipe or air over a wing. He defined the boundary layer as the region of the flow adjacent to the wall of a solid surface, where the viscous effects cause the molecules of the fluid to stick to the wall. Any solid body, such as a boat, airplane, car, or machine part, moving in a viscous fluid, such as water or air, creates a boundary layer around it. Prandtl's theory explained that friction, or drag, at the wall of the solid body is due to the presence of the boundary layer. His breakthrough led to the development of the science of fluid dynamics. The boundary layer theory was initially applied to laminar, or nonturbulent, flows, but Prandtl's later experiments in 1914 demonstrated that the boundary layer also exists in turbulent flows. The boundary layer theory helped scientists design machines and devices to account for the drag that results from the boundary layer.

Prandtl's work on friction drag resulted in his 1918 development of wing theory, which explained the flow of air over airplane wings. The Lanchester-Prandtl wing theory, named for both Prandtl and the British physicist Frederick Lanchester, whose simultaneous work was independent of Prandtl's, calculates the lift on the wing. Prandtl's other numerous contributions include his work in supersonic and subsonic flows and turbulence and in wind tunnel design. Prandtl's contributions to aerodynamics eventually led to manned flight and earned him the title of father of aerodynamic theory. After falling ill in 1952, Prandtl died in Göttingen on August 15, 1953.

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See also: Aerodynamics; Airfoils; Forces of flight; Wind tunnels

Propellers

Definition: Rotating airfoils driven by an engine, which provide thrust to an aircraft.

Significance: Propellers were a primary mode of thrust generation for all aircraft up to the development of the gas-turbine engine in the 1940's, and they remain in widespread use, especially on smaller commercial and general aviation aircraft.

History

Propellers have long been recognized as an efficient means of generating thrust. They were popularly used in aircraft design even before being used by Orville and Wilbur Wright to power the Wright *Flyer* in 1903. Leonardo da Vinci sketched propeller designs for helicopters in the 1500's. Early propellers were based primarily on designs used for ships and windmills, but experiments soon found that long, thin airfoils provided better thrust than the shorter, thicker hydrofoil designs used in water.

Nature and Use

The function of a propeller is to create thrust to accelerate an aircraft forward. Although a wing creates lift to overcome an aircraft's weight, a propeller creates thrust to overcome its drag. This thrust keeps an aircraft moving. When the propeller's thrust is equal to the aircraft's drag, the aircraft travels at a constant speed. When thrust is greater than drag, the aircraft accelerates until drag is equal to the thrust. Likewise, when the propeller's thrust is less than the aircraft's drag, the vehicle decelerates until the drag and thrust are equal and the aircraft's velocity becomes constant. Thus, varying the propeller's thrust will change the aircraft's velocity.

In a helicopter, the propeller is turned upward, so that the thrust is generated vertically to overcome the weight of the aircraft. When a propeller is oriented primarily to overcome weight instead of drag, it is usually called a rotor. The engine powering a propeller can be either a conventional piston (reciprocating) engine or a jet (gas turbine) engine. In the latter case, the propeller-and-engine combination is commonly referred to as a turboprop. Turboprops typically derive 95 percent of their thrust from the propeller, while the remainder comes from the jet-engine exhaust.

A propeller may be thought of as a severely twisted wing. In fact, the wings of many aircraft are twisted either to increase or decrease lift on certain portions of the wing by changing the local effective angle of attack. The propeller is twisted for a similar reason. Like an untwisted wing, a propeller could be designed without twist, as some of the first propellers were, but it would create less thrust than would a twisted propeller.

A propeller generates thrust in the same way that a wing generates lift. Instead of moving in a straight line, however, the propeller rotates about a hub that is turned by the engine shaft. A propeller actually traces out the shape of a helix as it travels around in flight. For this reason, propellers are often referred to as airscrews and are also analogous to the propeller screws found on a ship.

Both the rotating and forward movements of a propeller's airfoil have an effect on how much thrust is developed. The velocity at each radial location of the propeller will be different, because the total velocity is the vector sum of the propeller radial velocity and the aircraft velocity. Because the propeller is rotating at a certain rotation rate, the propeller velocity at any distance from the axis of rotation is the rotational speed times the radial distance. Thus, the propeller velocity will be almost zero near the hub and a maximum near the tip. This difference in velocity requires that the cross sections of the propeller's airfoil be twisted so that the chord line has a large angle of attack near the hub and a small angle of attack near the tip, in contrast to the airfoil of a wing that is nearly flat. The propeller's chord line increasingly points in the direction of the aircraft motion, as the propeller airfoil sections progress toward the hub.

The angle between the chord line of the propeller and the propeller's plane of rotation is called the pitch angle. To determine the local angle of attack of a propeller, one uses the propeller's pitch angle at each blade section and subtracts the angle of attack of the incoming relative wind.

Propeller Placement

A propeller can be placed anywhere on an aircraft, either at the nose, tail, wings, or on a pod. In a tractor configuration, the propeller is placed facing forward, usually on the nose, and pulls the aircraft. In a pusher configuration, the propeller is placed facing the rear of the aircraft and pushes the aircraft forward. One design has no real benefit over the other. The tractor configuration is more common, because it allows a better balance of the aircraft's center of gravity about the aerodynamic center of the wing with the engine placed near the nose. Pusher configurations are more common in canard aircraft for the same reason. In a tractor configuration, the slipstream from a propeller is often pushed over the wings, creating a faster flow over that part of the wing. This is sometimes used to generate more lift, but it is not commonly considered in aircraft design.

Propeller Efficiency

The propeller efficiency is a measure of how effectively a propeller transforms the engine power into propulsive power. It is measured by dividing the power output by the power input. The power output is the thrust generated by the propeller multiplied by the aircraft velocity. The power input is the amount of shaft power generated by the engine, measured in horsepower or watts. A propeller that is 100 percent efficient means that all of the power from the engine is transferred directly to the air. No propeller can achieve 100 percent efficiency, however, and is hindered by several factors. The propeller, as it rotates, adds energy to the air, and this energy is lost from the aircraft, because it remains with the air long after the aircraft has passed. Indeed, the most efficient propellers are the ones that take a large amount of air and increase the velocity of the air only slightly. Thus, all things being equal, larger-diameter propellers are more efficient than smaller ones. Also, the drag forces that act on the aircraft as a whole also act on the propeller. These forces include pressure drag, such as separation of the flow over a propeller, and friction drag, in which viscous effects of the air retard propeller motion.

Typical propellers have efficiencies in the 70 to 90 percent range. Fixed-pitch propellers have the lowest efficiency and can drop below 70 percent if they are operating at a velocity for which they were not designed.

Propeller Designs

The Wright brothers and Alexandre-Gustave Eiffel, among others, conducted early experiments on propellers. The Wright brothers were particularly concerned about maximum power output and thrust generation, because their early engines developed very little horsepower. They were able to design propeller blades with an efficiency of up to 70 percent, which was an extraordinary feat for the time. Eiffel, a French engineer and the builder of the Eiffel Tower in Paris, was also an ardent aerodynamicist who performed some of the first detailed wind-tunnel experiments on propellers. He was the first to show that propeller efficiency varied with the propeller's rotation rate, diameter, and aircraft velocity. This parameter is now called the advance ratio and is used in propeller design, optimization, and selection.

Fixed-Pitch Propellers

Propellers can be used on aircraft in several different ways. In the fixed-pitch propeller, the propeller blade has a fixed angle of attack. Although the angle varies along the length of the propeller, the blade has a fixed orientation throughout its flight envelope, meaning that the propeller design has been optimized for a single speed. If the aircraft travels at another velocity, the propeller efficiency is reduced. Fixed-pitch propellers were used on all airplanes up to the 1930's, when variable-pitch propellers were introduced.

Variable-Pitch Propellers

The angle of attack of variable-pitch propellers can be changed by rotating the blade about the hub. This allows pilots to adjust the propellers' relative angle of attack in flight to account for changes in the aircraft and wind velocity. A complex mechanism in the hub allows the pilot to change the propeller pitch in flight, thereby increasing overall performance. When variable-pitch propellers were introduced in the 1930's, propeller efficiency across the range of flight conditions was greatly increased. A major drawback, however, was that as the pitch was altered, the torque on the engine was also changed. This would, in turn, change the rotation speed of the engine, resulting in a lower engine-power output.

Constant-Speed Propellers

Consequently, the constant-speed propeller was introduced in the 1940's. It is a variant of the variable-pitch propeller in which the propeller pitch is changed automatically to keep the engine speed constant and to maximize total power output. Variable-pitch and constant-speed propellers may be feathered in flight during an engine-out scenario to minimize the propeller drag.

To keep the propeller efficiency from dropping, the velocity of the propeller tip must be kept lower than the speed of sound, or Mach 1. If this velocity is exceeded, shock waves form at the tip of the propeller, and the efficiency drops dramatically as the available power is reduced by pressure losses. Shock waves can create other problems, such as severe noise, vibration, and structural damage to the propeller. Because the velocity at the tip is a function of the propeller radius, engine-shaft rotational speed, and aircraft speed, these three factors come into play when determining what size propeller should be used. During the tradeoff analysis of an aircraft design, as the speed of an aircraft increases, the diameter of the propeller decreases.

To generate the same thrust for a smaller-diameter propeller given the same engine speed, an aircraft designer may opt to go with a larger number of propellers. The propeller must be balanced, and two blades are the minimum used. However, any number of blades greater than two may be chosen, as long as the blades are evenly spaced to maintain balance. Increasing the number of propeller blades means that to achieve the same thrust, a smaller diameter can be used. This is sometimes done to avoid the sonic tip speeds that may be encountered with long propeller blades on fast aircraft. Two-, three-, four-, and five-bladed propellers have been commonly used on aircraft throughout the twentieth century.

To overcome the drawback of the sonic tip speed limitation of propellers on some commercial aircraft using turboprops, the use of unducted fan propellers has been proposed. The unducted fan propeller is a many-bladed propeller with short, curved blades that allow craft to overcome the sonic tip concerns that plague high-speed aircraft using traditional propeller designs.

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See also: Airplanes; Forces of flight; Helicopters; Rotorcraft; Turboprops; Wing designs; Wright *Flyer*

Propulsion

Definition: The process of forcing an object to move. The word is also used to refer to the entire system of engines for achieving propulsion in the context of flight vehicles.

Significance: Propulsion is the force that allows aircraft to fly. Aircraft propulsion systems include engines, nozzles, and propellers. Methods of propulsion range from piston engines driving propellers on small airplanes to conceptual models that may use magnetic fields, laser beams, or antimatter to propel spacecraft in the future.

Types of Propulsion Systems

While the machinery is complex, the principles of opera-

The United States' first rocket-assisted airplane takes off on August 12, 1941. The Ercoupe plane was fitted with a solid-propellant 28-pound-thrust JATO (jet-assisted takeoff) booster. (NASA)

tion are common to most propulsion systems. According to Newton's second law of motion, the net force exerted on an object is equal to the rate of change of its momentum. According to Newton's third law of motion, every action (of a force) produces an equal and opposite reaction. For flight in the atmosphere, air is used as the working fluid whose momentum is changed by the propulsion system. The reaction to the resulting force acts on the propulsion system and drives the aircraft forward.

Since momentum is the product of mass and velocity, designers can choose to produce a given increase of momentum by either accelerating a large mass of fluid per second through a small change in velocity, or accelerating a smaller mass of fluid through a large increase in velocity. For flight at low speeds, it is more efficient to do the former. For example, helicopters and propeller-driven airplanes use large rotating blades to capture a large amount of air and accelerate it through a relatively small change in velocity. For flight at high speeds, turbojet and ramjet engines, which usually have small intake areas, add heat to the captured air. This heat is then converted to the work done in accelerating the air through a large velocity change, leaving hot jets of air behind. In effect, a force is exerted on the air by the engine to accelerate it backward from the aircraft. The reaction to this force acts on the engine and hence drives the aircraft forward.

The same principle applies to rocket propulsion, in the atmosphere or in outer space. Rockets generate gas at high pressure by burning chemicals, and this gas escapes at high speed through a nozzle. The reaction to the force used in doing so accelerates the rocket. The key idea is that the engine and the propellant gases are pushing against each other: no other medium is needed to be pushed. In the early days of rocket flight, several experts, including editorials in *The New York Times*, sneered at rocket pioneer Robert H. Goddard for his insistence that rockets could thus work in the vacuum of space, but today such flight is taken for granted.

Piston Engines and Propellers

Early aircraft propulsion systems used piston engines to drive propellers. The revolving blades of the propeller are like rotary wings, producing a force and accelerating the air encountered within the large area swept by the blades. Propellers were termed pusher or puller props, depending on whether they were mounted behind or ahead of the wings. Propellers are highly efficient as propulsion for slow-flying aircraft. Today many short-range aircraft and general aviation aircraft are powered by turboprop engines, where the engine uses the gas turbine principle, but the power generated is used to drive a propeller. For flight at more than about half the speed of sound (Mach 0.5), the speed at the tips of the blades exceeds the speed of sound, and shocks form, generating unacceptable levels of noise and drag.

Solar-Electric Propulsion

Renewed interest in propeller-driven aircraft comes from the idea of continuously flying airplanes in the upper atmosphere using solar power to drive a motor and propeller. The National Aeronautics and Space Administration (NASA) Solar Pathfinder demonstrated ascent to over 80,000 feet using wings covered with solar panels. The energy absorbed from the Sun during the daytime can drive the vehicle to such high altitudes that it can glide all night without coming down too low. Thus automatic, continuously flying aircraft can be propelled using solar power.

Rocket Engines

The earliest evidence of rocket usage is from China, where black-powder rockets stabilized with bamboo poles, perhaps with multiple stages, were used in the twelfth century. The South Indian king Tippu Sultan of Mysore used iron-cased rocket-powered projectiles with 2,400-meter range from 1780 to 1799 in order to protect his nation from British invaders. Using rockets captured from India, Britain's William Congreve developed solid rockets with a 3,000-yard range, used against Napoleon's forces in Bologne in 1806, and in the War of 1812 against the United States. Russia's Konstantin Tsiolkovsky (1857-1935) developed the idea of multistage rockets to escape Earth's gravity in a 1903 paper titled "Isslyedovanye mirovykh prostranstv ryeaktivnymi priborami" ("Exploration of Space with Reactive Devices," 1957) discussing the use of liquid oxygen and liquid hydrogen. American Robert H. Goddard (1882-1945) registered a patent in 1914 for the design of a rocket combustion-chamber nozzle and propellant feed system. He published "A Method of Reaching Extreme Altitudes" in 1919 through the Smithsonian Institute, and conducted experiments with liquid-oxygen and gasoline propellants between 1920 and 1940. In Germany, Hermann Oberth published *Die Rackete zu den Planetenräumen* (1923; the rocket into interplanetary space) and *Wege zür Raumschiffart* (1929; the road to space travel). During World War II, air-launched rocket-powered unguided missiles were used, followed by Russian use of rockets in artillery barrages, and the German V-1 and V-2 ballistic missiles which were launched into Britain. After the war, with German rocket engineers inducted into American and Soviet research organizations, the missile race accelerated. On October 4, 1957, the Soviet Union's Sputnik became the first artificial satellite of Earth, and by 1969, Apollo 11 had taken two men to walk on the Moon and return to Earth.

Solid, Liquid, Cryogenic, and Hybrid Rockets

The simplest rocket engine has a propellant grain of fuel and oxidizer in solid form, ignited at one end. As the solid melts and vaporizes due to the heat, the chemical reaction starts, releasing much more heat. The hot gases reach high pressure in the combustion chamber and exhaust through a nozzle, reaching high velocities. Rocket designers shape the propellant grain (the shape of the interior core of the solid propellant) in various ways to tailor the rate at which the solid material is consumed, thus predetermining how the thrust will vary with time. In general, the thrust of a solid rocket cannot be controlled once it starts, aside from releasing the pressure and thus stopping the combustion: most modern solid propellants do not burn unless the pressure is several atmospheres.

Liquid propellants are stored in one or more tanks, and pumped into the combustion chamber, where the pressure is usually much higher than in the storage tanks. While liquid rockets are more controllable, the pumps often pose failure risks; however, the lack of control of the solid rocket is also a disadvantage. Hybrid rockets use a bi-propellant, where the liquid propellant is metered to flow over a solid propellant grain.

The performance of a propulsion system is characterized by its specific impulse (Isp), which is the thrust developed per second, per unit weight of the propellant consumed, at the standard value of Earth's gravitational acceleration, and expressed in units of seconds. The specific impulse of solid-fueled rockets is limited to about 270 seconds. Liquid-fueled rockets using storable fuels are limited to about 250 seconds. Rockets with cryogenic fuels such as liquid oxygen and liquid hydrogen reach 390 to 450 seconds. Proponents of nuclear thermal propulsion hope to achieve an Isp of 825-925 seconds. Electrothermal propulsion, where the propellant gas is heated by an electric arc, promises 800 to 1,200 seconds; electromagnetic acceleration, 5,000 seconds; and ion propulsion, 10,000 seconds.

High Isp does not tell the whole story, since the higher Isp systems usually required heavy machinery, and produce very small amounts of thrust. The specific impulse of engines in space is proportional to the exhaust velocity of the propellant gas. For a given addition of momentum per unit mass, hydrogen, having the lowest molecular weight, provides the highest specific impulse. An efficient type of rocket engine is the solar-hydrogen engine used in orbit transfer vehicles shuttling between low-Earth orbit and geosynchronous Earth orbits. Here solar energy is focused by a collector to heat hydrogen, which then flows out at high speed through a nozzle.

Nuclear Propulsion

A heat source is crucial to propulsion, and one which generates the most heat with the least expenditure of fuel weight would produce the highest specific impulse. Nuclear reactions satisfy this criterion, but the weight of the shielding needed for the reactor, and the consequences of a crash, have limited their use in flight propulsion. The slow neutron reactors used in ships and submarines proved to be too heavy for use in aircraft, while other designs, which could heat air to high temperatures quickly, operated at temperatures too high for available materials and posed extreme radiation hazards. In the 1950's, an Aircraft Nuclear Propulsion (ANP) project led to several advanced designs for nuclear-powered intercontinental bombers, but none appear to have been flight-tested. Project Pluto, a secret project conducted in Nevada, developed a nuclear-powered ramjet supersonic cruise missile. Small nuclear reactors have been used in deep-space probes such as the Galileo mission, and it is expected that missions to other planets, such as an exploration of Jupiter's atmosphere, will require nuclear propulsion to provide the required specific impulse. Proposed nuclear thermal rockets will heat propellant gas (hydrogen) through the coolant channels of a solid-fuel reactor core at about 3,000 degrees Kelvin, and expand hydrogen through a nozzle.

Ion Propulsion

Ionized gases are accelerated to high exhaust velocity using electromagnetic fields in engines used to produce low thrust, available for station-keeping orbit corrections over long durations on spacecraft. The Boeing 702 Xenon Ion Thruster claims an Isp of 3,800 seconds and thrust of 165 million newtons (by comparison, the Saturn V at liftoff produced over 33 million newtons). The weight of the system required to produce the electromagnetic field has restricted the usage of ion propulsion to low-thrust applications, perhaps until superconducting electromagnets become available for use in such systems.

Air-Breathing Jet Propulsion

For flight in the atmosphere, the effective specific impulse can be increased greatly by using oxygen in the air as oxidizer, and air as the working fluid: air does not have to be added to the fuel cost or vehicle weight. There are three principles of jet propulsion: heat addition to the working fluid is most efficient if the heat is added at the highest pressure possible; the conversion of heat to work is most efficient if the temperature difference is largest; and the thrust is most efficient in driving the aircraft if the exhaust velocity is close to (but greater than) the flight speed.

In the gas turbine cycle, the working fluid is first compressed, then heat is added at constant pressure, and finally work is extracted from the hot, high-pressure fluid as it expands and flows out. Thus, gas turbine engines incorporate a compressor to increase pressure, a combustion chamber to add the heat through a combustion reaction between the fuel and air, a turbine to extract work and run the compressor, and a nozzle to expand the flow out. For large engines used by commercial aircraft, the optimal value of pressure ratio (between the highest pressure after compression and the outside) is as high as 50. At supersonic speeds, the deceleration of the air at the front of the engine itself raises the pressure substantially; the optimum pressure ratio may be only 7. As Mach number increases beyond 2.5, the need for a mechanical compressor vanishes, and ramjet engines can operate. Here the incoming air is decelerated, so that its pressure increases to such large values that mechanical compressors and the turbines to operate them are not needed.

All other gas turbine engines require compressors to increase the pressure of the incoming air, and turbines which drive the compressor and extract work required to run other components including propellers, rotors, and fans. These turbomachines change pressure through several stages. Each stage has a rotor where work is done on the fluid to change its momentum, and a stator, or counter-rotating rotor, to recover the momentum change and convert it into a pressure change. Turbomachine stages may be centrifugal or axial. In centrifugal stages, air comes in near the axis and is flung out pressurized at the periphery. In axial stages, the flow is predominantly parallel to the axis, with rows of blades successively increasing momentum by swirling the flow and recovering the pressure by reducing the swirl.

Turbofans, Turbojets, and Propfans

The first jet engines were turbojets, where all of the airflow went through the same compressor and combustion chamber. The first jet engine was patented in 1930 by Sir Frank Whittle (1907-1996). The PowerJets Model W.1 engine was first tested in April, 1937, and according to Sir Whittle, "made a noise like an air raid siren," sending onlookers running for cover. It weighed 700 pounds and produced 860 pounds of thrust, using a double-sided centrifugal compressor. The first British aircraft to use the engine was the Gloster Meteor, a night fighter which first flew in March, 1943, eventually reaching 420 miles per hour. The first jet-powered flight, however, was on a Heinkel aircraft powered by Hans von Ohain's (1911-1998) axial-compressor turbojet engine in Germany. The first jet fighter took off on July 18, 1942, a Messerschmitt Me-262 fighter piloted by Fritz Wendel of the German Luftwaffe, using a Junkers Jumo 004 turbojet engine producing 2,200 pounds of thrust. Earlier attempts had been made using BMW003 turbojet engines, which used a seven-stage axial-flow compressor and an annular combustion chamber with sixteen burners. Today, centrifugal compressors are used in the turbopumps of rocket engines, while axial compressors are dominant in most aircraft applications. Helicopter turboshaft engines use both centrifugal and axial stages. The thrust-to-weight ratio of modern jet engines has improved to well over 4:1.

Turboprop engines use a small turbine to extract enough work from the hot combustor gases to run the compressor, and a large power turbine to extract most of the work from the air to run a propeller. The propeller is connected through a gearbox to reduce the speed of revolution; this adds considerable weight to turboprop engines. The Soviet Bear long-range bomber used turboprop engines with a pair of counter-rotating propellers on each engine. The design tradeoff between high thermal efficiency (requiring high pressure and temperature) and high propulsive efficiency (requiring a small increase of air velocity from the flight speed) is addressed using bypass or turbofan engines, where a part of the captured air goes through a fan and a nozzle, bypassing the main compressor, combustor, and turbine. The bypass ratio is the ratio of the air bypassing the hot core of the engine to the air which goes through the core and has fuel burned in it. Fighter aircraft turbofan engines use a bypass ratio of approximately 1, while modern commercial aircraft engines, such as the GE90 used on the Boeing 777 and Airbus 340 airliners, use bypass ratios up to 12.

In the 1980's, propfans or unducted fans were explored to bridge the gap between the propeller and the ducted turbofan engine. Using modern computational aerodynamics technology, large fan blades of complex shape were designed to operate with supersonic tip speeds and large pressure rise across each stage. Some designs had counter-rotating rows of fan blades. To increase the capture area, the blades were left without the outer cowling used by turbofan engines. These engines promised large improvements in fuel efficiency for short-haul aircraft, but encountered severe problems of development cost and noise levels high enough to damage the aircraft structure through sonic fatigue.

For air-breathing flight at supersonic speeds, a supersonic inlet must slow down the supersonic flow with minimal losses due to shock waves, so that the fan, compressor, and combustion chamber can operate at subsonic speeds. Inlets vary in complexity from the normal-shock inlet of the early MiG and Sabre fighters, through the movable spike inlets of the MiG-21 or the SR-71, to the multiple-ramp inlets of the F-15 or Concorde. Hypersonic aircraft use the compression across the shock produced by the aircraft fuselage to decelerate, so that engine-airframe integration is vital to such designs. Instead of varying geometry, supersonic flows can also be decelerated and compressed using heat addition (thermal compression). At the other end, nozzles vary from simple convergent nozzles of subsonic aircraft, to the converging-diverging nozzles of fighters with afterburners, to the rectangular nozzles of modern fighters where the thrust can be vectored for maneuvering or vertical takeoff. High-speed aircraft concepts (NASA's X-33, Lockheed's VentureStar, and the Japanese ATREX turboramjet) use the Aerospike or Plug Flow nozzles to enable external variation of the nozzle expansion. Several other types of propulsion devices are being studied by researchers.

In the Mini-Magnetospheric Plasma Propulsion (M2P2) concept developed by Robert Winglee at the University of Washington, jets of heated gas plasma, fired from a spacecraft, interact with the magnetic field generated by the spacecraft to produce a mini-magnetosphere around the craft. The interaction of this magnetosphere with the plasma wind from the Sun (the solar wind) produces forces in a fashion somewhat similar to the interaction of an airfoil shape with flowing air generating lift. This force can be tailored to drive the spacecraft around the solar system at very high speeds. Unlike solar sails, which work better to drive a spacecraft in the inner solar system, M2P2 is seen as an option for travel to the outer planets.

Light Propulsion

Scientists have long speculated that photons could exert pressure on a spacecraft and drive it to speeds approaching the speed of light. Practical systems for focusing high-power lasers onto spacecraft are not yet in use in space. Experiments by Leik Myrabo of Rensselaer Polytechnic Institute and the U.S. Air Force had succeeded, by the year 2000, in lifting small objects to a height of a few dozen meters using ground-based lasers. In extended forms of this concept, the focused laser beam creates an "aerospike" of heated gas ahead of the vehicle, which helps reduce drag as the vehicle is driven up through the atmosphere by a shock created by expanding air beneath the vehicle.

Fusion and Antimatter Propulsion

Scientists hope that in the distant future, power generation by nuclear fusion or matter-antimatter interaction will allow the development of propulsion systems with immense thrust levels and very high specific impulse. For now, such systems remain impractical.

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See also: Engine designs; Forces of flight; Robert H. Goddard; Gravity; Helicopters; Hypersonic aircraft; Jet engines; Missiles; National Aeronautics and Space Administration; Hermann Oberth; Ramjets; Rocket propulsion; Rockets; Supersonic aircraft; Turbojets and turbofans; Turboprops; X planes

PSA

Also known as: Pacific Southwest Airlines

Date: From May 6, 1949, to April 8, 1988

Definition: California airline initially limited to intrastate routes to avoid Civil Aeronautics Board (CAB) regulation.

Significance: PSA was the largest airline to fly within one state. The airline had a unique business philosophy, that flying should be fun.

A "Friendly" Airline

Ken Friedkin started Pacific Southwest Airlines (PSA) in San Diego in 1949. Friedkin had run a flight school for the Women's Airforce Service Pilots (WASPs) during World War II. After the war, he wanted to continue training pilots. His flight school was successful, training hundreds of veterans using the G.I. Bill to get an education. By 1948, the school attracted fewer students as most of the veterans completed their education and entered the workforce. Friedkin decided to start a charter service transporting passengers around Southern California. The charter service grew into a scheduled airline, Pacific Southwest Airlines.

On May 6, 1949, the first PSA flight, a DC-3 with twenty-seven passengers, left San Diego's Lindbergh Field bound for Oakland, California, via Burbank. The airfare for the trip was $15.60. The airline flew only on weekends and had very low fares. As a result, PSA attracted a significant number of military personnel, causing some to suggest that its initials stood for the "Poor Sailor's Airline." By 1951, the airline was serving San Diego, Hollywood/Burbank, Oakland, and San Francisco. Because PSA flew only within the state of California, it was able to avoid regulation by the Civil Aeronautics Board.

PSA grew through the 1950's with the inauguration of service to Los Angeles International Airport in August, 1958. Passengers traveled from San Diego to Los Angeles or Burbank for $5.45. Passengers paid $17.26 for the flight from San Diego to San Francisco. In 1959, the airline added three Lockheed L-188 Electra propjets to its fleet. The airline required its stewardesses to wear false eyelashes and bright makeup. PSA would become known for its attractive flight attendants.

"Personality Sells Airlines"

In the 1960's, airline management encouraged crew-passenger interaction. Flight attendants collected tickets on the planes. Flight crews were instructed on how to make conversation with passengers, who were to be treated like guests in the crewmembers' own homes. By the end of the decade, the airline was dubbed the "Personality Sells Airlines." Ken Friedkin's business philosophy was that flying should be fun. When he died in 1962, his successors at PSA continued his philosophy.

PSA carried more than one million passengers over its four-city route in 1962, earning a profit of $1,368,770. Despite competing with TWA, United, and Western, PSA managed to garner a 50 percent market share. One secret to its success was its stewardesses. PSA was known nationally for its suntanned "California Girl" flight attendants, who wore outfits known as "banana skins." Introduced in 1962, form-fitting outfits zippered all the way up the front. One flight attendant noted that while wearing the outfit, "everything showed."

The airline entered the jet age in 1965 with the purchase of five Boeing 727-100's. The airline added San Jose to its route system in 1966. By the end of the decade, PSA's fleet included one DC-9, one Boeing 727-100, fourteen Boeing 727-200's, and nine Boeing 737-200's.

"Catch Our Smile"

A key element of PSA's corporate culture was adopted when smiles were painted on the aircraft in 1970. Soon all identifying artwork included the smile logo. The "Catch Our Smile" theme defined the airline until USAir purchased it in 1986.

Airline management made some strategic mistakes during the 1970's. In the early part of the decade, the airline launched a diversification campaign called "Fly/Drive/Sleep." PSA would provide passengers with air service, a rental car, and a hotel room. Among PSA's notable purchases was the Queen Mary, anchored in Long Beach, California. The campaign was not a financial success.

The late 1970's marked the beginning of a decade of expansion. PSA began interstate service to Nevada in 1978. The airline experienced tragedy on September 25, 1978, when PSA Flight 182 collided in midair with a privately owned Cessna 172, killing 144 people, including 37 PSA employees. PSA added additional interstate routes in the early 1980's. In 1980, PSA became an international airline with service to Puerto Vallarta and Mazatlan, Mexico. PSA pilots walked off the job for fifty-two days in 1980, causing the airline to cancel flights. More than 9 million passengers boarded PSA flights in 1985. As a result of fare wars, the airline lost $600,000, but the holding company recorded a $26.8 million profit from nonairline ventures in 1980.

The airline industry experienced significant consolidation during a two-year period from 1986 to 1987. PSA management worked to remain independent. In November, 1986, American Airlines purchased Air Cal, PSA's major competitor in California, a sign that PSA would soon be bought. The USAir Group purchased PSA for $400 million in 1987.

Tragedy struck PSA before the airline was completely integrated into USAir. On December 7, 1987, Flight 1771 was in the air between Los Angeles and San Francisco. David Burke, who had recently been fired by USAir, smuggled a gun aboard the plane. He shot the crew and then himself, causing the plane to crash from 23,000 feet into a cattle ranch near Harmony, California. The crash killed forty-four people. This incident was the first to be solved using data from the cockpit voice recorder. PSA's last flight, Flight 1486, departed from San Diego on April 8, 1988.

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See also: Accident investigation; Air carriers; Airline industry, U.S.; Flight attendants; Flight recorder; US Airways; Women's Airforce Service Pilots

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Qantas

Also known as: Qantas Air Ways, Queensland and Northern Territory Aerial Services Limited, Qantas Imperial Airways

Date: Beginning November, 1920

Definition: A leading Australian airline.

Significance: Established in 1920, Qantas is among the oldest airlines in the world. It is arguably the best-known Australian airline and remains famous for its safety record: without a single fatality through the year 2000.

Qantas History

In 1919, former Australian Flying Corps officers W. Hudson Fysh and Paul McGinness accepted an assignment to survey parts of the Australian outback. On August 18, 1919, they began their journey across Queensland and the Northern Territories in a Model T Ford. At that time, few roads cut through this deserted swath of land. As pilots, Fysh and McGinness saw the value in an air service that could link the remote outback settlements to one another.

In Brisbane, Fysh and McGinness approached Fergus McMaster, a wealthy rancher, about their idea. McMaster, who had himself once broken the axle of his car while crossing Queensland's Cloncurry River, needed little convincing. He persuaded several business acquaintances to invest in the two airmen's proposal.

Fysh and McGinness adopted a name for their company: Queensland and Northern Territory Aerial Services Limited, which was abbreviated to QANTAS. The company filed for incorporation on November 16, 1920, with Fergus McMaster listed as chairman.

In 1921, the fleet consisted of two war-surplus planes: an Avro 540K and a Royal Aircraft Factory BE-2E. Keeping the two biplanes aloft proved treacherous: Pieces sometimes fell off in midair. Fysh and McGinness hired their former flight sergeant Arthur Baird as fleet mechanic. Baird proved to be a superb engineer who coaxed 54,000 kilometers out of the planes. The airline flew 871 passengers in 1921.

By 1922, Qantas was running a scheduled airmail service between Charleville and Cloncurry and needed larger aircraft. In 1924, Qantas acquired a four-passenger De Havilland DH-50 for the Charleville-to-Cloncurry run. The enclosed cabin of the DH-50 allowed passengers to forego helmets and goggles for the first time.

In 1926, Baird proposed that Qantas build its own aircraft. The first craft, a DH-50A, was finished in August of that year. It was the first aircraft of its size to be built in Australia under license from an overseas company. Qantas remains the only commercial airline to have built its own planes.

In 1928, Qantas signed a contract for medical flights to the Australian Outback. An available doctor made the difference between life and death for people residing in remote settlements. The contract gave Qantas two shillings, or the equivalent of forty cents, per mile. Arthur Affleck, the regular pilot of the "flying doctors" route, was accompanied by K. St. Vincent Welch, a Sydney surgeon. Together, the two men traveled more than 28,000 kilometers to care for 255 patients in 1928.

In 1929, with extended service to Brisbane, Qantas now covered 2,380 kilometers. This year also marked the airline's first one million miles flown and 10,400 passengers carried. In June, the airline moved its headquarters to Brisbane.

Two years later, Qantas participated in an Australia-to-Burma-to-England airmail run. Qantas cemented its links with British Imperial Airways by registering in Brisbane in 1934 as Qantas Imperial Airways. Qantas and British Imperial each held a half-share in the new airline, and Hudson Fysh was named managing director.

By April, 1935, Qantas carried passengers and mail in a DH-86 on the four-day journey from Darwin, Australia, to Singapore. Demand along this route continued to grow, and by 1938, Qantas introduced Short C-Class Empire flying boats, for which the airline built mooring and fueling facilities in Sydney's Rose Bay. Sydney crowds gathered whenever one of these craft took off or landed. Soon, a Southampton-to-Sydney service with a stop in Singapore debuted.

When World War II broke out in 1939, the Sydney-to-Southampton route became a vital communication link between England and Australia, until Singapore fell to the Japanese in 1942. International passenger services were interrupted until the end of the war. The Australian government commissioned more than one-half of Qantas' airplanes for war service.

In 1943, Qantas participated in a plan to reestablish the England-Australia air route that had been severed by Japanese forces. The plan called for flights between the Swan River in Perth and Koggala Lake in Ceylon (present-day Sri Lanka). The 5,652-kilometer trip across the Indian Ocean would be the longest flight yet attempted. Because enemy aircraft patrolled the waters, radio silence had to be maintained at all times, requiring celestial navigation. The weight of the fuel limited the plane's load to only three passengers and 69 kilograms of diplomatic mail. Passengers were given certificates welcoming them as members of the "Rare and Secret Order of the Double Sunrise," a select group of people who had been in the air for twenty-four hours. By the last flight on July 18, 1945, Qantas had completed 271 successful crossings.

After the war, Qantas modernized its fleet. In 1947, the Australian government bought all remaining shares of Qantas, retaining Fysh as chairman. Two years later, the airline introduced Douglas DC-4 Skymasters on new routes to Hong Kong and Japan. Service to Johannesburg, South Africa, was introduced in 1952. In October, 1953, Qantas took over Australia-to-North America service from British Commonwealth Pacific Airlines, which Qantas eventually absorbed.

Qantas was the first airline outside the United States to buy jet airplanes. Qantas acquired seven Boeing 707-138's between July and September, 1959. Service to the United States began in July, and was extended to London via New York. By October, Qantas offered Sydney-to-London service via India. By 1964, most Qantas routes featured 707's, and the airline began to sell off its propeller-driven fleet.

Qantas, now officially known as Qantas Airways, began operating Boeing 747 jumbojets, which were better suited to long-haul flights, in September, 1971. By 1979, Qantas sold off all its 707's and was now the only airline with an all-747 fleet.

Throughout the 1980's, Qantas flirted with several versions of the Boeing 767. During this decade, routes were retailored to reflect Asia's growing prosperity and demand for air services.

In 1992, the Australian government approved a request for Qantas to buy Australian Airlines and its subsidiaries. The new group was completely privatized. In December of that year, British Airways bought 25 percent of Qantas. For the next several years, Qantas increased capacity along its domestic routes to match rising demand. The airline looks forward to continued domestic and international growth throughout the twenty-first century.

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See also: Air carriers; Jumbojets; World War II

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Radar

Definition: A device or system that transmits radio waves and receives and analyzes their reflections in order to determine the location and speed of objects, such as aircraft.

Significance: Radar is essential for air traffic control, aircraft navigation, various weather observations, and many aspects of modern warfare.

Nature and Use

The word "radar" is an acronym for "radio detection and ranging," where ranging refers to finding the distance to a target. Radar works in a fashion similar to that supposed by the early Greeks for the operation of the eye. The Greeks imagined that rays shot out from a person's eye, and that people saw objects as their personal rays struck those objects and somehow returned information. The concept was one of being able to reach out and touch and feel objects from a distance.

Radar reaches out by sending out a beam of radio waves oscillating electric and magnetic fields. When a radio wave passes a given point, the electric field strength at that point goes up and down in much the same way that the water level at a point on the ocean goes up and down as a water wave passes. The distance between adjacent crests in a radio wave is the wavelength, and the number of waves that pass a given point during one second is the frequency. The frequency multiplied by the wavelength gives the speed of the waves. The speed of radio waves is very nearly the speed of light, 3×10^5 kilometers per second. Light itself is an electromagnetic wave, but it has a much higher frequency than radio waves. At the speed of light, it takes only 2.5 seconds for radio waves to travel to the Moon and back.

Radar Components

A radar set usually consists of a transmitter, a transmitting antenna, a receiving antenna, a receiver, a computer, and a display. Normally, the same antenna is used both to transmit and to receive. The transmitter causes a current to flow back and forth in the antenna, causing radio waves of the same frequency as the current to travel outward from the antenna. When radio waves strike objects, the waves are reflected and absorbed, depending upon the waves' frequency and the properties of the objects. Metals, for example, are particularly reflective. When waves are reflected, a small fraction of the reflected energy may return to the radar antenna as an echo. The receiver amplifies this echo, and then the computer extracts information from the amplified echo and prepares this information to be displayed.

Target Direction, Range, Speed, and Size

A common type of radar, with a revolving antenna, sends out a short burst of waves and listens for an echo. The direction in which the antenna was pointing when it received the echo gives the target's direction, and the time delay between sending and receiving gives the target's distance. If the elapsed time is the time between sending the burst and receiving the echo, then the target's range is one-half the elapsed time multiplied by the speed of radar waves, or about 3×10^5 kilometers per second.

Radar and Air Traffic Control

Radar, essential to air traffic control (ATC), was developed from World War II instruments that sent radio waves from a transmitter and measured the time lapse before the radio signal, reflected from a solid object, returned to a receiver in the instrument. The time lapse told the distance between the target object and the radar.

In the 1950's, more accurate tracking systems and high-power radar able to detect aircraft at long ranges were developed. Amplifiers became available to better serve the power needs of long-range radar. Airborne pulse Doppler radar also was introduced, and Doppler frequency shifts of reflected radio signals led to Doppler radar, detection of moving targets, and useful images of targets, as in weather radar.

During the 1970's and 1980's, advances in digital technology enabled better signal and data processing, the ability to distinguish between different targets, and the ability to measure wind, ocean waves, and other environmental features. Solid-state technology helped to improve radar capabilities still further, and computer technology growth in the 1990's increased the amount of information obtainable from radar.

When the same antenna is used both to transmit and to receive, there must be some way to keep the stronger transmitted signal from completely swamping the weaker return echos. In the pulsed operation just described, this is done by timing. The transmission burst lasts about one microsecond, then the radar listens. The wait time during which the radar set listens for echos before sending out another pulse is keyed to the faintest echo that can be reliably detected. If targets up to 150 kilometers (90 miles) away can be detected, and radar waves can travel this distance and back in one millisecond, the pattern of pulse transmission and listening can be repeated about every millisecond.

When a radar wave is reflected from a moving target, the frequency of the wave changes in a fashion described as the Doppler effect. The target's speed can be determined from this change in frequency. If two targets are at the same distance and have the same radar reflective properties, a brighter echo indicates a larger object. Because radar reflectivity depends upon the shape and composition of the target, a better method to determine size is to send out a series of very short pulses, each lasting only a nanosecond or two. A large target may reflect two or more of these pulses, and the maximum distance between the echos yields the approximate size of the target.

Antennas and Operating Frequency

A simple wire antenna will send radio waves outward in all directions; however, a carefully spaced group of several antennas can concentrate most of the radio waves into a beam. Such antenna groups must be several times the size of the wavelength they broadcast, and they work reasonably well from 3 million to 300 million hertz (cycles per second), or 100-meter to 1-meter wavelengths. The largest radar system in the world is the U.S. Air Force's over-the-horizon backscatter (OTH-B) air defense radar system, built to detect a Soviet bomber attack from thousands of kilometers away but also used to study ocean currents and waves. Each of the six transmitting antennas are 1.1 kilometers long, and the receiving antennas are 1.5 kilometers long. They operate between 5 and 28 megahertz, from 60- to 1.1-meter wavelengths. These wavelengths bounce off the ionosphere, about 200 kilometers above the ground, and reflect back down to the earth's surface.

The need for finer resolution and more portable radar sets eventually led to the development of radar wavelengths only centimeters long. Such short wavelengths can be formed into a searchlight-like beam by reflecting them from a parabolic metal dish. Because the paths of these wavelengths are not bent by the ionosphere, they must have a straight line of sight to the target. However, they will pass through the ionosphere and can be used to track objects in space. Regardless of the type of antenna used, radar beams spread wider as they travel outward from the antenna. The amount of spreading is smaller for shorter wavelengths and for bigger antennas. That is, the narrowest beams are formed, and the finest details can be seen, with radars using the shortest wavelengths and the largest antennas.

The properties of the atmosphere also affect the choice of operating frequency. Atmospheric attenuation is negligible for frequencies up to 1 gigahertz (1 billion hertz). Above 3 gigahertz (1-centimeter wavelength), however, radar absorption by raindrops becomes significant, so weather radars operate at these frequencies. Above 12 gigahertz, clouds begin to absorb the radar waves.

Military Development and Applications

The development of radar was such a natural outgrowth of experiments with radio transmission that it was independently invented and developed by several countries during the 1930's. Probably more than any other device, radar dictated the course of World War II. Even before the war, Great Britain had begun installation of chain home (CH) radar stations along its coasts, with radar antennas on towers up to 110 meters high. Germany began massive bomber attacks on Britain in August, 1940. Chain home radars were so effective at giving warning and allowing the badly outnumbered Royal Air Force (RAF) fighters to position themselves for maximum effect, that by November of that year, daytime bomber attacks had stopped. The CH radar system determined the direction and elevation of an approaching aircraft by comparing the intensity of signals received at different antennas in the chain. When night attacks began the following year, CH radars were used to guide friendly fighters toward enemy bombers until the fighters got close enough to pick up the bombers on the short-range (5-kilometer) radar the fighters now carried. This technique was so successful that night attacks were also stopped.

Radar was also put to other uses. In order to aid radar operators to distinguish between friendly and enemy aircraft, identification, friend or foe (IFF) beacons were developed and used by the Allies. These were small radar receiver/transmitters that broadcast a coded radar signal that identified a craft as friendly when they detected a probing radar wave. Another device, a radar altimeter, is simply a small radar set that sends pulses toward the ground and determines the height from the time it takes for the echos to return. The atomic bomb dropped on Hiroshima in 1945 carried four radar altimeters and was fused to explode when any two measured the height as less than 600 meters (2,000 feet).

Had German submarines been able to cut off the flow of supplies and personnel from the United States and Canada to Great Britain and Europe, the Allied invasion of Europe would have been impossible. At first, the German submarines were very successful in sinking Allied ships, but then the Allies began to hunt the submarines with radar. As submarine losses mounted, the Germans equipped their submarines with radar detectors, and the warning they gained allowed the submarines to be safely hidden underwater by the time attack aircraft arrived.

The British then made one of the most important technological advances of the war, the microwave-cavity magnetron, a device for generating high-power radio waves of 10 centimeters or less. Shorter wavelengths meant radar antennas could be smaller, a great advantage in an aircraft, and smaller targets, such as submarine periscopes, could be detected. The German radar detectors could not pick up the short wavelength the Allies were now using, and the tide turned against them. In 1942, the Germans sank 8,245,000 tons of Allied shipping while losing 85 submarines. In 1944, they sank only 1,422,000 tons, but lost 241 submarines.

Radar Tracking

The familiar weather radar displays distances and directions to radar targets in a maplike image. A moving target such as a storm can be tracked by following its image on the radar screen as its position changes with time. Air traffic controllers use an extension of this method to guide aircraft in the vicinity of busy airports. A sophisticated version of this type of radar is used by the E-3 Sentry, or Airborne Warning and Control System (AWACS) aircraft, a modified Boeing 707 carrying a 9-meter (30-foot) radar dome. When aloft, AWACS can detect low-flying targets more than 375 kilometers (250 miles) away. Special equipment subtracts out the ground clutter that would swamp ordinary radars, thereby allowing AWACS controllers to monitor all the air traffic in the area and to direct friendly aircraft. AWACS assisted in thirty-eight of the forty air-to-air shoot-downs of the 1991 Persian Gulf War.

The efforts of civilian air traffic controllers have contributed to making air travel far safer than automobile travel. Airport surveillance radar (ASR) is a medium-range system that detects and tracks aircraft within about 50 miles of the radar installation. Controllers use this radar as they direct aircraft landings, takeoffs, and flight patterns. Air route surveillance radar (ARSR) tracks aircraft en route between airports. The ARSR-4 uses a wavelength of about 21 centimeters and has a range of about 400 kilometers. It broadcasts a series of pulses that interrogates the radar beacon or transponder carried by all large aircraft. The transponder broadcasts a reply from which the aircraft's identity, range, and direction can be determined. An air traffic controller follows the aircraft's progress and delivers instructions. When the aircraft leaves one controller's sector, it is progressively handed off to controllers in the sectors through which it flies until reaching the destination airport.

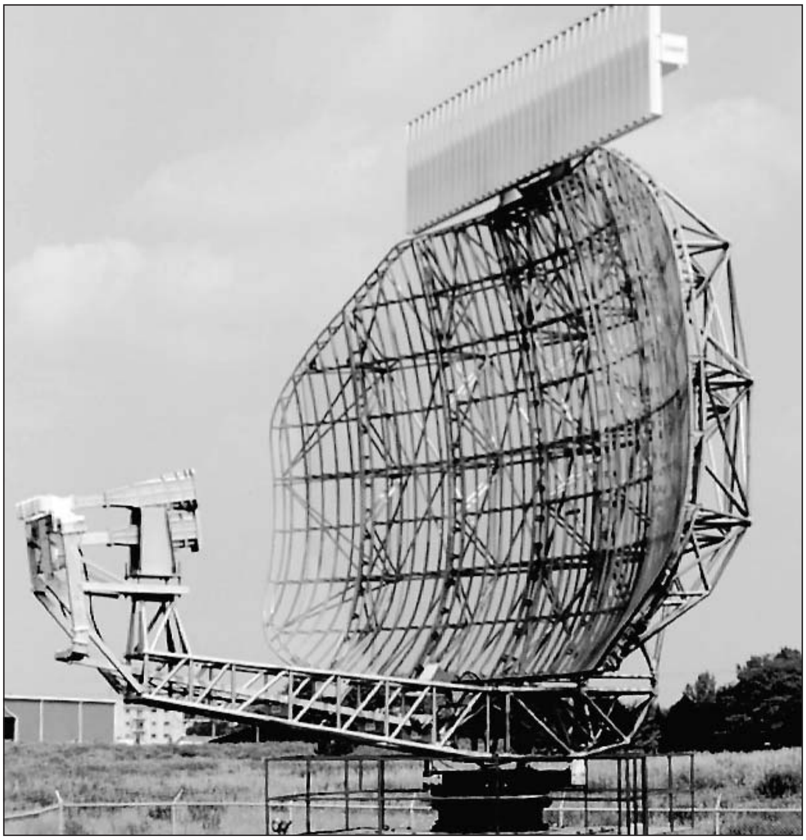
Radar sets can be designed to track a target automatically. During the Korean War, the U.S. Army used radar to track mortar shells. A shell follows a parabolic trajectory, and if the radar can follow it for more than one-half of its trajectory, its launch point can be deduced, and artillery fire can be directed against the mortar. The radar dish used could slew, or pivot, quickly in any direction, and a mask partially blocked the center of the radar beam. When the radar locked onto a target, the target was positioned in the center of the beam, where the return echo would be relatively weak because of the mask. If the target drifted from the beam's center, the echo strengthened, and the radar set used this information to move the antenna and keep the target centered. Although a similar scheme can be used to track aircraft, schemes that maximize the echo are more common. In any case, a relatively narrow beam must be used for tracking.

Although mechanical systems can neither move quickly enough to track rockets and nearby fast-moving aircraft nor track multiple targets, phased-array radars can. These arrays consist of hundreds or even thousands of small antenna pods mounted in a regular array on a reflecting surface. Each pod is like a four-leaf clover, with each leaf replaced by a pencil-length rod pointing back toward the reflector at an approximate 45-degree angle. The term "phase" refers to position in the wave cycle. When all of the antennas are in phase, they begin broadcasting the beginning of a wave at the same time, and the radar beam is strongest straight ahead. If, instead, neighboring rows of antennas begin to broadcast at progressively later times, the radar beam will be tilted off to one side. When the radar receives a target echo, a computer can calculate where the target should be a fraction of a second later and direct the beam at that point. It takes only millionths of a second to switch the beam between targets so that a phased array can track one hundred or more targets virtually simultaneously.

The U.S. Air Force maintains Pave Paws radars at Cape Cod, Massachusetts; Beale, California; and Clear Air Force Station, Alaska. "Pave" is an Air Force program name, and

"Paws" is an acronym of phased-array warning system. Each Pave Paws site has twin antennas consisting of 1,792 radiating elements mounted on massive reflecting faces measuring 31 meters across. The primary assignment for these installations is to detect and track intercontinental ballistic missiles or missiles launched from submarines at the United States. The Pave Paws radar beams extend 5,500 kilometers into space and are also used to track satellites.

The heart of the U.S. Navy's Aegis combat system is a 4-megawatt phased-array radar mounted on a special ship that is also equipped with missiles and a Phalanx close-in weapons system (CIWS) for destroying attacking aircraft and missiles.



A radar receiver locates objects and measures the distance to them by sending out short bursts of radio waves and measuring how long it takes for an echo of the bounced-back wave to return. (Raytheon Company)

Countermeasures and Stealth Technology

The crew of an aircraft carrying a radar detector will know whether the craft is being observed. Once alerted, the crew might eject strips of aluminum foil, called chaff. Clouds of chaff appear as new targets on the radar screen and confuse the radar operator. The U.S. Eighth Air Force dropped more than 10 million pounds (4.5 million kilograms) of aluminum foil during World War II. Specially equipped aircraft, such as Ferrets, and later, Wild Weasels, determine the location and frequencies of fire-control radars and jam them by broadcasting radar noise.

Modern radar countermeasures include recording the fire-control radar signals and then beaming them back at the ground installation, thus making false targets appear at various distances and directions. When the aircraft are close enough, pilots can fire high-speed antiradiation missiles (HARMs) that home in on the fire-control radar. This presents the fire-control radar operator with an impossible choice: In order to shoot down the attacking aircraft, the operator must turn on the fire-control radar. However, if the radar is on for more than a few seconds, a HARM can lock in on its beam. In the initial stage of the Persian Gulf War, F-4G Phantom Wild Weasels flew 2,596 sorties and used this technique to devastate the formidable Iraqi air defenses.

Perhaps the best radar countermeasure is to make an aircraft invisible to radar. The radar echos from an aircraft's rounded fuselage fan out over a broad range of directions, including back toward the originating antenna. Stealth aircraft are made with many flat surfaces that are tilted to deflect the reflected radar beam away from the originating antenna. In order to reduce the radar echo when it is observed from behind, a "W" shape is used for the wing's trailing edge. Right-angled corners such as those between the tail and fuselage of a normal aircraft are eliminated, because they can return strong radar echos. It is such right angles that make highway signs coated with corner reflector crystals appear to light up when lit by a car's headlights. Carbon fiber materials and coatings that absorb radar waves are used extensively. The F-117A Nighthawk can get 90 percent closer to ground-based radar than a normal aircraft before it can be detected. During the opening minutes of the Persian Gulf War, eight Nighthawks followed a wave of Tomahawk cruise missiles and arrived at Bagdad undetected by ground radar. Their presence was announced only by bombs falling on their targets. The massive B-2 stealth bomber first saw combat in Yugoslavia during March, 1999. It carries eight times the bomb load of the F-117.

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See also: Air traffic control; Avionics; Communication; Doppler radar; Gulf War; Instrumentation; Missiles; Nighthawk; Stealth bomber; Stealth fighter; World War II

Ramjets

Definition: A ramjet engine is a jet engine in which the working fluid is compressed solely by the deceleration of the fluid entering the engine.

Significance: Ramjet engines represent the simplest type of air-breathing engines. They are used to power long-range guided missiles, and they also offer the potential to improve the payload and reusability of space launch vehicles.

Principles

Jet engine designs can be understood in terms of the gas turbine cycle. The fluid is first compressed, heat is added at constant pressure, and then work is extracted as the fluid expands. Heat addition is more efficient at high pressure. At high flight speeds, the pressure rise due to the deceleration of air entering the engine is high enough for engine performance, without mechanical compressors. This also removes the need for a turbine to drive the compressor. Since compression depends on a high flight speed, ramjets cannot accelerate from rest, nor produce useful levels of thrust below Mach 0.6. Thus, ramjets are used on vehicles where there is some other propulsion device for the takeoff stage, with ramjet startup occurring at supersonic speeds.

In the theoretical case of the ideal ramjet, air entering at a supersonic Mach number is decelerated through a lossless diffuser. Fuel is added and mixed with the air before it enters the combustor, and then ignited, to complete the fuel-air reaction at constant pressure (no pressure losses) inside the combustor. The heated gas then expands out through a frictionless nozzle, the exhaust Mach number equaling the Mach number ahead of the inlet. This exhaust velocity is higher than the inlet velocity because the exhaust temperature and speed of sound are higher than the inlet values. The thrust of the ideal ramjet is limited by two factors. Firstly, the thrust becomes zero at the Mach number where deceleration of air raises the temperature to the material limits of the engine, preventing further heat addition. Secondly, when the flow velocity reaches the local speed of sound anywhere inside the engine duct, the mass flow rate of air and the amount of heat addition are maximized.

In practice, four other major factors limit ramjet efficiency. The first is that decelerating a supersonic flow usually produces shocks. Drag due to shock losses can be minimized by careful inlet design, but operation over a range of conditions requires variable-geometry inlets, which add weight and complexity. Second, there is a compromise in the burner design. Without flameholders to create zones of slow-moving fluid and turbulence, it is difficult to get the fuel and air to mix and react within the short distance available for a combustor. Increasing the distance usually increases the engine weight, but flameholders and turbulence increase drag. Third, heat addition in any form to a moving fluid entails an irrecoverable loss in the work available from the fluid. The higher the Mach number at heat addition, the greater this Rayleigh line loss. Fourth, the nozzle can rarely be made large enough to enable full expansion of the exhaust to the outside pressure. Solutions to each of these problems can be seen in the various designs of ramjets.

History

French engineer René Lorin is credited with inventing the ramjet in 1913. Practical applications had to wait until the 1940's. Small Lorin-type ramjets were tested atop a Luftwaffe Dornier Do-17Z-2 in early 1942. The Skoda-Kauba SK-P.14 ramjet-powered fighter (early 1945) was built around a 1.5 meter diameter, 9.5 meter long Sanger ramjet. The ramjet duct and two forward fuel tanks occupied much of the fuselage, with the pilot lying prone atop the ramjet in a cockpit located in the aircraft nose. The small unswept wings carried fuel tanks. Booster rockets on a tricycle undercarriage that could be jettisoned enabled takeoff and acceleration to ramjet startup speed. Germany also used ramjet engines to augment the V-1 Doodlebug rocket bombs sent over Britain. Sanger ramjets were also tested with the Messerschmitt Me-262 turbojet fighter and other Luftwaffe aircraft.

Studies using subsonic ramjets at the University of Southern California (USC) in late 1943 led to the 1945 contract to the Glenn Martin company to develop the Gorgon 4 guided ramjet missile. The Gorgon test vehicles had swept wings and tails, designed for Mach 0.7 flight with a range of 50 to 70 miles, with the engine firing for 270 seconds. The full-scale USC supersonic ramjet was tested in August, 1945. The Marquardt Company delivered the first engines for testing to the U.S. Navy, with the first free flight of a supersonic ramjet-powered vehicle on November 14, 1947, off Point Mugu, California. The National Advisory Committee for Aeronautics (NACA) used the F-23 Ramjet Research Vehicle in tests at their Wallops Island facility from 1950 to 1954. The two 1,000-pound-thrust engines of the F-23 used acetylene fuel, reaching Mach 3.12 and an altitude of 159,000 feet. In 1959, a French experimental aircraft set a speed record of 1,020 miles per hour using ramjet engines. Meanwhile Soviet designer Mikhail Bondaryuk developed a kerosene-fueled ramjet stage for the EKR launch vehicle in 1953 and 1954, producing 1,250 pounds of thrust, with a specific impulse (Isp) of 1,580 seconds. This engine was studied for an experimental winged cruise missile, which formed the basis for the later Burya missiles.

On August 29, 1947, the McDonnell XH-20 “Little Henry” helicopter first flew, powered by ramjet engines at its rotor tips. While this concept eliminated the need for a countertorque system such as a tail rotor, it was too noisy to be a practical helicopter propulsion device. At the turn of the twenty-first century, a ramjet-powered spinning disc was being developed as an efficient power-generation device. With these two exceptions, all ramjet applications have been for high-speed flight. Ramjets are thought to be useful for flight at up to Mach 18, with advances in materials and fuels.

Ramjet-Powered Missiles

The British Bloodhound and SeaDart series, the U.S. Navy’s Mach 2.7 Talos, which could carry a 5 kiloton nuclear warhead, the Soviet SA-6, and the Indian Akash are examples of surface-to-air missiles which use a solid-fueled rocket boost, followed by ramjet-powered acceleration. The BAe Meteor beyond visual range air-to-air missile (BVRAAM) uses a solid-fueled variable-flow rocket-ramjet engine. The ramjet engine enables the thrust to be distributed and controlled over a longer duration, widening the range of parameters within which the missile has a high probability of destroying its targets. Ramjet air-to-surface missiles include the Russian KH-31/AS-17 Krypton. In 1955, the U.S. Navy launched and then canceled full-scale development of the Triton, a ramjet-powered, Mach 3.5, 21,600-kilometer-range, submarine-launched cruise missile. France has deployed the ramjet-powered, air-launched, nuclear-armed, Mach 3.5, 300-kilometer-range ASMP cruise missile. Newer programs are the U.S. Fasthawk Mach 4 booster-ramjet cruise missile to replace the Tomahawk, and the CounterForce Mach 4-6 surface-to-air missile (SAM).

Turboramjets and Ramrockets

Most missiles which use ramjets are actually rocket-ramjets or ramrockets. They use a rocket booster either as a separate stage or as an integral part of the engine. At liftoff, the intake is closed or blocked by fuel, and the vehicle operates as a rocket. As the rocket propellant grain burns down, the intakes are opened, and a combustion chamber formed for the ramjet to start operating. In some missiles, the ramjet engines are separate strap-ons which do not operate fully until the rocket booster stage is expended. High-speed aircraft use engines which operate partially as ramjets. For example, the SR-71 Blackbird has engines which start as turbine engines. At high altitudes and speeds, larger air intakes open, allowing air to bypass the fan and operate as a ramjet. The Japanese ATREX project developed an expanding air turboramjet engine. In this concept, liquid hydrogen fuel was used to precool the incoming air before sending it through a fan (at takeoff) or around the fan at high speeds. Combustion was conducted in subsonic flow. A tip-turbine operated in the high-speed bypass flow to recover work to be used to run the liquid hydrogen turbopump. A plug nozzle was used, where the flow adjusted itself to be optimally expanded as the external conditions changed.

Hypersonic Ramjets

The vehicles discussed above are mostly limited to publicized Mach numbers below 3.5. The ramjet also offers several advantages as a propulsion system for space launch vehicles and hypersonic missiles. Without complex turbomachinery, the engine can be quite light, offer an unobstructed airflow path, and can use a wide variety of fuels, ranging from cryogenic hydrogen to storables like kerosene and methane. However, major problems face engine designers. Above Mach 4, shock losses suffered in decelerating the flow to subsonic speeds for combustion may exceed the Rayleigh line losses of heat addition to a supersonic stream. The pressure rise incurred in deceleration to subsonic speeds would demand heavy casings, and the temperature rise is such that further heat addition would melt the burner. Improvements in materials can yield only limited gains, because most fuels would decompose and not release heat at very high temperatures. For these reasons, supersonic-combustion ramjets (scramjets) are being developed in several countries, including the United States, Russia, Britain, Europe, Japan, and India. In these designs, the fuel is mixed into a supersonic airstream and the heat added by reaction until the Mach number comes down close to unity. The technology for air liquefaction, where oxygen is recovered from air at the lower altitudes and stored in liquid form for rocket flight at high altitudes, appears to be key to making these into viable space launch engines.

In the 1960's, scramjet research produced a few designs, such as those by Aerojet General, which showed positive net thrust (more thrust than drag) at hypersonic Mach numbers in wind tunnel tests. Such engines injected the fuel in jets perpendicular to the supersonic airstream, enabling fast mixing, albeit with high drag. Antonio Ferri's "thermal compression" idea removed the need for variable geometry. The X-15 project, intended to study scramjet operation, was canceled before testing full-scramjet mode. In the mid-1980's, NASA, the U.S. Air Force, the U.S. Navy, Britain, France, Germany, and Japan each conducted large programs directed toward different vehicle concepts. Best-known among these was the National Aerospace Plane (NASP) project announced by President Ronald Reagan, with the French Hermes, German Sanger, and British HOTOL springing up concurrently. When American funding for NASP dried up in the mid-1990's, citing difficulties with supersonic fuel-air mixing, all these programs dropped from public view, citing high cost. Scramjet engines have since been developed for missile applications. A November, 1991, test lasting 130 seconds near Baikonur Cosmodrome in Kazakstan is reported to have taken a scramjet on a SAM booster to Mach 8. The Russian GELA hypersonic experimental flying testbed, believed to be an air-launched strategic cruise missile, was shown at Moscow in 1995. The Mach 6-10 Hyper-X program, the Boeing/NASA X-43, and a DARPA scramjet program are examples. The Johns Hopkins Applied Physics Lab reported success with a dual-combustor ramjet which proved operation of a scramjet engine up to Mach 6 with JP-10 storable liquid hydrocarbon fuel.

Nuclear Ramjets

The heat addition in the ramjet need not be chemical. In the 1950's, the U.S. Air Force's Project Pluto developed a Mach 3 ramjet-powered missile where the flow was heated to over 2,500 degrees Fahrenheit by a fast neutron nuclear reactor. The missile would carry nuclear weapons and loiter around the periphery of the Soviet Union in tense times. In a nuclear war, these 150,000-pound "Doomsday Missiles" were to dash supersonic at low altitudes (500 feet) and deliver their 50,000-pound payloads to their targets. After dropping bombs, the missiles were to cruise back and forth across the Soviet Union indefinitely, destroying property with the shock waves created by their passage, and contaminating everything with radiation from their engines. The nuclear ramjet engine was tested in the Nevada desert. The danger of the missile going out of control during flight testing and cruising back and forth across the United States ensured the project's cancellation.

Robert W. Bussard described an interstellar ramjet. The vehicle would create a magnetic field and capture hydrogen ions (protons) occurring in space. Nuclear fusion of these protons would heat the gas and propel them through a nozzle. The critical speed needed for ramjet startup was estimated to be about 6 percent of the speed of light, and the inlet diameter was of the order of 6,000 to 10,000 kilometers. Lasers were proposed to ionize hydrogen ahead of the inlet. There is debate whether the protons would actually enter the engine, and would sustain fusion.

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See also: Engine designs; Forces of flight; Robert H. Goddard; Gravity; Helicopters; Hypersonic aircraft; Jet engines; Missiles; National Aeronautics and Space Administration; Hermann Oberth; Rocket propulsion; Rockets; Supersonic aircraft; Turbojets and turbofans; Turboprops; X planes

Raptor

Also known as: F-22
Date: First flew on September 7, 1997
Definition: Next-generation air superiority fighter.
Significance: The F-22 is expected to become the predominant fighter plane in the world when it becomes operational in 2005, and supporters argue that it will guarantee the U.S. Air Force dominance over potential enemies through at least 2040.

Evolution of the Raptor

First conceived in the midst of the Cold War arms race with the Soviet Union, the F-22 grew out of U.S. fears that future Russian fighters might prove superior to the F-15 Eagle. Experts called for the creation of an advanced tactical fighter in 1981, and after competition between various manufacturers the Air Force awarded Lockheed Martin a contract to build the plane in 1991. Assembly of the first test model began in 1994, the aircraft flew for the first time in 1997, and in 1999 the Air Force approved a low-rate production plan that would put eight Raptors into advanced flight testing by the end of 2001. The Air Force hoped to purchase 339 F-22's and to form the first operational Raptor squadron in 2005.

Capabilities

Although the F-22 is fully capable of attacking ground targets with precision, its primary mission is to destroy enemy aircraft at either close or long range under any weather conditions. It incorporates a number of advanced technologies, including a stealth airframe design which utilizes flattened surfaces and special materials to make the aircraft difficult to detect with radar. The Raptor is powered by two revolutionary Pratt & Whitney F-119-PW-100 engines, which allow it to fly for extended periods at supersonic speed (beyond the speed of sound) without using its afterburner. An afterburner essentially pumps raw fuel into the flame of a jet engine, generating great thrust and speed in exchange for a great increase in fuel consumption. This ability to supercruise allows the Raptor to fly farther and faster while using less fuel than any jet fighter to date. In addition, the F-22 uses thrust vectoring, in which the nozzle of each engine moves to help the plane turn, climb, or dive, to greatly enhance maneuverability. The F-22 also has an integrated avionics suite in which all the computers on the plane, such as weapons, radar, and flight control, function well together, with a central integrated processor one hundred times more powerful than the computers on the space shuttle. These technologies allow the single pilot of an F-22 to see enemy aircraft at long range and destroy them with very little risk of being detected, or to close with and eliminate adversaries in a close-range dogfight under any circumstances. They represent an enormous advance over previous aircraft.

Weapons

The F-22 carries a 20-millimeter Gatling gun and air-to-air missiles or ground-attack ordnance in an internal weapons bay which reduces drag and enhances stealth characteristics. Extra weapons or fuel tanks may be carried on external racks if necessary, though this arrangement makes the aircraft more visible to enemy radar. A normal weapons load would include six radar-guided AIM-120 medium-range air-to-air missiles or two AIM-120's and two GBU-32 joint direct attack munitions (JDAM). In either case, the Raptor could also carry two AIM-9 Sidewinder short-range air-to-air missiles on its wingtips.

The Future of the Raptor

Supporters of the F-22 point to its unparalleled capability and argue the United States should make the aircraft operational as soon as possible. They maintain that the current fleet of Air Force F-15 Eagles and F-16 Fighting Falcons are old and increasingly difficult to maintain, and that advances in computers, radar, and surface-to-air missiles make existing U.S. aircraft more and more vulnerable to the air defenses of potential enemies.

Critics counter that cost overruns and production delays have made the F-22 the most expensive fighter plane in history, and that the end of the Cold War and the diminishing aerial threat posed by other nations means the United States can delay production of the aircraft for at least a decade. They point to current estimates which place the cost of the entire Raptor program at approximately $62.7 billion for 339 planes (or $187 million each), and to studies which show that F-15's and F-16's will remain superior to the aircraft of any potential adversary through perhaps 2014. They suggest that Raptor production be delayed while the Air Force purchases additional aircraft based on current designs, and then accelerated when the threat posed by possible enemies is commensurate with the Raptor's cost. No matter who wins this argument, the Raptor seems certain to enter service in at least limited numbers between 2005 and 2007.

F-22 Specifications

The Raptor's length is 62 feet, 1 inch, and its height is 16 feet, 5 inches, with a wingspan of 44 feet, 6 inches. Its maximum takeoff weight is 60,000 pounds, although its normal takeoff weight is yet to be determined. Its maximum cruise speed is Mach 1.5 (one-and-a-half times the speed of sound) or better, with an absolute maximum speed of Mach 1.7. Its maximum altitude is 50,000 feet, although its range is not yet known. The plane has two Pratt & Whitney F119-PW-100 engines, each rated at approximately 35,000 pounds of thrust.

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See also: Air Force, U.S.; Eagle; Fighter pilots; Jet engines; Lockheed Martin; Military flight; Supersonic aircraft

Reconnaissance

Definition: The military exploration of enemy territory to gain strategic information.

Significance: Aerial reconnaissance was one of the earliest military uses of aircraft and remains a vital tool for military intelligence gathering.

History and Development

Aerial reconnaissance was the first mission of combat aviation, from which all other combat missions were outgrowths. Since their humble beginnings in World War I (1914-1918), when pilots flew over battlefields looking for the enemy, reconnaissance aircraft, their sensors, and their missions have evolved in directions that would have been unimaginable to those pioneers in their flimsy aircraft over no-man's-land.

By the late twentieth century, the most frequently used battlefield reconnaissance aircraft were scout helicopters, such as the OH-58, which fly at low altitudes, following the terrain to minimize their vulnerability. These aircraft look for artillery targets and information for the divisional intelligence staff and flush out victims for attack helicopters. High-performance fighters are unsuited for these vital and dangerous missions, which require aircraft that can move slowly enough to find targets as small as a single vehicle or group of soldiers and can hover over the battlefield long enough to make a difference.

At an echelon above the battlefield scouts are high-performance reconnaissance aircraft, generally modified fighter aircraft. In World War II (1939-1945), they tended to be stripped-down versions of the fastest aircraft available, such as the F-5, a modified P-38 Lightning, or the De Havilland Mosquito. Their speed and high-altitude performance usually allowed them to evade pursuit and to avoid flak. Two primary missions of high-performance reconnaissance aircraft during this period were finding targets for strategic bombers and reporting on the results of bombing raids.

With the introduction of satellites and more specialized strategic reconnaissance aircraft, the modified fighter declined in prominence and now primarily supports the intelligence-gathering needs of the theater commander. Thus, the modified fighter reconnaissance aircraft no longer has the best available airframe. In recent decades, aircraft types have remained in service for reconnaissance long after they have been replaced as fighters. A prime example, the RF-4C Phantom, flew reconnaissance missions for the U.S. Air Force for more than a decade after the F-4 fighter was retired from the active inventory. Although these aircraft can mount a variety of sensors, including side-looking airborne radar (SLAR), their primary tool is usually photography.

During the Cold War, the modified fighter was phased out of strategic reconnaissance missions. Because it had never been feasible to send a modified fighter deep into the interior of the Soviet Union, this region remained a total mystery to the West at the start of the Cold War. During the early 1950's, nations of the North Atlantic Treaty Organization (NATO) routinely learned about new Soviet weapons systems only after they had been paraded across Moscow's Red Square on the May Day holiday. The first effective U.S. attempt to address this problem was the U-2, a low-speed, high-altitude aircraft with a ceiling of 70,000 feet. Stategists hoped that the U-2 would fly high enough to avoid any possibility of intercept. The U-2 succeeded at its mission from 1956 until 1960, when an SA-2 brought one down with disastrous political consequences.

The next stage in the development of strategic reconnaissance aircraft was the SR-71. Its existence was first made public in 1964, and it officially remains the fastest airplane in the world. To this day, the SR-71 has never been successfully intercepted, and it remains outside the altitude and speed envelopes of the most capable surface-to-air missiles.

During the late 1940's, it was realized that the most effective solution to the strategic reconnaissance problem was the Earth-circling satellite, but it was many years before the technology was implemented. In August, 1960, a satellite, launched under the name Project Corona, took the first photograph from space. By the 1970's, both the United States and the Soviet Union had routinely deployed a broad array of surveillance satellites. Satellites initially used cameras, which would jettison their film after their mission was completed. A recovery aircraft would then snag the film capsule in midair as it drifted down to Earth.

With time, further sensors have been added to satellites to include infrared and electronic intercept capabilities, and encrypted satellite downlinks have removed the need for midair recovery of falling film canisters. Satellites, however, continue to be hindered by their predictable and difficult-to-change orbits and by their limited ability to see targets that are obscured by the effects of clouds and other atmospheric conditions.

The Intelligence Process

Aerial reconnaissance, although extremely important, is not the only tool available to the intelligence analyst. Intelligence can be described as a mosaic, in which each aerial image, communications intercept, or spy report is a piece. Although each piece, in itself, might not reveal much information, when placed in the context of all other intelligence from all other available sources, the pieces come together to form a coherent picture. Each intelligence source has its own complementary strengths and weaknesses.

Human Intelligence

Human intelligence (HUMINT) is information gained from human beings: spies, prisoners of war, scouts, or combatants in contact with the enemy. In an airborne context, human intelligence usually consists of spot reports of visual sightings by pilots or observers. On the modern battlefield, with video feeds to ground stations becoming increasingly common, the line between human intelligence and imagery intelligence has become somewhat blurred.

Imagery Intelligence

Imagery intelligence (IMINT) has always been the aircraft's forte. Imagery has traditionally involved photography, and although photographic imagery remains an important tool, technology has added additional tools to the IMINT toolbox. Infrared, electro-optic video, and radar also produce images that can provide valuable intelligence and see things that conventional photography cannot.

The aerial photograph provides a powerful intelligence tool. It freezes in time an image that can be minutely examined. The exact make and model of enemy equipment, the strength and deployment of enemy forces, the condition of roads and other lines of communication, the output of industrial plants, and the effectiveness of prior attacks can all be determined through aerial photography.

Photographic intelligence does have weaknesses, however. It cannot be gathered through obstructions such as clouds or smoke. It freezes a single instant in time, allowing detailed analysis, but may miss something that happened an instant before or after, and it may lack the context of a moving image.

There are three forms of aerial photographic image: the vertical, the oblique, and the panoramic. The vertical image is taken from directly over the target. It provides a constant scale, which can be determined from the focal length of the camera and altitude of the platform. It is the preferred format, but because it requires the camera platform to fly directly over the target, it can be a bit too dangerous in a high-threat environment.

An oblique image is taken at an angle from the target. It covers a good deal of ground and is much safer to take. While it gives definition to tall objects, such as radio aerials, it also allows terrain to mask possible targets. Because it does not provide a constant scale, measurements taken from it are far less precise. In addition, only the first one-third of the image is generally usable, whereas the rest of the image is captured at too flat an angle for any meaningful interpretation.

The U-2 spy plane piloted by Francis Gary Powers was shot down over the Soviet Union on May 1, 1960, becoming one of the most notorious reconnaissance planes in history. (NASA)

The panoramic image is a combination of the vertical and oblique images. It covers a vast area below the platform and off to both sides and combines the strengths and weaknesses of vertical and oblique.

Infrared Imagery

Infrared imagery (IR) provides an effective and deadly addition to the aerial reconnaissance toolbox. IR sees electromagnetic radiation at a wavelength lower than visible light, which is radiation that is produced by heat.

IR works most effectively when the difference between the heat of the targets and the ambient temperature is high. IR is far less effective at high noon than it is at midnight. At night, the ambient temperature usually drops well below the heat of human bodies and vehicle engines. When the differential is high, hot targets appear as glowing objects on a dark background.

In the 1980's, forward-looking infrared (FLIR) was widely deployed. FLIR provides cueing for other intelligence assets and also works as a lethal target-acquisition tool for attack helicopters and low-altitude fighter-bombers. FLIR operates in real time and can capture movement as well as heat. If a target is both hot and moving, it will be detected.

Although FLIR can see much that conventional photography cannot, it cannot see through anything that absorbs or dissipates radiated heat, such as thick fog, rain, or solid obstacles.

Radar

Side-looking airborne radar (SLAR) has greatly expanded the vision and range of the aerial observer. The resolution has been improved to the point where individual buildings, roads, woods, and even vehicles can be reliably located. Added to these advantages is SLAR's ability to use Doppler measurements to determine which of the returns is currently moving. These moving target indicators (MTIs) mean that mass ground targets such as armored regiments can be picked out and targeted in real time.

The U.S. Air Force has invested in a new class of battlefield surveillance aircraft based on various forms of SLAR. The mission of the joint surveillance target attack radar system (Joint STARS) is to fly parallel to the front line and look deep into the enemy's rear for large-scale enemy movements and targets of opportunity. When teamed with the airborne warning and control system (AWACS), which uses radar to watch the skies deep into the enemy's rear, the U.S. Air Force sees the battlefield in three dimensions, making it extremely difficult for any conventional modern army to operate without being under constant attack by aircraft, long-range artillery, and rockets.

Radar can see through darkness, fog, clouds, and all but the heaviest weather. It can also see through camouflage and any sort of obstacle that is not dense enough to stop radio waves. It also provides location information that is accurate enough for immediate targeting.

The weakness of radar is that it behaves in a way that is different enough from familiar visible light that its ability to identify targets is very limited. The shape of a radar return can vary according to the angle at which it strikes a target. Although much effort has been expended toward making radar blips more descriptive, none so far has been reliable. Objects smaller than a B-52 can be identified no more precisely than as probable armored vehicles or possible radars.

Signals Intelligence

In addition to imagery, aircraft make excellent platforms for devices that collect and analyze the signals from communications systems, radars, or other devices broadcasting electromagnetic radiation into the atmosphere. Signals intelligence (SIGINT) consists of communications intelligence (COMINT) that intercepts and locates radio communications and electronic intelligence (ELINT), which is the location and identification of non-communication emitters, primarily radars.

The Future

The turn of the twenty-first century has brought a revolutionary change in the nature of aerial reconnaissance. The reconnaissance pilot "alone, unarmed, and unafraid" has become increasingly rare. The future, and to a large degree, the present of aerial reconnaissance lies with the uninhabited aerial vehicle (UAV). Systems such as the U.S. Army's Predator system are taking over the mission of battlefield reconnaissance. Using a combination of video and the Global Positioning System (GPS), they provide battlefield intelligence staffs with real-time intelligence information and accurate targeting without risking the lives of pilots.

The next stage of aerial reconnaissance is the replacement of many large radar and SIGINT platforms with long-endurance UAVs such as the Global Hawk. The long-range strategic mission will soon be performed by high-altitude uncrewed aircraft that will fly three times faster than the SR-71. These superfast UAVs, with their ability to fly on demand and address specific targets rather than follow fixed orbits, may eventually render the spy satellite obsolete.

New-generation UAVs carry sensors that will change the way imagery is collected and analyzed. Intelligence analysts will be able to interpret an image while the aircraft is still over the target, and advancements in digital image enhancement are making imagery even more useful. The future belongs to real-time sensors on a variety of aerial platforms (mostly uncrewed) networked to computerized command centers.

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See also: Balloons; Communication; Fighter pilots; Military flight; Radar; Satellites; Uncrewed spaceflight; Uninhabited aerial vehicles; World War I; World War II

Record flights

Definition: Flights that surpass previous performance achievements.

Significance: Since the earliest days of human flight, pilots have attempted to fly faster, higher, longer distances, and longer periods of time than their predecessors. This competitive attitude has created the impetus to improve aircraft technology, and feats that were once remarkable become commonplace features of commercial aviation.

The desire to "push the envelope" of aircraft performance has provided the impetus to improve aircraft technology since the eighteenth century, from hot-air balloons to solar-powered aircraft. Record keepers usually compare the performances of aircraft of comparable weight and engine type.

Turboprop Landplanes with Takeoff Weights of 3,000 to 6,000 Kilograms

On September 1, 1988, Einar Envoldson flew a Burkhart Grob Egrett-1 to a record altitude of 16,329 meters without a payload. Propulsion consisted of one Garrett TPE-33 1-14A 750-shaft horsepower engine. During that same flight, over a course in Greenville, Texas, Envoldson also set a record in altitude in horizontal flight without a payload of 16,238 meters.

On March 31, 1994, Werner Kraut of Germany set a record in altitude with a 1,000-kilogram payload of 15,552 meters. He flew a Burkhart Grob G-520 Egrett over Mindelheim, Germany.

On December 13, 1985, Sergei Gorbik of the Soviet Union set a record altitude of 6,150 meters with a 2,000-kilogram payload. He flew an Antonov An-3 powered by one 1,450-horsepower IX-TBD2O engine. On that same flight, Gorbik set another record for the greatest mass carried to a height of 2,000 meters: 2,375 kilograms. He flew over Podkievscoe Airfield, Soviet Union.

On April 16, 1985, Charles E. "Chuck" Yeager of the United States and Renald Davenport set a record in time to climb to a height of 3,000 meters: 1 minute, 48 seconds. They flew a Piper PA-42-1000 Cheyenne 400LS aircraft powered by two 1,000-shaft horsepower Garrett TPE-3 31-14 engines over Portland, Oregon. On that same flight, the pilots set a record of time to climb to a height of 6,000 meters of 3 minutes, 43 seconds, and to 9,000 meters of 6 minutes, 34 seconds. They also set a record of time to climb to a height of 12,000 meters of 11 minutes, 8 seconds.

On May 22, 1982, Joachim H. Blumschein of Germany set a speed record over a closed circuit of 100 kilometers without a payload of 571.43 kilometers per hour. He flew a Gulfstream Commander 695/980 powered by two 717.5-shaft horsepower Garrett TPE-33 1-10-501 engines over Leine, Germany. During the same flight, he set a record for speed over a closed circuit of 500 kilometers without a payload of 571.43 kilometers per hour. He also set records for speed over a closed circuit of 1,000 and 2,000 kilometers without payload of 572.08 kilometers per hour and 569.85 kilometers per hour, respectively.

On March 21, 1983, Joe Harnisch of the United States and David B. Webster set a speed record for eastbound flight around the world of 490.51 kilometers per hour. They flew a Gulfstream Commander 695A powered by two 820-horsepower Garrett TPE 33 1-501K engines. Their course began in Elkhart, Indiana, and extended across Goose Bay, Canada; Keflavik, Iceland; Vienna, Austria; Cairo, Egypt; Luxor, Egypt; Sharjah, Iran; Colombo, Sri Lanka; Singapore; Manila, Philippines; Agana, Guam; Wake Island; Midway Island; Honolulu, Hawaii; and San Francisco, California.

Turboprop Landplanes with Takeoff Weights of 6,000 to 9,000 Kilograms

On June 16, 1966, James F. Peters of the United States set a record in altitude in horizontal flight without a payload of 9,753 meters when he flew a Grumman OV-1C Mohawk over Calverton, Long Island, New York. The aircraft was powered by two 1,160-ESHP Lycoming T-53-L-7 engines.

On December 12, 1985, Vladimir Lysenko of the Soviet Union set an altitude record with a 1,000-kilogram payload of 6,100 meters. During the same flight, he set another record by reaching the same altitude with a 2,000-kilogram payload. He flew an Antonov An-3 powered by one 1,450-horsepower TBD-20 engine over Podkievscoe Airfield in the Soviet Union.

Turboprop Landplanes with Takeoff Weights of 9,000 to 12,000 Kilograms

On August 30, 1993, William G. Walker and Wyatt C. Ingram of the United States set a record of altitude reached without a payload: 10,892 meters. They flew a Marsh S-F3T Turbotracker powered by two 1,645-shaft horsepower Garrett TPE 331 engines over a course in Santa Rosa, California. During that same flight, they set a record for time to climb to a height of 3,000 meters of 3 minutes, 40 seconds, and speed over a closed circuit of 100 kilometers without payload of 454.53 kilometers per hour.

Turboprop Landplanes with Takeoff Weights of 12,000 to 16,000 kilograms

On May 7, 1982, Marina Popovitch and Galina Kortchuganova, both of the Soviet Union, set a record of altitude without payload of 11,050 meters. They flew an Antonov An-24 powered by two 2,820-horsepower AN24 engines over Podkievscoe Airfield in the Soviet Union.

On May 11, 1982, the same two pilots set a record of altitude in horizontal flight without payload of 10,920 meters in an Antonov An-24 powered by two 2,820-horsepower engines, again over Podkievscoe Airfield.

On February 16, 1976, Canadians Thomas E. Appleton, W. E. Pullen, and Harry Hubard set a record for time to climb to a height of 3,000 meters of 2 minutes, 13 seconds. They flew a De Havilland Canada DHC-5D Buffalo powered by two 3/33-ESHP engines over Downsview, Canada. During the same flight, these crew members also set a record for time to climb to a height of 6,000 meters of 4 minutes, 27.5 seconds, and time to climb to a height of 9,000 meters of 8 minutes, 3.5 seconds.

Turboprop Landplanes with Takeoff Weights of 16,000 to 20,000 Kilograms

On December 17, 1991, Matt Klunder and Pete Tomczak of the United States set a record for speed over a closed 100-kilometer circuit without a payload of 600 kilometers per hour. They flew a Grumman E2-C Hawkeye powered by two 5,250-horsepower Allison T56-A-427 engines. During the same flight, the crew set a record for speed over a closed 100-kilometer circuit with 1,000-kilogram payload of 600 kilometers per hour and one of speed over a closed 100-kilometer circuit with 2,000-kilogram payload of 600 kilometers per hour.

On December 19, 1991, Matt Klunder and Steven Schmeiser of the United States set a record for altitude in horizontal flight without payload of 12,150 meters. They flew a Grumman E2-C Hawkeye powered by two 5,250-horsepower Allison T56-A-427 engines. They flew over Patuxent River Naval Air Station in Maryland. During the same flight, they set a record for altitude with a 1,000-kilogram payload of 12,518 meters.

On May 19, 1993, Gideon Singer and Kjell Nordstrom of Sweden set a record for time to climb to a height of 3,000 meters of 2 minutes, 26 seconds. They flew a Saab 2000 powered by two 2,100-horsepower Allison T2100 engines. During the same flight, they set a record for time to climb to a height of 6,000 meters of 4 minutes, 45 seconds, and to 9,000 meters of 8 minutes, 1 second.

Turboprop Landplanes with Takeoff Weights of 20,000 to 25,000 Kilograms

On December 18, 1991, Eric Hinger and Steven Schmeiser of the United States set a record for altitude with a 2,000-kilogram payload of 12,178 meters in a Grumman E2-C Hawkeye powered by two 5,250-horsepower Allison T56-A-427 engines, over Patuxent River Naval Air Station in Maryland.

On November 5, 1985, Petr Kirichuk and Alexandre Tkachenko of the Soviet Union set a record of altitude with a 5,000-kilogram payload of 11, 230 meters in an Antonov An-32 powered by two 5,180-ESHP Am-20 engines. They flew over Podkievscoe Airfield, Soviet Union.

On July 7, 1982, Marina Popovitch and Galina Kortchuganova of the Soviet Union set a record for greatest payload carried to a height of 2,000 meters of 8,096 kilograms. They flew an Antonov An-24 powered by two 2,820-horsepower engines over Podmoskovnoe Aerodrome in the Soviet Union.

Turboprop Landplanes with Takeoff Weights of 25,000 to 35,000 Kilograms

On October 28, 1985, Alexandre Tkachenko and Vladimir Lysenko of the Soviet Union set a record for altitude with 1,000-kilogram payload of 11,120 meters in an Antonov An-32 powered by two 5,180-EHPS engines. They flew over Podkievscoe Airfield in the Soviet Union. During the same flight, they set a record altitude of 10,890 meters with a 2,000-kilogram payload.

On November 4, 1985, Petr Kirichuk and Alexandre Tkachenko of the Soviet Union set a record for altitude with a 5,000-kilogram payload of 10,510 meters in an Antononov An-32 powered by two 5,180-EHPS engines. They flew over Podkievscoe Airfield in the Soviet Union. During the same flight, they set a record for the greatest mass carried to a height of 2,000 meters of 7,256 kilograms.

Turboprop Landplanes with Takeoff Weights of 45,000 to 60,000 Kilograms

On April 20, 1999, Arlen D. Rens, Lyle H. Schaffer, and Timothy L. Gomez of the United States set a record for speed over a closed 1,000-kilometer circuit without a payload of 637.58 kilometers per hour. They flew a Lockheed Martin C-130J powered by four 4,700-horsepower AE engines over Dobbins Air Force Base, Georgia.

On March 22, 1991, Evgenii Bistrov and Alexei Marenkov of the Soviet Union set five records for speed over a closed 1,000-kilometer circuit of 587.53 kilometers per hour for an aircraft without a payload, with a 1,000-kilogram payload, with a 2,000-kilogram payload, with a 5,000-kilogram payload, and with a 10,000-kilogram payload. They flew an Antonov AN-12 powered by four 4,250-horsepower AI engines over Jasmine Aerodrome, Akhtubinsk, Soviet Union.

Turboprop Landplanes with Takeoff Weights of 100,000 to 150,000 Kilograms

On October 5, 1989, Igor Malychev and M. M. Bachkirov of the Soviet Union set four altitude records. The first was of 12,265 meters without a payload. The second, third, and fourth also reached 12,265 meters with payloads of 1,000, 2,000, and 5,000 kilograms. They flew a VP-021 (TU-95) powered by four 15,000-EHP Kuznetov engines over the Jasmine Aerodrome, Akhtubinsk, Soviet Union.

On September 26, 1989, V. E. Mossolov and I. A. Tchalov of the Soviet Union set multiple speed records over a closed 1,000-kilometer circuit of 807.37 kilometers per hour without a payload and with 1,000, 2,000, 5,000, 10,000, 15,000, 20,000, 25,000, and 30,000-kilogram payloads. They flew a VP-021 (TU-95) powered by four 15,000-horsepower HK engines.

Turbojet Landplanes

On May 17, 1975, Piotr Ostapenko of the Soviet Union set a record for time to climb to a height of 30,000 meters of 3 minutes, 10 seconds. He flew an E-266M powered by two 14,000-kilogram RD engines over the Podmoskovnoe Aerodrome in the Soviet Union.

On March 23, 1988, Nikolai Sadovnikov of the Soviet Union set a record for time to climb to a height of 15,000 meters of 1 minute, 10 seconds. He flew a P-42 powered by two 13,600-kilogram P-32 engines over the Podmoskovnoe Aerodrome in the Soviet Union.

On May 7, 1987, Vladimir Tersky and Yuri Resnitsky of the Soviet Union set a record for distance over a closed circuit without landing of 20,150.92 kilometers. They flew an Antononov An-124 powered by four 23,4000-kilogram D-1 8T engines.

On August 31, 1977, Alexandr Fedotov of the Soviet Union set a record for altitude without a payload of 37,650 meters. He flew an E-266M powered by two 14,000-kilogram RDF engines over the Podmoskovnoe Aerodrome in the Soviet Union.

On July 25, 1973, Fedotov set one record of altitude with a 1,000-kilogram payload of 35,230 meters and one for altitude with a 2,000-kilogram payload of 35,230 meters. During this flight, he flew an E-266 powered by two 11,000-kilogram PD engines.

On July 20, 1983, Sergei Agapov and Boris Veremei of the Soviet Union set altitude records of 18,200 meters with 10,000, 15,000, 20,000, 25,000, and 30,000-kilogram payloads. They flew a 101 aircraft, known in the military as the Tu-144, powered by four 20,000-kilogram Model 57 engines over Podmoskovnoe Aerodrome in the Soviet Union.

On October 29, 1959, Boris Stepanov and Boris Lumachev, both of the Soviet Union, set altitude records of 13,121 meters with 35,000, 40,000, 45,000, 50,000, and 55,000-kilogram payloads. They flew a 102M powered by four 13,000-kilogram D.15 engines over Podmoskovnoe Aerodrome in the Soviet Union.

On July 26, 1985, Vladimir Tersky and Alexandre Galounenko of the Soviet Union set altitude records of 10,750 meters with 160,000, 165,000, and 170,000-kilogram payloads. They flew an Antonov AN-124 powered by four 23,4000-kilogram Lotarev D-18T engines over the Podmoskovnoe Aerodrome in the Soviet Union.

On June 27, 1988, James C. Loesch and Howard B. Greene of the United States set a record for the greatest mass carried to a height of 2,000 meters of 405,656 kilograms. They flew a Boeing 747-400 powered by four 56,000-pound P&W 4056 engines over Moses Lake, Washington.

On November 18, 1998, Bryan Galbreath of the United States set a record for the greatest mass carried to a height of 15,000 meters of 1,503 kilograms. He flew a Lockheed Martin U-2 powered by one 16,500-pound F118 GE1O1 engine over Palmdale, California.

On April 8, 1973, Alexandr Fedotov of the Soviet Union set a record for speed over a closed 100-kilometers circuit without a payload of 2,605.10 kilometers per hour. He flew an E-266 powered by two 11,000-kilogram RD engines over Podmoskovnoe Aerodrome in the Soviet Union.

On July 27, 1976, Adolphus Bledsoe of the United States set a record of 3,367.22 kilometers per hour for speed over a closed circuit of 1,000 kilometers both without a payload and with a 1,000-kilogram payload.

On July 13, 1983, Sergei Agapov and Boris Veremei of the Soviet Union set speed records of 2,0351.55 kilometers per hour for speed over a closed circuit of 1,000 kilometers with 5,000, 10,000, 20,000 and 30,000-kilogram payloads. They flew a 101 (military Tu-144) powered by four 20,000-kilogram 57 engines over Podmoskovnoe Aerodrome in the Soviet Union.

On September 24, 1981, G. Volokhov and A. Turumine of the Soviet Union set records of 962 kilometers per hour for speed over a closed circuit of 1,000 kilometers with 40,000, 45,000, 50,000, 55,000, 60,000, 65,000, 70,000, 75,000 and 80,000-kilogram payloads. They flew an Ilyushin IL-86 powered by four 13,000-kilogram Kuznetzov engines over Podmoskovnoe Aerodrome in the Soviet Union.

On January 12, 1961, Henry J. Deutschendorf of the United States set records of 1,708.82 kilometers per hour for speed over a closed circuit of 2,000 kilometers with 1,000 and 2,000-kilogram payloads. He flew a Convair B-58A Hustler powered by four GE J-79-SA 15,000-pound engines over Edwards Air Force Base in California.

On April 7, 1994, Michael S. Menser of the United States set a record of 964.95 kilometers per hour for speed over a closed circuit of 10,000 kilometers without a payload. He flew a Rockwell B-1B powered by four F101-GE-102 12,000-pound engines from Grand Forks, North Dakota, to Mullan, Indiana, via Monroeville, Alabama.

On August 26, 1995, Russell F. Mathers and Daniel G. Manuel of the United States set records of 884.26 kilometers per hour for speed over a closed circuit of 10,000 kilometers with 1,000, 2,000, and 5,000-kilogram payloads. They flew a Boeing B-52H powered by eight P&W TF-33 17,100-pound engines over Edwards Air Force Base in California.

On June 3, 1995, Douglas L. Raaberg, Ricky W. Carver, Gerald V. Goodfellow, and Kevin D. Clotfelter of the United States set a record for speed around the world, eastbound, with refueling in flight, of 1,015.76 kilometers per hour. They flew a Rockwell B-1B powered by four GE F101-GE-102 30,780-pound engines.

On October 28, 1977, Walter H. Mullikin, Albert A. Frink, and W. Beckett, Jr., of the United States set a record for speed around the world over both of the earth's poles of 784.31 kilometers per hour. They flew in a Boeing 747 SP powered by four P&W JT9D-7 46,150-pound engines, from San Francisco, California, via the geographical north pole, London, Capetown, South Africa, the geographical south pole, and Auckland, New Zealand.

Gas Balloons

On September 8, 1984, Coy Foster of the United States set a record distance of 695.74 kilometers in a gas balloon over 250 cubic meters or less when he flew from Plano, Texas, to Lee's Summitt, Missouri.

On July 1, 1922, Georges Cormier of France set a record distance of 804.17 kilometers for a gas balloon of 400 to 600 cubic meters volume when he flew from Paris, France, to Muszen, Germany.

Oliver Griffin

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See also: Airplanes; Experimental aircraft; High-altitude flight; High-speed flight; Hypersonic aircraft; Pilots and copilots; Supersonic aircraft; Test pilots; Transatlantic flight; Transcontinental flight; Transglobal flight; Turbojets and turbofans; Turboprops

Reentry

Definition: The action of reentering the earth's atmosphere after space travel.

Significance: The study of reentry and the aerodynamics associated with the high-speed penetration of a planetary atmosphere allow humans to understand the nature of spaceflight.

History

Since 1830, small groups of scientists have studied meteors, natural objects entering Earth's atmosphere at high speed. Their studies have ranged from chemical analyses of recovered meteors to speculations about the physical changes that might take place during the meteor's high-speed passage through the atmosphere. However, when the technology became available to send manufactured objects outside the atmosphere, various engineering disciplines such as aerothermodynamics, high-temperature materials science, and trajectory analysis were developed.

Reentry Bodies

A craft that is built to withstand reentry into the earth's atmosphere is known as a reentry body (RB). The engineering requirements that must be met by any reentry body design depend upon the purpose of the reentry body. For example, a reentry body containing an astronaut must be able to soft-land. Such a reentry body must not only survive the environment of passage through the atmosphere, but also impact the earth at a very low vertical speed. For a reentry body such as the space shuttle, there is the additional requirement that the landing occur at a specific location. In other cases, such as that of the early Mercury capsule, a soft landing in the ocean was all that was required. For military weapons, a soft landing may be of no importance.

The most fundamental aspect of reentry bodies is their overall material requirements. In physics, the unit of measurement for energy is the joule. About 1,054 joules are required to raise the temperature of 1 pound of water 1 degree Fahrenheit. A material is vaporized when it passes from a solid to a gas. About 60,000,000 joules are required to vaporize 1 kilogram (2.2 pounds) of carbon. Nearly all other materials require less energy to be vaporized. A little more than 2,000,000 joules are required to vaporize 1 kilogram of water, for example. The kinetic energy, or the energy of motion, of a typical reentry body just entering the atmosphere might be 30,000,000 joules. Therefore, if all the reentry body's kinetic energy were converted to heat or thermal energy, the entire reentry body would vanish, unless it were made entirely of carbon.

The fact that many reentry bodies survive to make soft landings indicates that a significant amount of energy is dissipated in some way other than the vaporization of the reentry body itself. Some of the kinetic energy, turned into heat, is radiated or conducted into the air surrounding the reentry body. This energy changes the chemical makeup of the air by changing its molecules. The process of changing a molecule by the application of high temperature is called disassociation.

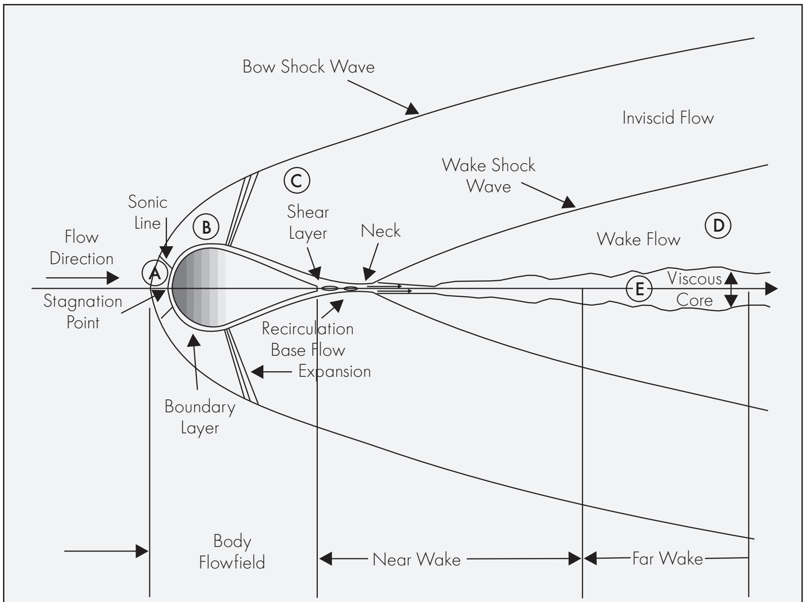
The amount of heat absorbed by the reentry body and the amount absorbed by dissociation depends upon the reentry body's speed; it also depends upon the reentry body's altitude, because the gases that make up the atmosphere vary with altitude. In addition, the reentry body's shape also strongly influences the amount of heat it absorbs. A blunt shape is very effective in directing the heat away from the reentry body.

The accompanying figure illustrates some of the important parts of the flow about a typical reentry body. This figure assumes that the observer is stationary with respect to the reentry body. Consequently, the flow of air is moving from the left to the right. An important way of describing such flows is with the term Mach number, or the ratio of the speed of the flow to the speed of sound at the point in flow. The speed of sound varies with the temperature and the temperature varies throughout the flow region. The speed of the flow approaching the reentry body is much greater than the speed of sound. A very strong shock wave, identified in the accompanying figure by the term "bow shock," is formed. This shock wave is detached from the reentry body and stands ahead of the reentry body into the oncoming flow. The distance between the shock wave and the body is called the standoff distance.

In region A, between the reentry body and the bow shock wave, the speed of the flow is less than the speed of sound. The stagnation point is where the flow is brought to rest. In the vicinity of the stagnation point, the heat flow to the reentry body is the greatest. Therefore, the reentry body is often covered with a carbon heat shield in region A. Much of the flow in region A passes into region B. The flow that passes into region B increases in speed, finally equaling the speed of sound. The line called the sonic line shows where this transition from a speed lower than to a speed higher than the speed of sound occurs. In region A the speed is less than the speed of sound, in region B the speed is greater than the speed of sound. Some of the flow in region A goes into what is called the boundary layer.

Somewhere beyond the maximum thickness of the reentry body is a series of weak pressure waves called expansion waves, which bring the flow from the higher-pressure region B to the lower-pressure region C. The pressure in region C is slightly higher than that external to the bow shock wave. The region outside of the bow shock wave is unaffected by the presence of the reentry body until it encounters the bow shock.

The body shown in the accompanying figure has the shape of a teardrop with the blunt end facing the oncoming flow. A very thin layer forms around the reentry body where the friction of the air becomes important. This layer is called the boundary layer when it is in contact with the reentry body and the shear layer when it continues past the reentry body. Fluid friction comes about when adjacent layers of air have greatly different speeds. Fluid friction is illustrated by the following simple experiment: If one rubs the heel of one's hand rapidly along the surface of a desk, one becomes aware of a warmth in that part of the hand contacting the desk. The desk acts as one



Flow Field Regions of a Reentry Body

layer of fluid, and the heel of the hand acts as an adjoining layer. Because one layer is moving rapidly relative to the other, heat is generated in much the same way as in reentry. In this experiment, the mechanical energy of forcing the hand over the desk against friction is converted into heat energy, raising the temperature of the outside of the hand. The region where fluid friction is important is known as viscid, and the region where friction is unimportant is known as inviscid.

The air in direct contact with the reentry body must come to rest relative to the reentry body, whereas the air at a short distance from the reentry body has a speed greater than the speed of sound. Therefore, the fluid experiences a rapid change in speed over a small distance. Therefore, friction becomes a predominant part of the fluid motion in the vicinity of the reentry body. This friction force generates heat, which can cause vaporization of the surface of the reentry body.

The vaporization of the surface of the reentry body is often called ablation. The material forming the surface of the reentry body changes directly from a solid to a gas. The products of vaporization, usually compounds of carbon and oxygen, enter the flow near the body. Because vaporization requires heat energy, the reentry body is deliberately designed to sacrifice a portion of its surface to prevent heat from penetrating into the interior of the reentry body.

In region C, all the flow has about the same speed, and friction effects are rather insignificant. Just behind the reentry body is a small region where the flow seems trapped and is being pulled along by the reentry body. The shear layer from around the body comes to a small area called the neck, beyond which there is an expansion of the flow into a wake. The wake has a core region, where friction effects are significant, and an outer region, where the flow is essentially inviscid. Whereas the friction in the wake core cannot affect the reentry body, it does provide a means by which the trajectory of the reentry body can be detected from the ground.

The shape of the reentry body does affect the size of the wake and the chemical activity within the wake, and therefore the ability of a ground station to detect or track the reentry body. The flow field produces a great amount of heat, which must be controlled by selecting the shape and materials of the reentry body. In addition, the flow field produces drag. The magnitude of the drag forces in some cases can be one hundred times the weight of the reentry body. A crewed reentry body must be designed in a shape that will avoid such high drag loads. It has been found that very blunt bodies, rather than streamlined bodies, limit the peak drag forces.

Reentry Body Control

A reentry body can be controlled by altering the trajectory or path that it follows as it moves through the atmosphere. The two major reasons for controlling a reentry body are first, to reduce its speed and, second, to direct it to an impact or landing site on Earth. An impact, or high-speed Earth encounter, results in destruction of the reentry body, a landing, or low-speed Earth encounter, allows recovery of the reentry body intact.

The aerodynamic forces on a reentry body are those of drag and lift. Drag, identified as the force in the direction of the velocity, tends to reduce the velocity. Lift acts at right angle to the velocity and therefore changes the direction of the velocity.

Small gas jets applied to the body, similar to those of the Mercury capsule, can make small but significant changes to the direction of the velocity. Such controls are used well outside of the atmosphere to limit the side forces during reentry. Expandable flares can also be used to increase drag and slow down the reentry body.

A versatile control system is the split windward flap. This control consists of two side-by-side flaps that have the appearance of rectangular paddles. When the flaps are extended at equal angles, they cause a pitching of the reentry body; when they are extended at unequal angle, they cause the reentry body to roll as well.

The space shuttle is controlled much like a high-performance airplane with a rudder and a combination of elevator and ailerons called elevons.

Another method of controlling a reentry body is by bending or canting its nose, or front part. The reentry body's center of gravity may also be moved laterally by moving an object within the reentry body. Lift can then be developed in a preferred direction, similar to the way hang glider pilots move the gliders' center of gravity, and thereby change direction, by moving their own weight.

Reentry bodies operate in flight conditions that make great demands upon the vehicles' materials and shape. Heat loads threaten to vaporize a large part of the structure. In addition, the structure must support aerodynamic loads that can reach values as high as one hundred times the weight of the reentry body. With a human crew aboard, heat and aerodynamic loads must be very carefully managed to ensure integrity right down to a soft landing.

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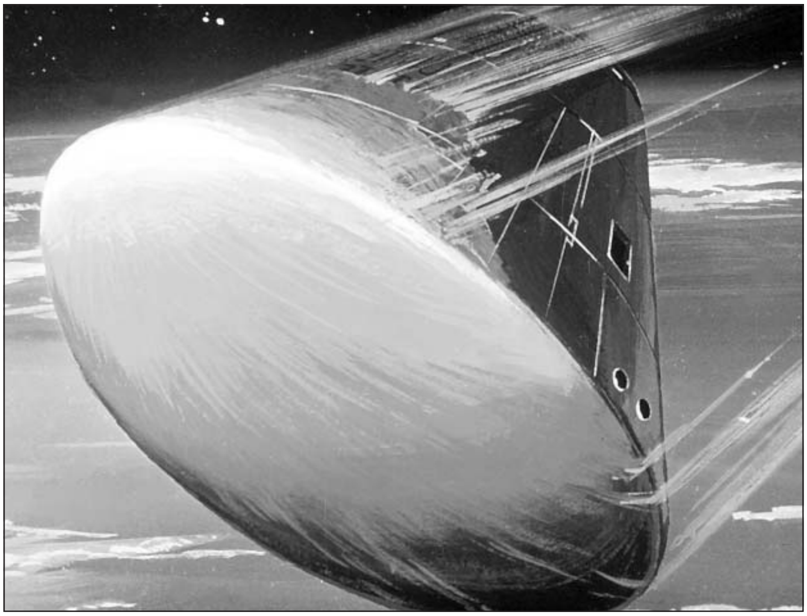
See also: Aerodynamics; Crewed spaceflight; High-speed flight; Orbiting; Spaceflight; Supersonic aircraft; Uncrewed spaceflight



The Apollo 11 space capsule reenters Earth's atmosphere. (NASA CORE/Lorain Valley JVS)

Hanna Reitsch

Date: Born on March 29, 1912, in Hirschberg, Germany; died on August 24, 1979, in Frankfurt am Main, Germany

Definition: Germany's best-known female pilot during and after World War II.

Significance: Reitsch tested aircraft for the Luftwaffe during the war and set more than forty records for powered and motorless flight.

Hanna Reitsch began her career by learning to fly gliders in 1930, becoming the protégé of the influential glider instructor Wolf Hirth. In May, 1933, riding the rising air of a storm cloud, she set a new world altitude record for gliders. After gaining certification and experience as a glider instructor, she was chosen in 1934 to be a glider test pilot for the German Institute for Glider Research. She tested newly developed dive brakes, demonstrating controlled terminal-velocity dives. These brought her to the attention of Ernst Udet, perhaps the most famous World War I pilot. Through Udet's efforts, she became the first German woman to win the honorary title of Flugkäpitan, or flight captain.

With Udet's assistance, Reitsch began testing the Luftwaffe's latest fighters and bombers in 1937. That year, she was among a group of five pilots who made the first glider flights over the Alps. In 1938, she was sent to the United States to demonstrate glider aerobatics at the Cleveland Air Races. In 1942, she was the first German woman to win the Iron Cross, an honor that gained her access to the experimental Me-163 rocket-powered airplane.

Fiercely patriotic, Reitsch in 1943 organized with two friends a suicide bomber squadron to turn the tide against the Allied march. She performed tests on a piloted version of the V-1 rocket in 1944. In the closing days of the war, Hitler requested in his bunker the presence of Reitsch's friend General Robert Ritter von Greim, whom Reitsch accompanied. After von Greim was wounded by Russian gunfire, Reitsch took command of his airplane. Although she wanted to die with Hitler, he commanded her to fly von Greim to where he could take command of the Luftwaffe. Reitsch flew the last German plane out of Berlin in late April, 1945, before it was seized by the Russians.

Reitsch was captured and interned for fifteen months by the U.S. Army, during which time she gave testimony about Hitler's last days. When permitted by the Allies, she returned to her first love, gliding. In 1953, she gained a bronze medal at the World Gliding Championship in Spain, as the sole woman competitor. In 1957, she won a bronze medal at the German glider championships and set two women's altitude records. She helped establish the national school of gliding in Accra, Ghana, beginning in

1962. Only a few months after her last flight, in 1979, she died of a heart attack.

W. N. Hubin

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See also: Aerobatics; Airplanes; Experimental aircraft; Gliders; Luftwaffe; Test pilots; Women and flight; World War II

Rescue aircraft

Date: First utilized by the U.S. Coast Guard in 1920

Definition: Aircraft capable of rescuing individuals in distress either on land or at sea.

Significance: Quick response and the ability to access remote or geographically difficult terrain allow rescue aircraft to assist individuals that have been stranded, are in need of medical attention, or are in danger from problems such as forest fires or high seas.

U.S. Coast Guard Rescues

In 1920, the U.S. Coast Guard borrowed several Curtiss HS-2L flying boats from the Navy and began the first air rescue operations out of the former naval base at Morehead City, North Carolina. The following year, the station was closed due to a lack of funding. Four years passed before Lieutenant Commander C. G. von Paulsen convinced officials that the Coast Guard needed aircraft to prevent the smuggling of alcohol during Prohibition. The U.S. Congress appropriated $152,000 for the Coast Guard to purchase three Loening OL-5 amphibians and two Chance Vought UO-4's, which were stationed at Gloucester, Massachusetts, and Cape May, New Jersey.

Although law enforcement remained the primary function of the Coast Guard, pilots also executed rescue operations. During the 1920's, the number of seafaring vessels increased and the Coast Guard received more and more calls for assistance. By 1928, the number of rescues had increased to a level that justified the creation of an aviation section, under the command of Commander Norman Hall. The Coast Guard purchased five General Aviation Flying Life Boat PJ-15's and two Douglas Dolphin RD-2's capable of landing on rough seas to perform rescue operations.

Over the next few years, the Coast Guard engaged in numerous rescue operations. Although the aircraft were capable of taking off from water, sometimes the seas were too rough and the plane and pilot were stranded along with the victims. Some of the aircraft were later recovered, including one plane, the *Arcturus*, which washed ashore with the pilot and the little boy he was sent to rescue still on board. During the Great Depression, the secretary of the Treasury, Henry Morgenthau, transferred the aviation department of the Customs Service to the U.S. Coast Guard and then persuaded Congress to designate Public Works Administration funds for the purchase of forty-two additional planes and the establishment of six air stations.

During World War II, the U.S. Coast Guard defended the coast of Greenland and in the process engaged in many rescue operations during snowstorms and in frozen areas. In 1943, the Coast Guard formed an Air Sea Rescue Squadron in San Diego, California, and within two years, the agency had 165 aircraft and operated out of nine air stations. The extreme weather conditions of the Arctic required the development of the Northrop YC-125 Raider that could land on short, uneven runways. The first of the Raiders were delivered to the Air Force in 1949, but within a few years the planes were declared surplus.

By 1945, the importance of the air rescue operations had led to the use of helicopters. After two aircraft attempted and failed to rescue nine members of the Royal Canadian Air Force who had crashed in Labrador, the Coast Guard shipped an HNS-1 helicopter to Goose Bay, Labrador, where it was reassembled and flown to the crash site by Lieutenant August Kleisch, who successfully retrieved all the survivors. The post-World War II period witnessed a dramatic increase in the number of rescues conducted by the Coast Guard, with helicopters providing the quickest method of extricating people from dangerous situations. With the ability to hover between objects in close proximity, such as trees and telephone lines, the helicopter provided the maneuverability necessary to perform the delicate operations.

During the Vietnam War, the U.S. Coast Guard participated in search-and-rescue operations that commenced in 1968. Assigned to the Thirty-seventh Aerospace Rescue and Recover Squadron at Da Nang, Vietnam, more than seven thousand pilots rescued marines under fire from enemy forces. During the 1980's, the Coast Guard utilized Sikorsky HH-52 Seaguards, HH-52's, and Aerospatiale HH-65 Dolphins, as well as the now-retired amphibian Sikorsky HH-3F Pelican helicopter. By 2000, the Coast Guard continued to rely primarily on the HH-65 for its search-and-rescue operations.

U.S. Air Force Rescues

The Air Force used the Sikorsky R-6A Hoverfly II, designed primarily for observation, as a rescue aircraft beginning in 1944. The helicopter, with a main rotor diameter of 38 feet and a length of 38.25 feet, was equipped with capsules on each side of the fuselage that could be used to carry litters for medical evacuation. Capable of flying at speeds up to 96 miles per hour with a range of 305 miles, the Hoverfly II also carried 650 pounds of bombs and continued to be used throughout World War II.

During the Korean War, the primary helicopter used by the Air Force for search-and-rescue missions was the Sikorsky YH-5A Dragon Fly. The YH-5A, built with a main rotor diameter of 48 feet and capable of reaching speeds of 90 miles per hour with a range of 280 miles, rescued United Nations troops from behind enemy lines and evacuated wounded personnel from the front lines. The Sikorsky UH-19B Chickasaw rescue helicopter was also used during the Korean War. Equipped with a 400-pound capacity hoist mounted above the door and an external sling with a 2,000-pound limit, the Chickasaw was used mainly for rescue and medical evacuation. Capable of traveling at 112 miles per hour, the aircraft has a range of 330 miles and is able to carry 8,400 pounds. The large cargo area allows for the evacuation of several people at once.

By 1952, the Chickasaw was joined by the Vertol CH-21B Workhorse on rescue missions. Originally designed to transport troops, the aircraft was modified to carry twelve litter patients. The Workhorse had a longer range than the Chickasaw, being able to fly 400 miles at speeds of 132 miles per hour, making evacuation quicker. In 1958, the U.S. Air Force Tactical Air Command received the first Kaman HH-43B Huskie helicopter. The Huskie was used in Vietnam for both aerial firefighting and for rescuing downed pilots. Capable of being airborne within sixty seconds, the helicopter reaches speeds of 120 miles per hour and has a range of 185 miles. The aircraft is manned by two rescuers or firemen, who use foam pushed down by the backwash of the rotors to clear an area large enough to extricate trapped persons. The Air Force purchased over 175 Huskies at a cost of $304,000 each.

In 1955, Bell Helicopter introduced the UH-1P Iroquois that would later be known as the Huey. Used in Vietnam as a medical evacuation aircraft, with enough room for eleven passengers or six littered patients, the Huey also flew as an armed gunship. The Huey was the first Air Force helicopter capable of cruising on one engine. The maximum speed for the Huey was 140 miles per hour, with a range of 330 miles at altitudes below 24,830 feet. Each aircraft cost $273,000. The Hueys replaced the Huskies in 1970.

Another rescue helicopter used by the U.S. Air Force is the Sikorsky CH-3E. The CH-3E, nicknamed the Jolly Green Giant, was modified for combat rescue and is fully armored, has defensive armaments on board, and is equipped with self-sealing refueling tanks and a rescue hoist. It also has the ability to refuel while in flight. The CH-3E has a rotor diameter of 62 feet, a length of 73 feet, and weighs 22,050 pounds when loaded. The aircraft is armed with two .50-caliber machine guns. With a maximum speed of 177 miles per hour and a range of 779 miles with external fuel tanks, the three-man crew flies missions at altitudes of 21,000 or less. Each costs $796,000.

In addition to rescue helicopters, the U.S. Air Force has also relied on various airplanes for medical evacuation or extrication. One of the earliest airplanes used for rescue was the Cessna O-1G Bird Dog. Although designed for reconnaissance, the Cessna O-1G, with a top speed of 150 miles per hour and range of 530 miles, rescued many downed pilots and trapped military personnel.

By the time the Vietnam conflict reached its apex in the late 1960's, the Air Force relied on the North American OV-10A Bronco. Designed for combat support and equipped with four 7.62-millimeter machine guns in fuselage sponsons and 3,600 pounds of mixed ordinance carried externally, the Bronco performed rescue missions and was capable of transporting two litter patients and a medical attendant. The key characteristic of the aircraft was that it was capable of short takeoffs and landings. Each aircraft cost $480,000 and had a maximum speed of 281 miles per hour and a much longer range of 1,240 miles. With a wingspan of 40 feet, length of 41 feet, 7 inches, and height of 15 feet, 1 inch, the aircraft flew at altitudes below 26,000 feet.

During World War II, the U.S. Army, Navy, and Air Force used different versions of the Consolidated OA-10 Catalina aircraft. The Catalina had twin engines and was a parasol-mounted monoplane with a flying boat hull, retractable tricycle landing gear, and retractable wingtip floats. Used primarily for amphibious rescues, the Catalina was instrumental in saving the lives of hundreds of pilots. The aircraft, nicknamed the Dumbo, had a wingspan of 104 feet, weighed 36,400 pounds fully loaded, was armed with two .50-caliber machine guns in the waist and two .30-caliber machine guns, with one located in the bow and the other in the rear tunnel, and carried 8,000 pounds of bombs. Each aircraft cost $50,000 and had a maximum speed of 184 miles per hour, a range of 2,325 miles, and a service ceiling of 22,400 feet.

On June 9, 1945, the first Grumman OA-12 Duck joined the sea-rescue aircraft of the U.S. Air Force Air Rescue Service and performed numerous over-water rescues. With a 39-foot wingspan, the Duck had a maximum speed of 188 miles per hour and a range of 780 miles. Each airplane, capable of flying to altitudes of 20,000 feet, cost $69,000.

The most versatile of the rescue airplanes is the Grumman HU-16B Albatross, with a design that allows for operation from land, water, snow, or ice. The first Albatross flew on October 24, 1947. During the Korean War, the Air Force used the Albatross to rescue U.N. forces along the coast and behind enemy lines. In 1962, the Air Force received 297 of the airplanes and assigned most of them to rescue duty in Vietnam. Since the 1960's, the Air Force has relied on helicopters as the primary aircraft for rescue operations. Working with civilian authorities through the Aerospace Rescue and Recovery Service, these rescue aircraft and their crews save hundreds of lives a year.

Cynthia Clark Northrup

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See also: Firefighting aircraft; Helicopters; Rotorcraft; Vertical takeoff and landing

Manfred von Richthofen

Date: Born on May 2, 1892, in Breslau, Germany (now Wrocław, Poland); died on April 21, 1918, near Vaux-Sur-Somme, France

Definition: The most famous fighter ace of World War I.

Significance: Von Richthofen, best known as the "Red Baron," and leader of the "Flying Circus" air fighter group, was the most famous fighter pilot of World War I. Most of his air-combat operations manual, written shortly before his death at age twenty-five, remains valid.

Early Years

Born in 1892, Manfred Freiherr von Richthofen was the eldest son of a family of the lesser nobility of Silesia and heir to a Prussian military tradition. He grew up at the turn of the twentieth century in an atmosphere comparable to that of an English country squire. Von Richthofen did not choose a career, but rather had one chosen for him. His father packed the boy off at the age of eleven to the German military school at Wahlstatt. Von Richthofen was not a good student, but he proved to be athletically gifted. After passing cadet school at Wahlstatt, he went to the Royal Military Academy in Lichterfelde, near Potsdam, an important military center.

The Fighter Pilot

In 1911, von Richthofen became a lieutenant in the First Uhlan Cavalry Regiment of the Prussian Army, fighting in Russia during World War I and participating in the invasion of Belgium and France. After the cavalry lost its importance as a fighting force in the era of trench warfare, von Richthofen joined the infantry. He then transferred to the Imperial Air Service and entered combat as a fighter pilot in September, 1916.

An important role model and teacher to von Richthofen was Captain Oswald Boelcke, who, until he was overtaken by von Richthofen, was Germany's greatest ace, with forty victories in aerial combat. It has been said that Boelcke was the father and teacher of combat pilots, whereas von Richthofen developed his mentor's methods to the highest degree of mastery. Von Richthofen was present in his fighter on October 28, 1916, when Boelcke was killed in an aerial collision with another plane.

The Flying Circus

Von Richthofen eventually became commander of Fighter Group I, known officially as Jagdgeschwader I (JG I). JG I was officially chartered on June 26, 1917, by the Kogenluft, the German Air Service Headquarters. Because of its fancifully decorated triplanes, JG I came to be known as the "Flying Circus." Von Richthofen's own triplane was painted red, a color he had favored for his previous fighter planes. Von Richthofen thus became known as the "Red Baron."

The JG I comprised four fighter units. To weld his group into what became the most notoriously feared air-fighting formation in history, von Richthofen chose his subordinate leaders with great care. He was a shrewd judge of character and chose men whom he felt were capable of leadership yet could follow his instructions and orders. With his subordinates' assistance, he would coordinate the motions and mass the forces of the JG I at whatever target he deemed appropriate.

Under von Richthofen's leadership, the Flying Circus became a very successful fighter group. One of the most successful days in JG I's history was March 27, 1918. During that day, JG I carried out 118 sorties, and had 39 inconclusive air combats and 13 successful combats. Von Richthofen had his seventy-first, seventy-second, and seventy-third victories. He was eventually credited with shooting down a total of eighty enemy aircraft, making him the top ace of World War I.

The Legend

The precise circumstances of von Richthofen's death remain unclear. Von Richthofen was reputedly shot down on April 21, 1918, by Captain A. Roy Brown, a Canadian ace flying in the Royal Air Force (RAF). It has been said that von Richthofen disobeyed one of the basic tenets of his air combat operations manual and stayed in pursuit of an enemy plane too long, while Captain Brown's plane came up behind him. However, it is possible that von Richtofen may have been killed instead by ground fire from Australian troops. Brown died in Ontario, Canada, in March, 1944, without ever categorically claiming that it was he who shot and killed von Richthofen.

After the end of World War I, von Richthofen's remains were first transferred to a large German military cemetery at Fricourt. In 1925, the remains were exhumed, and a formal state funeral was held in Berlin with President von Hindenburg present. Von Richthofen was then interred with some of Germany's greatest heroes in the *Invalidenfriedhof* in Berlin. In 1976, von Richthofen was once again exhumed and reinterred, this time in a family plot in Mainz in western Germany.

Dana P. McDermott

Image Not Available

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See also: Dogfights; Fighter pilots; Fokker aircraft; Triplanes; World War I

Eddie Rickenbacker

Date: Born on October 8, 1890, in Columbus, Ohio; died on July 23, 1973, in Zurich, Switzerland

Definition: A decorated World War I American air ace who returned home to enter business, founding an automobile company and, later, an airline.

Significance: Rickenbacker exploited the fame he enjoyed as a decorated air ace in World War I to popularize air travel and airmail. As manager of Eastern Air Lines for many years, he helped develop many of the features of air travel now taken for granted.

Edward Vernon "Eddie" Rickenbacker, the third of eight children, entered the world of work as a boy, first by selling newspapers and then by moving to jobs in a glass factory, a foundry, a brewery, a shoe factory, and a monument works. He became interested in automobiles, and, at age sixteen, he was hired by Lee Frayer, a race-car driver and auto company executive who introduced him to the world of automobile racing. By 1912, Rickenbacker was working with auto designer Fred Dusenburg and entering races on his own. In 1914, he set a world speed record at Daytona Beach, Florida.

Rickenbacker became interested in aviation after an aircraft-designer friend, Glenn Martin, took him on a flight in 1916. He was further intrigued by flying after meeting some Royal Air Force (RAF) fliers on a trip to England later that year.

When the United States entered the war in 1917, Rickenbacker volunteered for service, becoming a driver for General William "Billy" Mitchell. Soon he was able to persuade Mitchell to assign him to flight training, and he joined the Ninety-fourth Aero Pursuit Squadron near Toul, France. He had spent fewer than three weeks in training.

World War I Fighter Ace

During 1918, Rickenbacker's flying skill steadily improved, and he began to shoot down enemy planes with increasing frequency. In October of that year, Rickenbacker scored fourteen victories. Although there is controversy over his exact wartime total of downed aircraft, it was certainly at least twenty-four, including four balloons. Rickenbacker survived 134 aerial battles and logged more combat hours than any other American pilot. These achievements made him famous when he returned home, promoted to the rank of major. Rickenbacker was awarded the French Croix de Guerre in 1918 and the Congressional Medal of Honor in 1930.

Business Career

After the war, Rickenbacker declined numerous offers to endorse products or to go act in motion pictures and returned to the automobile industry as president of the Rickenbacker Motor Company. After a bold start in 1922, the company went bankrupt in 1925, leaving its namesake deep in debt. Undaunted, Rickenbacker bought a controlling interest in the Indianapolis Motor Speedway, wrote a book about his war experiences, and even authored a syndicated comic strip. His primary occupation was as a sales manager for General Motors. Even with all these activities, he still found time to travel the country giving speeches on aviation and its future. He urged many city governments to consider building municipal airports.

In 1934, Rickenbacker became general manager of Eastern Air Lines. Under his management the airline added routes and became the first profitable airline in the United States. Stewardesses tended to passengers during each flight, and pilots were provided with up-to-date navigational instruments. Eastern also started its own meteorology division and instituted regular medical checkups for pilots. Maintaining a close relationship with Donald Douglas, Rickenbacker bought planes from Douglas Aircraft, and made a record-breaking flight from California to New Jersey in the new Douglas airliner, the DC-1.

World War II Achievements

Always an advocate for air travel and military air power, Rickenbacker traveled all over the country to give talks. Early in 1941, on a trip to Atlanta, he was seriously hurt in a plane crash and required months of surgery and physical therapy. The United States was now involved in World War II, and Rickenbacker, when he was well, was sent by the War Department on special missions. He gave inspirational talks to pilots and recommended improvements in aircraft and procedures. He traveled to England, where he met with Prime Minister Winston Churchill and was entrusted with supreme commander of the Allied Expeditionary Force Dwight D. Eisenhower's planning documents for the invasion of North Africa, which he brought back to Washington, D.C.

In October, 1942, on a mission to New Guinea, the plane carrying Rickenbacker and a crew of seven ran out of fuel and crashed in the Pacific Ocean. Using three small rubber rafts, the men managed to survive for twenty-four days with virtually no shelter, water, or provisions. Only one man died; the others kept alive by drinking rainwater and by eating small fish and a gull they caught with their bare hands. At the end of this unprecedented ordeal, the survivors were spotted by a navy pilot and rescued. Prodded by Rickenbacker, the Navy made many modifications to the survival gear carried in planes, increasing the size of the rafts and providing for sails and solar water

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stills. During the remainder of the war, many other servicemen benefited from these steps.

After the war, Rickenbacker rejoined Eastern Air Lines, but was never as successful in business as he had previously been. He was gradually eased out of management and retired in 1964, but he continued to speak and write until his death in 1973, on a trip to Switzerland.

John R. Phillips

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See also: Airline industry, U.S.; Fighter pilots; World War I; World War II

Sally K. Ride

Date: Born on May 26, 1951, in Encino, California

Definition: An astronaut for the National Aeronautics and Space Agency (NASA) and the first American woman in space.

Significance: As the first American female astronaut, Ride illustrated the potential of women in space. As a mission specialist, she demonstrated the importance of scientists who could conduct experiments in space.

Sally Kristen Ride was born on May 26, 1951, in Encino, a suburb of Los Angeles, California. In 1968, she enrolled at Swarthmore College in Pennsylvania as a physics major, but left after three semesters to concentrate on tennis after winning a national collegiate tennis tournament. After a few months, she reassessed her potential and decided against tennis as a professional career. She returned to her studies at Stanford University and completed an undergraduate program with a double major in physics and English. She continued her studies in physics at Stanford, earning a master's degree. While completing work on a doctorate in astronomy and astrophysics at Stanford, she was attracted by NASA's call for astronauts. In 1977, she entered astronaut training as a mission specialist with a group of thirty-five successful applicants, including six women. She completed her doctorate in 1978.

Shortly after earning her doctorate, Ride reported to the Lyndon B. Johnson Space Center outside Houston, Texas, to begin the intensive training required of mission specialists. As she worked her way toward a flight assignment, Ride worked on the design of the remote arm used on the space shuttle to deploy and retrieve satellites and was part of the ground team for the second and third flights of *Columbia*.

Ride's chances at flight came in 1983 and in 1984 when she flew on *Challenger* for a total of more than 343 hours. The June 18, 1983, flight earned her the distinction of being the first American woman in space and the youngest person ever in orbit. While on these flights, Ride tested the remote arm and oversaw the onboard science experiments. Other scheduled flights were canceled after the explosion of the *Challenger* in 1986. Ride was the only astronaut to serve on the commission that investigated the explosion.

Ride retired from NASA in 1987 to join Stanford's Center of International Security and Arms Control. In 1989, she became the director of the California Space Institute and professor of physics at the University of California, San Diego. She later left academia to enter private business. She became interested in science education and, in 2000, resigned as president of space.com, a World Wide Web site devoted to education and the space industry, to spend more time and effort promoting improvements in science education. Ride's personal crusade is to encourage women to enter math and science disciplines.

Kenneth H. Brown

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See also: Astronauts and cosmonauts; Crewed spaceflight; Johnson Space Center; National Aeronautics and Space Administration; Space shuttle; Spaceflight; "Vomit Comet"; Women and flight

Rocket propulsion

Description: The movement of a device by the ejection of matter, without the need for taking on ambient air for combustion.

Significance: Rocket propulsion permits the application of rockets both inside and outside the atmosphere, in space, or under water.

Most rockets exhaust propellant at high velocities and temperatures. The propellant is produced at high pressure through the release of chemical, nuclear, or electrical energy to the working fluid. In outer space, the propellant escapes from the rocket chamber to a high-exit kinetic energy in proportion to its available energy per unit mass. This explains why the reaction of low molecular weight fuel, such as liquid hydrogen, with liquid oxygen can produce an effective exhaust velocity almost twice that of rockets using solid fuel mixed with oxidizer crystals. Newton's second law shows that rocket thrust is the product of the effective exhaust velocity multiplied by the mass flow rate. Thus the higher the "effective" exhaust velocity, the lower the mass of propellant required for a given mission. Future long-range space missions may be based on electric, nuclear, or solar energy to increase the effective exhaust velocity up to ten times, thereby reducing required propellant mass by a factor of ten. A quick estimate of a rocket thrust is to multiply the rocket chamber pressure by the smallest flow area of the exhaust nozzle, called the throat.

Common rockets contain at least the following components: engine, nozzle, propellant storage, payload, airframe, and guidance and control devices. Payloads vary widely and include spaceships, instrument packages for upper atmosphere observations, warheads on missiles, artillery projectiles, and fireworks.

History

As early as 600 C.E., the Chinese manufactured black powder, a mixture of charcoal, sulfur, and saltpeter, for use as rocket propellant. In the year 1232, the Chinese used rocket-propelled fire-arrows successfully to defend their towns against hordes of invading Mongols. In the early eighteenth century, Sir William Congreve developed a sophisticated military missile, known as the Congreve rocket, which provided the "rocket's red glare" observed by Francis Scott Key in 1812 at Fort McHenry.

The first liquid fuel rocket, propelled by hydrogen and oxygen, was designed in 1903 by the Russian scientist Konstantin Tsiolkovsky. Physicist Robert H. Goddard was the first in the United States to succeed in launching a liquid fuel rocket using oxygen and gasoline on March 16, 1926. Within 2.5 seconds, Goddard's rocket gained an altitude of about 40 feet and a speed of 60 miles per hour.

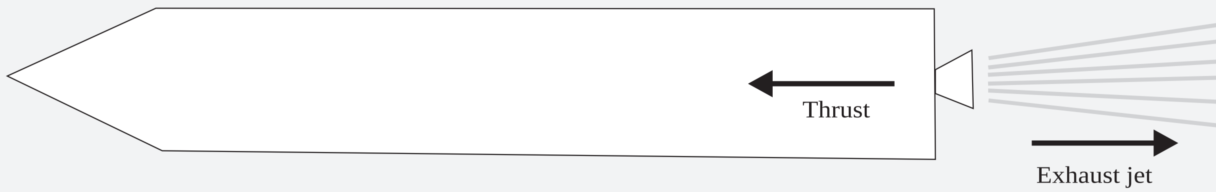
The Soviet Union was the first nation to achieve spaceflight, with the Sputnik 1 satellite on October 4, 1957, and with the pilot Yuri Gagarin's flight on Vostok 1 on April 12, 1961. The next crewed spaceflight was made by the United States one month later, on May 5, 1961, in Mercury capsule *Freedom 7*, piloted by astronaut Alan Shepard. In the 6-by-6-foot capsule, Shepard experienced a gravity load of 7 g's (seven times his weight) during launch and a gravity load of 1 g during recovery. Rocket flight has remained a continual challenge to crews.

At the end of the twentieth century, rockets had already launched the space shuttle more than one hundred times. Rocket technology development in the last half-century has made a major impact on modern space exploration and warfare strategies. Examples of such technology include the nearly 3,000,000-pound-thrust solid booster rockets developed for the space shuttle and the approximately 100,000 horsepower required by the turbine-driven pumps to pressurize the liquid hydrogen and oxygen for each of the three shuttle main engines. Improving materials and thrust-level control throughout the burn period is an ongoing technical challenge.

Rocket Science

Rockets have been developed for many different purposes and therefore differ widely in dimension, takeoff weight, thrust, range, propellant type, pressure, and temperature. The combustion process itself pressurizes solid fuel rockets, making solid fuel rockets more simple than liquid fuel rockets and capable of higher thrust levels. In the case of the space shuttle, two solid booster rockets are used to launch the vehicle, each with almost 3,000,000 pounds of thrust. Their function is to accelerate the shuttle as quickly

Basic Rocket Propulsion



as the crew can tolerate to near orbital velocity. From then on, the liquid fuel space shuttle main engines (SSME) continue to provide thrust with almost twice the effective exhaust velocity but only about one-seventeenth the thrust level. Typical fireworks rockets have burn times of only seconds and therefore require exceptionally high acceleration rates or thrust-to-weight ratio. Air-pressure-driven, water-type toy rockets have low exhaust velocities, similar in magnitude to the nozzle velocity of a garden hose.

The most important difference between rockets and jet engines is that rockets do not need to take in air, whereas jet engines require air for combustion and temperature control with mass-flow rates of up to one hundred times that of their fuel-flow rate. Because jet engines must ingest air, they can only operate below 100,000 feet altitude. However, rockets can operate anywhere inside and outside the atmosphere, even under water.

The rocket nozzle is used to accelerate the propellant to high exit velocity. To keep this nozzle small and therefore lightweight, the propellant must be generated at high pressure inside the rocket chamber. The corresponding smaller exit area also minimizes the nozzle thrust loss from ambient air pressure. The use of a low molecular weight propellant at high temperature increases the effective exhaust velocity, thus minimizing the required propellant mass-flow rate.

The most energetic chemical propellants are produced by the combustion of liquid hydrogen with liquid fluoride as the oxidizer. This mixture generates a combustion temperature of 7,200 degrees Fahrenheit and nozzle gas velocities of up to 15,400 feet per second. Less corrosive is a combination of liquid hydrogen with liquid oxygen, which produces a combustion temperature of 5,400 degrees Fahrenheit and nozzle gas velocities of up to 14,600 feet per second.

To pressurize these liquid propellants, very high-horsepower turbopumps are used. For example, the SSME requires both fuel and oxidizer pumps of a delivery pressure of around 8,000 pounds per square inch. With their combined-flow rate of approximately 1,000 pounds per second, this requires almost 100,000 horsepower for pumping per engine.

In contrast, a solid fuel rocket is much more simple to operate and therefore less expensive, as it does not need a pump to pressurize its combustion chamber. To understand the pressurization process, one must realize that the maximum amount of mass-flow which can escape through a rocket nozzle is directly proportional to gas density or pressure inside the chamber. Prior to ignition, the rocket chamber is at ambient pressure. The solid propellant inside is typically a mixture of oxidizer crystals, such as ammonium perchlorate, combined in a synthetic rubber binder, which serves as fuel. The fuel inner surface geometry is designed to adjust the combustion rate and thereby provide the desired thrust/time characteristics. When this solid surface is ignited, the amount of hot gas produced exceeds that escaping out the nozzle. Therefore, gas mass accumulates inside the rocket chamber and increases the gas pressure. This pressure rise continues until it is high enough to allow as much gas to escape out of the nozzle as is being generated inside the combustion chamber. In a fireworks rocket, this operating pressure is reached within a fraction of a second.

Some small liquid-propellant rockets can be operated without a pump, if the fuel and oxidizer are pressurized by a container of high-pressure inert gas. An even more basic liquid rocket uses a monopropellant, such as hydrogen peroxide. This liquid, when brought into contact with a catalyst, transforms into a 1,000-degree-Fahrenheit steam-and-oxygen gas that makes a good propellant.

Liquid propellants have the advantage over solids in that the exhaust velocity is higher and that thrust is controllable with a valve. Thrust control can also be obtained by combining a liquid oxidizer with a solid fuel, which is termed a hybrid engine. Hypergolic propellants such as nitric acid and hydrazine spontaneously combust upon contact, thereby eliminating the need for an igniter.

Rocket staging is an important technology used to increase payload capacity. The dropping off of empty fuel and oxidizer containers reduces weight and drag, which, in turn, reduces the thrust required in the subsequent stage. The disadvantage of rocket staging in launching the space shuttle is that retrieving and refurbishing the solid booster rocket casings adds several months to the launch turnaround time. This means many units are needed for a frequent launch schedule. The cost associated with this arrangement is the main reason for current research efforts to develop a space shuttle replacement in the form of a single-stage-to-orbit vehicle. In such a vehicle, the weight savings normally achieved by the staging process must be replaced by reducing the amount of oxidizer carried on board, necessitating takeoff with an air-breathing jet engine instead of a rocket. The switch to rocket propulsion cannot occur until after the vehicle reaches a speed of Mach 10. Then, a nonstaged rocket is sufficient to continue into orbit. Such an air-breathing jet engine is called a supersonic combustion ramjet, or scramjet, and its technology as yet remains nonoperational.

Long-range space missions in orbital trajectories represent flight in a zero-gravity environment for a majority of the mission. In those cases, a very small thrust supplied over a long time period can be made more fuel-efficient than can the use of chemical rockets. The energy for this type of rocket is supplied by either nuclear or solar energy. Electric energy can be used to heat gas to temperatures of up to 10,000 degrees Fahrenheit in an electric arc and produce a very high exit velocity. Ion rockets are even more propellant efficient. They accelerate charged particles in an electric field to exhaust velocities up to ten times those possible in chemical rockets.

International cooperation in rocket launch systems expanded at the end of the twentieth century. Near Moscow, the Russians have built more than 10,000 rocket engines. Based on the Russians' experience, Lockheed Martin placed an order for 101 type RD-180 rocket engines. The RD-180 is a single-engine rocket, producing up to 933,400 pounds of thrust and using two combustion chambers, each with its own steerable nozzle. It burns a kerosene-oxygen mixture, with up to 1 ton of oxygen per second at maximum thrust. It can be throttled back to 40 percent thrust level for accurate trajectory control. These rockets were planned for used in the U.S. Atlas III Program, designed to put 9,000 pounds of payload in Earth geosynchronous orbit.

Other applications of rocket technology are in the airbags used for passenger safety in modern automobiles. These bags are filled with the exhaust gases from a small solid rocket, which is ignited when the vehicle experiences a collision.

John L. Loth

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See also: Robert H. Goddard; Jet Propulsion Laboratory; Microgravity; National Aeronautics and Space Administration; Rockets; Russian space program; Spaceflight

Rockets

Definition: Entirely self-contained projectiles or vehicles that are self-propelled by jets of gas.

Significance: Because they are self-propelled and self-contained, rockets are capable of operating independently of any outside support equipment. Furthermore, because rockets do not need to take in air to operate, they are capable of operations outside of Earth's atmosphere.

Nature and Use

A rocket is propelled forward by a jet of material coming from one of its ends. This jet is generally hot gases resulting from burning fuel in the rocket. The fuel is burned in a combustion chamber and the exhaust gases are expelled from the rocket. Frequently the exhaust gases are directed using a nozzle. Forcing the gases to be expelled in one direction pushes the rocket in the other direction. The amount of force pushing on the rocket as a result of expelling the jet of gas is called thrust.

An important consideration for a rocket is its thrust-to-weight (TTW) ratio. The higher a rocket's TTW, the greater its acceleration. If a rocket has a TTW of less than one, it cannot lift off vertically from the surface of a planet or moon, though it can still fly horizontally with the aid of wings. As a rocket burns fuel, it has less mass and, thus, less weight. As the mass of the rocket decreases, its TTW increases. Rockets, therefore, tend to accelerate faster the longer they burn, unless the thrust is reduced. The Saturn V rocket that carried the Apollo missions to the Moon had an initial TTW of 1.25. The space shuttle was designed with a TTW of approximately 1.5.

A rocket is an entirely self-contained system. Jet engines also rely on the expulsion of hot gases in order to achieve thrust; however, jet engines take in air that mixes with the fuel and burns to provide the exhaust gases. Rockets, in contrast, carry everything they need with them and do not need to take in air to mix with the fuel. Depending on the fuel and the rocket design, rockets sometimes carry oxygen or another chemical that acts as an oxidizer to combine with the fuel in order to make it burn. The fuel and oxidizer taken together are called the rocket propellant. Other rockets contain self-oxidizing fuel, sometimes called a monopropellant, which does not need to be mixed with anything in order to burn. A few advanced rocket designs are able to expel gases without burning fuel at all and, thus, do not need an oxidizer to mix with the propellant.

Different propellants burn with different efficiencies and release different amounts of energy. As a consequence, not all combinations of propellants yield the same thrust even when used in the same rocket. Rocket engineers characterize the efficiency of a rocket propellant by its specific impulse. The specific impulse of a rocket propellant is determined by dividing the thrust provided by the propellant by the weight of propellant consumed per second. The amount of thrust produced depends not only on the propellant used, but also on the rocket design. Thus, the specific impulse of a propellant is valid only for that propellant used in a particular rocket, hence it is specific to the rocket.

Applications

Rockets have many uses. Some rockets are used in conjunction with other propulsion sources to provide additional thrust. Such rockets are called booster rockets. Some rockets are designed to carry cargo or scientific instruments. Anything carried by the rocket that is not part of the rocket itself is called the payload of the rocket. Many military rockets carry a payload of a bomb or other explosive weapon. In such cases, the rocket is called a missile, and the payload is called a warhead.

Rockets have been used with aircraft, either as the sole propulsion system or as strap-on boosters used to achieve extra thrust needed for heavy aircraft to lift off on short runways. The main use of rocket-assisted takeoff is for military transports that need to take off from airfields with runways that are too short to allow for takeoff with conventional engines.

Because rockets can continue to accelerate for as long as they have propellant, they are useful for achieving very high speeds. Such high speeds are needed to achieve orbit around Earth or to leave the vicinity of Earth. Rockets used to launch vehicles into space are called launch vehicles. Furthermore, because rockets are self-contained, they can operate outside of Earth's atmosphere. All spacecraft use rockets for propulsion.

Sometimes rockets are used to propel other rockets. In such cases, the combined rockets are called multistage rockets. The first rocket is known as the first stage and is often called the rocket booster.

Types of Rockets

Rockets are often classified by the type of fuel that they use. Early rockets used a fuel composed of a paste made from gunpowder. Many modern rockets use a fuel that is a solid chemical. These are called solid-fueled rockets or, occasionally, simple solid rockets. Solid-fueled rockets have an advantage in that the fuel is often easy to manufacture and can be cast into the rocket casing itself. A single piece of solid fuel is called a grain or charge. The shape of the grain can be adjusted to yield different specific impulses as needed. The shape can even be adjusted to yield a different thrust at different times after the grain is ignited. Furthermore, solid fuel is often stable at normal environmental temperatures, and the rocket can be left fully fueled until needed. A disadvantage, however, is that once ignited, solid fuel burns by itself and cannot be easily controlled. A solid-fueled rocket is nearly impossible to turn off once it is ignited, and the amount of thrust cannot be much changed from the initial design considerations taken into account during rocket construction. Once the propellant of a solid-fueled rocket is ignited, it generally has to continue burning until it is all gone.

In 1926, the American physicist Robert H. Goddard designed and built a rocket that used a liquid rather than a solid propellant. The initial liquid propellant consisted of gasoline and liquid oxygen. Since that time, many other liquid propellants have been used. A major advantage of liquid-fueled rockets is that the amount of thrust can be easily controlled by simply adjusting valves that govern the amount of propellant that goes into the combustion chamber. Furthermore, liquid-fueled rockets can be turned off at any time by simply shutting off the propellant control valves. Most liquid-fueled rockets can even be turned on again by opening the valves again after they have been shut off. Although some liquid propellants need an ignition source to start burning the fuel, a few mixtures of fuel and propellant simply begin to burn on contact. These selfigniting fuels are called hypergolic propellants. Although liquid-fueled rockets have some clear advantages over solid-fueled rockets, there are some serious disadvantages. Many liquid propellants are cryogenic liquids that must be kept at extremely low temperatures. These cryogenic fluids generally cannot be stored for extended periods of time in the rocket. The rocket, therefore, can only be fueled shortly before use. Furthermore, most liquid propellants are extremely dangerous to transport and to store. Liquid-fueled rockets tend to have complex valve and control systems and, thus, are usually more complicated to design and more expensive to construct than are solid-fueled rockets.

Most rocket designs require the burning of either solid or liquid fuels to provide the source of hot gas and energy that expels a jet of gas that powers the rocket. A few rocket designs do not require burning of the propellant to provide the exhaust jets needed to power the rocket. One such design would employ a reservoir of compressed gas, which would be released and expelled from the rocket. Alternately, the compressed gas could force another propellant, such as water, from the rocket. Some toy rockets are of this extremely simple and inexpensive design. A major disadvantage of this design, however, is that it is very inefficient and cannot provide very much thrust for very long.

Another rocket design calls for the use of a nuclear reactor to heat gases to cause them to be expelled from the rocket. Such nuclear-powered rockets are extremely efficient and powerful. A few nuclear-powered rocket motors have been constructed and tested on the ground or in very short flights, but, due to safety concerns, none have been used in extended flight.

Another technology used to provide the jet of gases is the acceleration of charged atoms or molecules, called ions, with electric fields. The ions are ejected from the rocket in the direction in which the electric field accelerated them. Ion-drive rockets are quite economical. The electric fields can be generated using solar power, and almost any gas can be used as a propellant. The major disadvantage of an ion rocket is that the gas must be very diffuse for the system to work, and this results in very low thrust. The thrust, however, can be sustained for extended periods, resulting in very high speeds after long periods of operation. Because ion-driven rockets have a very low thrust, they cannot be used to launch a vehicle into space, but they can be used once a rocket is already in space.

Parts of a Rocket

Different rocket designs obviously require different components. Some of the most complicated and diverse rockets are liquid-fueled rockets. There are general similarities among most liquid-fueled rockets, however. The bulk of the rocket's volume holds tanks storing the propellant. For most propellants, there must be separate tanks for the fuel and the oxidizer. The location of the tanks does not really matter, but generally the oxidizer tank is located forward of the fuel tank. This placement allows for a shorter path for the fuel to travel from the tank to the rocket motor. If the rocket is designed to operate within the atmosphere, the rocket body may have fins that help stabilize the rocket in flight, but a true rocket does not use the fins as wings to fly. Some rockets are guided rockets, able to steer while in flight. The mechanisms for guidance and steering are also located within the rocket body. Generally, a rocket's control mechanism is located away from the rocket motor in order to minimize any damage to the guidance system from the rocket motor's heat or vibration.

The rocket motor consists primarily of the combustion chamber, which is where the propellant is burned. The rest of the rocket motor is generally composed of valves and plumbing to deliver the propellant and to mix the fuel and oxidizer as efficiently as possible. Frequently, because the fuel and oxidizer are cryogenic fluids, the fuel lines carry the propellant past the combustion chamber before injecting the fuel into the chamber. This has the advantage of helping to cool the combustion chamber and warm the fuel, generally resulting in a more efficient burning process.

Most rockets contain a nozzle to help direct the exhaust gases from the combustion chamber. A nozzle is not strictly necessary, because a properly designed combustion chamber tends to direct the exhaust gases away from the chamber as a jet through an opening at one end of the chamber. The exhaust gases, however, tend to expand as soon as they are out of the combustion chamber and the jet of exhaust gas becomes less directional after leaving the combustion chamber. A nozzle will direct the gas jet in the desired direction. The more directional the jet of gas leaving the rocket motor, the higher the thrust that the rocket motor will have. Thus, a properly designed rocket nozzle is an important part of a rocket motor. The most efficient type of nozzle is the bell-shaped Venturi nozzle, which is narrow at the point where it connects to the combustion chamber and flares out to a much larger diameter farther from the combustion chamber. Some nozzles are fixed in position, whereas others are capable of tilting slightly, thus changing the direction of the jet of gases and, consequently, the direction of the rocket's thrust. Such movable rocket nozzles are important in guided rockets. For rockets designed to operate outside Earth's atmosphere, the motion of the rocket nozzle is the chief mechanism for steering the rocket.

Solid-fueled rockets are more simple in design than are liquid-fueled rockets. Both types of rocket have similar rocket bodies and nozzles; the main difference between the two types is in the design of the combustion chamber and the propellant storage. Often, the solid-fueled rocket contains a single grain of fuel. The combustion chamber is often located inside the grain, with the grain itself forming the walls of the combustion chamber. As the grain burns, the combustion chamber expands outward. Alternately, the grain fills the combustion chamber and burns from one end to the other. This is generally a less efficient design. The design and shape of the grain can be adjusted to yield variable thrust according to a predetermined formula, but the thrust variations are determined by the manufacture of the grain and cannot be changed after the rocket is ignited.

The Physics of Rockets

One of the fundamental laws of physics is the law of conservation of momentum. Momentum is defined as the mass multiplied by velocity. The conservation of momentum law says that the total momentum of a system does not change unless an external force acts on the system. Rockets operate using this principle. Jets of material streaming away from one end of the rocket carry momentum. This may be thought of as negative momentum since it is in a direction opposite to the direction of the rocket's flight. As a consequence, the rocket must have momentum in the opposite, or positive, direction. The sum of the two yields zero. As the jet of gas leaves the rocket carrying negative momentum, the rocket must have an increase of positive momentum. This means that the rocket must increase its forward speed as the rocket's mass decreases.

Thus, the more mass that is expelled from the rocket, the more momentum it carries. Likewise, the faster the mass leaves the rocket, the more momentum that it carries. The rate at which negative momentum is carried from the rocket determines the thrust of the rocket. For a highly directional jet of gas from a rocket, the thrust is given by the first rocket equation:

$$F = Ru$$

In this equation, F is the thrust, u is the speed at which the jet of gas leaves the rocket, and R is the rate of propellant used, measured in mass per time.

As a rocket continues to burn, its mass decreases, and, thus, the acceleration increases if the thrust remains constant. The final speed of a rocket operating outside of the influence of other forces can be determined by the second rocket equation:

$$v_f = v_i + u \times \ln\left(\frac{m_i}{m_f}\right)$$

In this equation, v_f is the final rocket velocity, and v_i is the initial rocket velocity. The *ln* indicates the natural logarithm function. The initial rocket mass is given by m_i and the final rocket mass is given by m_f. The u term represents the exhaust velocity of the gas as it leaves the rocket.

Both of these equations describe idealized rockets. Real rockets are generally not ideal, and, thus, modifications to the equations must be made. Generally, the adjustments to the equations are to yield an effective thrust less than the thrust determined from the first rocket equation and to yield a final velocity less than that determined by the second rocket equation. These equations, therefore, provide the maximum thrust and maximum possible final velocity for a rocket. The goal of rocket engineers is to construct rockets that are as close to ideal as possible.

Much of a rocket consists of storage space for the propellant. After propellant has been used, the portion of the rocket used in storing the propellant becomes dead weight. As indicated in the second rocket equation, if the final mass were reduced, then the final velocity could be increased. This mass reduction could be accomplished by jettisoning the propellant storage spaces. Rather than building rockets that jettison used propellant storage areas, rockets are often designed to propel other rockets, called stages. The first rocket, or first stage, fires until it has used up its propellant. After the first stage has finished using its propellant, it drops off, and the second stage begins operation. A rocket can have as many stages as needed. However, the difficulty and expense of designing and constructing multiple stages, each with its own rocket motors, makes it generally economically unfeasible for a rocket to have more than two or three stages.

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See also: Wernher von Braun; Forces of flight; National Aeronautics and Space Administration; Orbiting; Propulsion; Rocket propulsion; Spaceflight

Roll and pitch

Definition: Roll is the angular motion of an airplane about its centerline, a line of equal distance between the wings through the fuselage. Pitch is the angular motion of an airplane about a line from wingtip to wingtip perpendicular to its centerline.

Significance: Roll is important because pilots can use this motion to direct the lift on the wings and change the path of the airplane; by pitching the airplane, the pilot can change the magnitude of the lift on the airplane. For example, in setting up an airplane for a landing, the pilot must continually redirect the lift force to keep the airplane aligned with the runway. In landing, changes to the pitch angle can make small changes to the lift force and therefore alter the descent rate of the airplane.

Ailerons and Elevators

The primary airplane controls that generate roll are the ailerons, which are located on each side of the wing and are identified as the left and right ailerons. Both ailerons are of the same size and are located at the same distance from the centerline of the airplane. These controls are essentially the same in both expensive, high-performance general aviation jets and low-performance training airplanes. In both, each aileron is attached to its corresponding wing by a hinge. The ailerons deflect upward and downward about the hinge line. When one aileron deflects upward, the other aileron deflects downward. The pilot deflects the ailerons by moving the control wheel. If the control wheel is rotated counter-clockwise, the left aileron moves upward and the right aileron moves downward.

This movement is in contrast to that of the elevator; both right and left elevators move together. The elevator is the primary control for changing the pitch angle or the angle that the centerline makes with the horizontal. The pilot deflects the elevator by moving the control wheel or stick backward and forward. Rearward movement of the wheel raises the elevator and therefore the nose of the airplane.

Rudders

Even though the ailerons are the primary roll control, the rudder is often moved with the ailerons in making turns. The rudder moves the nose of the airplane in the direction of the lower wing. However, movement of the rudder also can affect the airplane roll. In a turn (to the left, say), the aileron on the left wing is raised and the aileron on the right wing is lowered. In this aileron position, the rudder is moved to the left. This rudder movement pushes the tail to the right and therefore the nose to the left. The force on the tail due to the rudder deflection is shown pointed to the right. A force at the tail to the right will push the nose of the airplane to the left. Since this force due to the rudder is to the right and above the centerline of the airplane, the result is an initial rolling action opposite to that resulting from the aileron movement. Therefore even though the rudder is required to move left to help turn the airplane to the left, there is a secondary effect as soon as the rudder is applied, which detracts from the rolling motion of the ailerons.

However, because the rudder forces the nose to the left, in spite of its contrary rolling effect, the nose is moved to the left of the direction of the oncoming air. This deflection produces a cross-flow coming from the right to the left for the left turn.

Airplane wings are designed with a slight upward bend. This bend is called a wing dihedral, and the angle that the wing makes with the horizontal is called the dihedral angle. As a result of both dihedral angle and cross-flow, the right wing has a slight increase in upward flow, and the left wing has a slight decrease in upward flow. The result is that the lift on the right wing is increased and the lift on the left wing is decreased. The result is a roll angle, left wing down and right wing up, that is in the same direction as that caused by the deflection of the ailerons. The rudder initially causes the airplane to roll in a direction opposite to that of the ailerons; however, the yawing motion of the rudder causes a cross-flow to develop, and that flow, along with the built-in dihedral angle, causes the airplane to roll in the proper direction for the turn: left wing down for turn to the left, right wing down for turn to the right.

An airplane can, however, have an excessive amount of dihedral, the result of which would be that wind gusts from the left or right would cause a rolling motion that would increase with the dihedral angle. The airplane would have an unpleasant rocking motion in response to even small gusts.

As has been pointed out, the rudder can cause the airplane to roll, but the ailerons can cause the airplane to yaw. The aileron can cause the airplane to yaw because there is always a drag associated with lift. If lift is increased, then the drag is increased. When the right aileron is deflected downward, the lift increases on the right wing. At the same time, the left aileron is moved upward, decreasing the lift on the left wing. Thus, there is an increase in drag on the right wing and a decrease in drag on the left wing, which will cause the nose of the airplane to swing to the right. Because the ailerons are moved to turn to the left, the yaw that results from aileron deflection is called adverse yaw. The main purpose of the rudder is to counteract this adverse yaw. When the airplane rolls to the left, the nose-right adverse yaw of the ailerons is countered by moving the rudder left.

The primary roll control on an airplane is managed by the ailerons, one on each wing. The pilot controls airplane roll by rotating the control wheel in the direction of the desired roll. Aileron deflection produces an adverse yaw, which is countered by the rudder. Pitch is controlled by movement of the elevator, moved in turn by the pilot by a backward, or nose-up, and forward, or nose-down, movement of the control wheel.

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See also: Aerodynamics; Ailerons and flaps; Airplanes; Flight control systems; Forces of flight; Rudders; Stabilizers; Tail designs; Wing designs

The F-15B is equipped with nozzles that allow it to control both pitch and yaw. (NASA)

Rotorcraft

Also known as: Rotary-wing aircraft

Definition: Any aircraft that uses a rotor, or rotating wings, to provide the craft's lifting force.

Significance: Rotorcraft, the first aircraft able to perform short and vertical takeoffs and landings, continue to comprise the majority of all short takeoff and landing (STOL) and vertical takeoff and landing (VTOL) aircraft.

Rotary- Versus Fixed-Wing Aircraft

All aircraft can be divided into two general categories: fixed-wing aircraft and rotary-wing aircraft, or rotorcraft. The principal difference between the two types of aircraft is the method used to provide the lifting force that allows the aircraft to fly. Fixed-wing aircraft use large, stationary wings to provide the required lift. The lift on the wings is generated by pulling the entire aircraft through the air with some type of propulsion system, such as propellers or jet engines. Rotorcraft, on the other hand, are equipped with at least one rotor, made up of a set of two or more rotating wings, that provides the lift that the aircraft needs to stay aloft. The lift on each of the rotating wings is generated as the rotor spins through the air, around the rotor shaft. As a result, the rotor can generate lift without the entire aircraft necessarily having to be in motion.

Types of Rotorcraft

The two most common types of rotorcraft are the helicopter and the autogiro. Helicopters and autogiros are similar in that they both have large-diameter rotors that provide lift for the aircraft in all flight conditions. Helicopters are used in a large number of civilian and military applications. Civilian applications include airborne ambulance, police surveillance, news gathering, fire fighting, logging, heavy construction, intracity passenger transportation, tourism, cargo transportation, and search and rescue. Military applications include troop transport, logistical support, combat air support, and combat search and rescue. Autogiros, in contrast, have few commercial or military applications and are flown mainly by sport aviators.

Virtually all other rotorcraft can be broadly grouped into a category called tilting proprotor aircraft. These aircraft include the tilt-shaft/rotor, tilt-prop, tilt-wing, and tilt-rotor aircraft. All have two or more rotors, which provide either lift or propulsive force by tilting to a vertical position for vertical flight and to a horizontal position for forward flight. In vertical flight, the rotors provide all the lift necessary to keep the aircraft aloft in takeoff, landing, and hover. In forward flight, wings perform that function, and the rotors provide propulsive force. With the exception of the V-22 Osprey, a tilt-rotor aircraft, tilting proprotor aircraft have never progressed beyond the prototype stage.

Helicopters

Helicopters can be distinguished from other rotorcraft by the fact that their rotors have a fixed orientation relative to the aircraft fuselage and simultaneously provide lift and propulsion. On a helicopter, engines provide the power that drives the rotation of the rotor. Most modern helicopters have either one or two rotors that provide lift and propulsive force. The maximum forward speed of a helicopter is limited by the fact that the rotor (or rotors) must provide both propulsion and lift. Under high-speed flight conditions, the vibratory forces on the rotor blades become extreme, thereby limiting the top speed of the helicopter. In order to increase the top speed, some helicopters, known as compound helicopters, have been equipped with auxiliary propulsion, such as propellers or jet engines.

Helicopters have been built in a variety of configurations. The most common configuration is the single-rotor helicopter, which has a single main rotor for thrust and pitch and roll control and often has a smaller tail rotor that provides directional control. Another common configuration is the tandem helicopter, which has two large rotors, one near the forward end of the helicopter and the other near the aft end. This configuration is particularly well suited for the transport of heavy cargo, because the two rotors can accommodate large changes in the aircraft's center of gravity.

Less common configurations include the coaxial and side-by-side helicopters. The coaxial helicopter has two counterrotating rotors that share a common mast. Side-by-side helicopters also have two rotors, but one is located on the right side of the aircraft and the other is located on the left side. A variant of the side-by-side helicopter is the synchropter, on which the two rotors are placed close together so that they intermesh.

The concept for the helicopter has been around since the Chinese top, which predates the Roman Empire. Leonardo da Vinci also considered the possibility of vertical flight. However, like the airplane, the helicopter did not become a practical concept until the invention of the internal combustion engine. Significant developments in the direction of a practical helicopter began to be achieved not long after Orville and Wilbur Wright flew their first airplane in 1903. Men such as Emile and Henry Berliner, Raoul Pescara, Louis-Charles Breguet, Heinrich Focke, and Anton Flettner made major contributions to the development of the helicopter. Although some give credit to Igor Sikorsky for building the first successful helicopter, the VS-300, others argue that the Focke-Wulf Fw-61 was the world's first practical helicopter. At the same time, other individuals, including Arthur Young, Frank Piasecki, and Stanley Hiller, were developing their own designs.

After World War II ended, a number of companies began designing and building helicopters. The most successful were Sikorsky, Bell, Piasecki (later Boeing), Kaman, and Hiller. During the Korean War, the use of helicopters for medical evacuation showcased the usefulness of helicopters and spurred further developments. Among the most important developments was the introduction of the turboshaft engine. Later, during the Vietnam War, the role of helicopters was expanded to include troop and cargo movement and attack missions. The expanded uses for the helicopter led to more developments that resulted in modern helicopters.

Autogiros

Autogiros look very much like helicopters, except that they typically have only one rotor. The rotor on an autogiro also has a fixed orientation relative to the fuselage, but, in contrast to that of the helicopter, the autogiro's rotor provides only lift. Propulsive force is provided by an auxiliary power source, such as a propeller. In addition, the rotation of the rotor is driven not by an engine, but by the air that passes through the rotor disk as it is dragged through the atmosphere by the aircraft. This behavior is similar to that of a maple seed, which spins as it falls from the tree. Because the rotor requires the aircraft's forward motion in order to rotate, the autogiro can neither take off nor land vertically, nor can it hover. It is a short takeoff and landing (STOL) vehicle.

Autogiro development began in about 1920 and was considered a viable alternative to the helicopter until the development of Sikorsky's helicopter. The father of the autogiro is Juan de la Cierva of Spain. After building two unsuccessful aircraft, Cierva flew his first successful autogiro in 1923. In the United States, the Pitcairn and Kellett Aircraft Companies were principally responsible for the development of the autogiro. Operating under a license from Cierva, they cooperated with Cierva in developing his original design. Cierva used conventional aircraft controls to fly his autogiro. By 1932, control was achieved by tilting the rotor with respect to the fuselage, eliminating the need for all aircraft controls except the rudder. Also, early autogiros started their rotors by taxiing around on the ground. Later models were equipped with a geared connection to the engine.

Tilting Proprotor Aircraft

The principal reason for the development of tilting proprotor aircraft was to overcome the inability of helicopters to fly at high forward speeds, while retaining the ability to hover, take off, and land vertically. A comparison of the rotors of helicopters and autogiros to those of tilting proprotor aircraft shows that the latter have much smaller diameters. Tilting proprotor aircraft also have wings and vertical and horizontal tail surfaces like those of conventional fixed-wing aircraft.

Tilt-shaft/rotor aircraft were the predecessors of the modern tilt-rotor aircraft. This rotorcraft was able to take off and land vertically, as well as hover, by virtue of the fact that its rotors could pivot to provide lift for takeoff, landing, and hover, as well as propulsive force in forward flight. Stationary wings provided the required lift in forward flight. The first tilt-shaft/rotor aircraft was the Model 1-G, which was built by the Transcendental Aircraft Corporation and became the first such aircraft to successfully make the transition from hover to forward flight in December, 1954. The rotors on the Model 1-G were located at the ends of the wings, and the engine that provided power to them was located in the fuselage. The Model 2 followed the Model 1-G and was tested from 1956 to 1957. Bell Helicopter Company, which had been working on a similar concept since 1951, introduced the XV-3 in 1955. Two prototype aircraft were eventually built and flew many flight tests. The XV-3 was similar in design to the Model 1-G, which was not surprising because aircraft engineer Robert Lichten played a major role in the design of both aircraft.

The concept for the tilt-prop aircraft was similar to that of the tilt-shaft/rotor aircraft, except that the diameter of the tilt-prop rotors was smaller, like a large propeller. Only two aircraft of this type were ever built, both of which were built by Curtiss-Wright and called the X-100 and the X-19. The X-100 had two tilting props at the ends of a stationary wing. The X-19 had four tilting props, two at the ends of the main wing and two at the ends of a smaller wing at the tail of the aircraft.

The tilt-wing aircraft was another variant of the tilting proprotor aircraft. As with the others, the orientation of the rotors could be changed from horizontal to vertical, so that the aircraft could both hover and fly at high forward speeds. However, on a tilt-wing aircraft, the rotors were rigidly attached to the wing, and the entire wing pivoted. The first tilt-wing aircraft was the Vertol 76 (VZ-2), which first flew in 1958. Hiller Aircraft then built and flew the X-18 in 1959. The two most successful tilt-wing aircraft, the LTV-Hiller-Ryan XC-142 and the Canadair CL-84 Dynavert, appeared in the mid-1960's. In 1964, the XC-142 became the largest vertical takeoff and landing aircraft to fly. Five prototypes were built, but all eventually crashed or were otherwise accidentally destroyed.

Similar in configuration to other tilting proprotor aircraft, the tilt-rotor appears to be a fixed-wing aircraft with large propellers attached to nacelles at the tips of the wings. The engines that provide the power to turn the rotors are located in the nacelles. In 1975, Bell Helicopter Company began the development of the XV-15 tilt-rotor research aircraft. Two prototype aircraft were built, and the first successful flight with conversion to forward flight took place in 1977. Since that time, the XV-15 has performed hundreds of hours of research flight testing and flight demonstrations. The unprecedented success of the XV-15 led directly to the development of the Bell-Boeing V-22 Osprey, the first operational tilt-rotor aircraft.

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See also: Apache helicopter; Bell Aircraft; Firefighting aircraft; Gyros; Helicopters; Military flight; Osprey helicopter; Rescue aircraft; Vertical takeoff and landing

Royal Air Force

Also known as: RAF
Date: Founded in 1918
Definition: The military air force of one of the world's most powerful countries.
Significance: The Royal Air Force is credited with halting Adolf Hitler's campaign to invade Britain in 1940, and has since taken part in many of the United Kingdom's and the British Commonwealth's military actions.

The Royal Air Force is the airborne fleet and pride of the United Kingdom. The history of this air fleet dates as far back as 1880 when balloons were first used in British military maneuvers at Aldershot. Britain's first military air unit, the Air Battalion of the Royal Engineers, was founded in 1911, and one year later, the Royal Flying Corps (RFC) was constituted. Three days after the assassination of the Austro-Hungarian Archduke Ferdinand, which sparked World War I, the Royal Naval Air Service (RNAS) was formed from the naval wing of the RFC. These two branches of the British military constituted Britain's air force throughout most of World War I. Finally, on April 1, 1918, the Royal Air Force was founded by reamalgamating the RNAS and RFC. The RAF was engaged in several small wars between the two World Wars, but it was World War II that offered the service the opportunity to show their true prowess.

The Battle of Britain

The RAF particularly distinguished itself in 1940 during the Battle of Britain and prevented a German invasion. The German dictator Adolf Hitler saw England as a key target to be taken for his own designs. The Battle of Britain began its first phase of defense against the German aggression in August and September of 1940, when the fall of France had left Britain exposed to immediate German invasion. This period also forms what has been referred to as the most dangerous period of the war. England had scarcely enough equipment to arm two divisions, but the Prime Minister, Winston Churchill, raised the fighting spirit in the people and particularly among the RAF pilots who were called on night after night to fight in the skies over England. His famous words regarding the absolute need for victory are well known: "We shall defend our island whatever the cost may be, we shall fight on the beaches, we shall fight on the landing grounds, we shall fight in the fields and in the streets, we shall fight in the hills; we shall never surrender!"

Hitler's plan for Operation Sea Lion, the German code name for their planned invasion of Great Britain, called for heavy use of the German Luftwaffe air fleet. In order to achieve a successful invasion, it was necessary for the Luftwaffe to gain control of the airspace above the English Channel and, geographically, the southern portion of England. In the first phase of the Battle of Britain, the Luftwaffe attempted to destroy the Royal Air Force and its bases. Initially it seemed as if the Luftwaffe had a better advantage and would be successful in their battle for control of British airspace and indeed Britain itself. The British credit the determination and courage of the Royal Air Force pilots who fought the Germans in the air as one of the key factors that led to the success of the Royal Air Force. The RAF also greatly benefitted from a newly developed radar warning system. While the British suffered great damage and loss of life from the continued air raids and attacks from the Luftwaffe, the Germans suffered severe losses as well. Home defenses were prepared that had strengthened coastal areas, and local militia volunteers supported the RAF in any way they could. Later called the Home Guard, their ranks swelled to about half a million and worked for the defense of the country, as well as helping the RAF in any way possible.

It was generally assumed that Hitler had a grandiose scheme for Operation Sea Lion, but in truth there was no such plan. The Germans had hardly thought beyond the defeat of the French government, simply assuming that once France had been conquered and occupied—knocked out of the war, as it were—the British would see the folly of further armed resistance and capitulate. In actuality, it was not until May, 1940, that Hitler began to formulate thoughts about the invasion of Britain, and not until approximately July that preparations for a landing in England began to take shape. Such a plan required naval power and a command of critical airspace. Churchill and his war advisory ministers faced what he termed the "hateful decision" that the French fleet could not fall into German hands to be used against England, and thus, after a long and heated debate with the war ministers, knowing that superiority at sea was their only serious advantage, British warships began a bombardment and destruction of French naval fleets in Oran, Nigeria, and Dakar, French West Africa.

At the same time, Germany increased and intensified their air raids against Britain. Furious at the British for not capitulating and surrendering, Hitler issued orders for an all-out campaign, with orders to seek out and destroy the Royal Air Force, their bases, and the British aircraft industry itself. For approximately three weeks in late August and early September, 1940, an average of one thousand Luftwaffe planes were over Britain daily. Their targets were airfields, known factories, suspected radar stations, and the famed docks of East London. The Germans had successfully used a technique called Blitzkrieg, or "lightning war," whereby they invaded by sea, land, and air. They could not use the Blitzkrieg successfully to land in England, but they did indeed blitz from the skies day after day, night after night, in an attempt to wear down the pilots, people, and government of King George VI.

Initially, the RAF was unorganized, and there was doubt they could hold against the German onslaught. However, by the first week of September, the RAF grew in strength and sheer determination as the pilots flew round the clock to keep the Germans from gaining critical air superiority. By mid-September, 1940, the RAF was displaying greater effectiveness and efficiency in the air, and were downing two Luftwaffe planes for every one British loss. Thus, the German attempt to invade England was a dismal failure and cost them dearly. Hitler finally conceded that his Operation Sea Lion plans were in defeat and postponed and eventually cancelled further land or sea plans to invade England. He was forced to disperse the shipping units poised for the invasion, and by the end of September, 1940, the British government felt safe in assuming that there would be no invasion of their island homeland.

The Germans continued heavy night raid bombing, as defenses were rendered more difficult at night because of darkness and cloud cover. Hitler moved to systematically destroy any identifiable center of British industry. Particularly during the winter of 1940-1941, London was under constant bombardment from the Luftwaffe. On the night of December 8-9, 1940, more than four hundred Luftwaffe bombers blitzed London, inflicting great damage. Other industrial areas, including Coventry, Birmingham, Plymouth, and Liverpool, suffered the same heavy air attacks. In June, 1941, Hitler diverted his attention to Russia, which diminished the pressure on England and its Royal Air Force. Ultimately, just a handful of courageous pilots had saved the island, and Prime Minister Churchill gratefully thanked the Royal Air Force pilots, saying that "never had so many owed so much to so few."

There were great odds against the RAF, but one of their main advantages was their planes. The German planes were heavy and could only fly for a limited time without returning to refuel. The planes were also big and bulky, making changes in flight pattern and maneuvering difficult, if not impossible. The RAF flew in smaller planes, the Spitfire and Hurricane fighters. While these are the most popularly known planes, there were others that fought in

Image Not Available

the Battle of Britain and throughout the war, such as the Gloster Gladiator and the Bristol Blenheim. The British aircraft gained advantage from their ability to dart and dive around, above, and below the heavier Luftwaffe planes. It was hard for the Germans to hit such moving targets. The British planes were lighter and smaller, and ultimately proved far more efficient in the long run. There are restoration programs underway to restore some of the original Spitfire and Hurricane planes.

The Modern RAF

Today, the Royal Air Force is a viable fleet of aviation power. Their training is world-renowned and intense. The Battle of Britain is not forgotten as pilots and career service personnel train in various schools and branches of the Royal Air Force. They are the air defense system of the United Kingdom and the Commonwealth, incorporating other Commonwealth nation units among their own, training together in a common cause of defense and international friendship. In May, 2001, the British Ministry of Defense announced plans to incorporate New Zealand's top combat pilots after that country decided to scrap the Royal New Zealand Air Force's fighter squadrons. Anticipating what may be the largest ever influx of New Zealand airmen into the Royal Air Force since World War II, the Ministry of Defense is nonetheless looking to fill their many vacancies, primarily for pilots, but also for necessary support personnel such as doctors and engineers. The Royal Air Force has indicated its willingness to pursue any enquiry received from the New Zealand service. Ironically, the Royal Air Force has been suffering an outflow of pilots despite greater and special financial incentives to remain in RAF service. New Zealand's termination of its fighter squadrons comes at a beneficial time for the RAF, affording the RAF the opportunity to recruit fully trained pilots who could easily assimilate the RAF's culture and traditions. Planning to sell off its fighter planes and equipment, New Zealand's fleet could easily supply the shortages the Royal Air Force is facing in planes and helicopters.

Present career training in the Royal Air Force includes such specific and demanding work as the air battle combat support course. This particular course is done in four phases, which culminate in war games. Run twice a year for two intensive weeks, each class is limited to eighteen students, who must demonstrate the ability to withstand the class. Other classes include the air electronic warfare course, an intensive aerosystems course, an air battle staff course, and an air electronic warfare course.

Senior RAF personnel study joint targeting and missions, joint air weapons systems, senior officers air warfare, and targeting and battle damage assessment. If one takes the aerosystems course, the phases contain such topics as platforms and weapons, navigation, electronics and communications, information systems, sensors, and integrated systems. With a long history behind it, the Royal Air Force remains one of the strongest air force fleets in the modern world.

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See also: Battle of Britain; Luftwaffe; Military flight; Radar; World War II

Rudders

Definition: Large, vertical, moveable, flaplike devices attached to the vertical stabilizers on most aircraft, or movable vertical fins on a missile.

Significance: The rudder is the primary device used to yaw, or steer the nose of the aircraft to the left or right, in a turn or to counteract the yaw resulting from aileron use in certain cross-control maneuvers.

An aircraft's or a missile's rudder, a flap or a wing-shaped surface mounted at or near the craft's rear, serves a purpose similar to that of a rudder on a ship. When the rudder is deflected to one side or the other, it produces a force and a resulting moment, or yaw, about the vehicle's center of gravity. The force rotates the vehicle in the same direction as the deflection of the rudder.

Because rudders have been used for centuries to steer ships, early airplane designers naturally assumed that they could be used to steer airplanes. However, these designers often failed to anticipate the roll of the aircraft that resulted from the use of the rudder. When the rudder causes an airplane to yaw, it causes one wing to travel slightly more quickly through the air than the other and, hence, to produce more lift, which subsequently causes the airplane to roll in the direction of the turn. This roll was a problem with early airplanes, which flew very close to the ground, and required the use of ailerons and similar devices to control the resulting roll. Through experimentation, early aviators learned that the most successful turns are coordinated turns, made using a combination of rudder and ailerons.

On wingless missiles, the rudder is the only device used to make the vehicle turn. A missile's rudder yaws the missile such that it flies at an angle to the airflow and develops a side-force on its body, or fuselage. This side-force produces the needed acceleration along the turn radius to carry the missile through the desired turn.

Turns

Airplane turns are more complex and require more than the use of a rudder. As noted above, when the rudder is deflected, the fuselage yaws, and the wings develop different lift forces. The wing on the outside of the turn develops a larger lift than does the wing pointing into the turn. The difference in lift between the wings results in a roll of the fuselage, which tilts or rotates the lifting force of the wings into the direction of the turn. Because the lifting force of the wings is much greater than the forces on any other part of the airplane, it is the tilted lift that provides the force to turn the airplane. When the turn is properly coordinated, the combination of yaw caused by the rudder, roll caused by the ailerons, and the slight increase in thrust will produce just the right amount of lift to balance the weight of the aircraft, so that the aircraft can make the turn without losing altitude.

Engine Loss

The rudder must also be used to keep the airplane from yawing or turning when a multiengine airplane loses one of its engines. When a multiengine plane encounters an engine-out situation, the rudder must be used to produce enough yaw to counteract the effect of having more thrust on one side of the airplane than on the other. For this reason, multiengine airplanes have much larger rudders than do single-engine airplanes.

Landings

Another common use of the rudder is to cross-control an airplane, especially in its approach to landing. In an ideal landing, the atmospheric wind would be blowing straight down the runway. In the real world, the wind is often at an angle to the runway and, when landing or taking off, the pilot must adjust the flight of the plane to account for the crosswind. On takeoff, this is done by allowing the plane to yaw into the wind as soon as it leaves the ground and by flying away in a straight line extending from the runway centerline with the airplane turned somewhat into the wind in a slightly sideways motion. The approach to landing can be made in the same manner, with the plane yawed into the wind; at some point, the pilot must align the fuselage with the runway before the wheels touch down, so the aircraft can be properly controlled on the ground. To do this, the pilot uses the rudder to yaw the airplane until it is parallel to the runway and uses the ailerons to keep the wings level. This use of rudder and aileron is the opposite of that used in a turn and is referred to as cross-control.

The rudder is controlled on most aircraft by cables or hydraulic lines connected to pedals on the floor of the cockpit. The pilot presses the right rudder pedal to move the rudder and, thus, the nose of the aircraft, to the right, or presses the left rudder to rotate left. Modern airliners and fighters use power-augmented hydraulic or electrical systems to connect the rudder pedals to the rudder, and the rudder is often connected to an automated control system which will allow control of the airplane by a computer system.

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See also: Aerodynamics; Ailerons and flaps; Airplanes; Flight control systems; Forces of flight; Landing procedures; Roll and pitch; Stabilizers; Takeoff procedures

Runway collisions

Definition: Unplanned contact between aircraft while on an airport runway or inadvertent contact between an aircraft and a ground vehicle, pedestrian, obstruction or animal while on an airport runway.

Significance: Runway collisions are among the greatest hazards of aviation.

The world's most deadly aviation accident, the collision of two fully loaded Boeing 747's, occurred in 1977 on a foggy runway at Tenerife Airport, Canary Islands. In this incident, the captain of a KLM jumbojet, in a hurry to take off and suffering from a profound loss of situation awareness, accelerated down the runway directly into a Pan American jet taxiing in the opposite direction. In the ensuing carnage, 583 people were killed and nearly all of the survivors were injured to a significant degree.

Causes

The threat of runway collisions has increased along with the growth of air travel around the world. Since World War II, commercial aviation has steadily grown, dramatically so during most of the 1990's. In the United States, air travel grew four times more quickly than any other form of ground transportation, pushed by the introduction of jet aircraft into commercial service on a large scale in the early 1960's. By the year 2000, some 600,000 pilots had made almost 70 million takeoffs and landings at 450 different American airports. Alarmingly, the rate of runway collisions, incidents, and near-misses has exceeded the rate of growth of air travel, even throughout the 1990's, exhibiting a 75 percent increase between 1993 and 1999, according to the Federal Aviation Administration (FAA).

Despite unparalleled airline passenger volume growth, the actual number of runways in the United States has diminished during this time, due, in large part, to extremely strict noise and environmental pollution regulations. As a result, more operations have been crowded onto fewer runways, taxing the abilities of pilots and air traffic controllers alike. This situation remains largely unresolved, with a particularly hazardous combination of large, complex airports and inexperienced pilots, who are common during times of industry growth.

Human Factors

Except for the rare instance of an aircraft colliding with an animal crossing a runway, the cause of most runway collisions is human error, on the part of pilots, air traffic controllers, or a combination thereof. Such collisions are said to involve human factors.

Air traffic controllers have the primary responsibility of providing safe separation for all forms of traffic at large, busy airports. On infrequent but regular occasions, controllers fail in this mission, due to workload, loss of situation awareness, faulty procedure design, or simple short-term memory loss. Such was the case in 1991 at Los Angeles International Airport, where a USAir 737 landed on top of a Skywest turboprop commuter, which had been directed by a controller to stop on a dark runway awaiting clearance for takeoff. Momentarily distracted by a third aircraft, the controller then cleared the USAir jet to land, without ever directing the Skywest aircraft to take off. Thirty-four people died in the resulting collision.

For both pilots and air traffic controllers, two elements contribute heavily to human-factor errors: a loss of situation awareness and miscommunication. Loss of situation awareness occurs when perception and reality are incongruent, especially with regard to location. To a large degree, this is due to poor or zero visibility, because sight is by far the most dominant sense. With impaired vision, usually due to darkness, fog, obstruction, or sun glare, the ability of pilots and controllers to develop a mental picture of the locations of all relevant aircraft and vehicles is significantly decreased. This leads to participants acting on imperfect information, which, in aviation, can have deadly consequences.

Communication problems repeatedly cause human-factor errors. Except in infrequent instances, in which light-gun signals are used, all operational aviation is coordinated by radio. The quality of radio communications on the frequencies used in aviation is markedly inferior to that of other forms of electronic communication, such as telephone or television, and is subject to static, interference, garble, and outright transmitter or receiver failure. Difficulties can also arise from controllers speaking at a rapid-fire rate, from pilots' unfamiliarity with an airfield, from passengers or crewmembers asking questions of the pilot, and from poorly marked taxiways. The opportunity for misunderstanding is multiplied when controllers and pilots do not speak the same native tongue, forcing one or both of them to speak a second language.

Preventing Runway Collisions

In-flight safety has improved steadily since World War II, to the extent that, according to the FAA, ground operations have become the most dangerous phase of flight. With this in mind, and with the memory of the Tenerife disaster still fresh, FAA officials aggressively attacked the issue of runway safety throughout the 1990's. In 1991, 1995, and again in 1998, the FAA developed action plans to address specific issues relating to safer ground operations. The agency also made the reduction of runway accidents and incidents its highest priority, with the goal of markedly reducing occurrences each year. To this end, the National Runway Safety Program Office, formerly known as the Runway Incursion Program Office, was created in 1996 as part of the FAA to focus and coordinate resources and efforts. Four areas were targeted for improvement: management and procedures, airport signs and surface markings, technology, and runway incursion awareness efforts.

Management and Procedural Changes

Recognizing that confusion, usually due to miscommunication or complex instructions, was often a root cause of runway safety incidents, the FAA took steps to clarify the instructions provided to pilots and required more confirmations from pilots of critical elements of information. Additionally, new restrictions were placed on pilots conducting land and hold-short operations, air traffic control procedures used to expedite the flow of arriving and departing aircraft at airfields with intersecting runways.

Signs and Surface Markings

Another effort to reduce confusion and to increase situation awareness was to develop more visible and easily recognizable airport signage and markings. Hold-short lines on a taxiway mark the limit of travel toward a runway with specific clearance to cross or enter it. It is essential that these lines are easily seen and recognized. The FAA mandated that all airports double the size of these lines and provide a black background to improve contrast and visibility. In cooperation with the Aircraft Owners and Pilots Association, the FAA examined the possibility of using an anamorphic projection, or unequal magnifications along two perpendicular axes, to create a sort of three-dimensional painted hold-short line. The FAA also examined the possibility of using a stop light system, similar to those used at European airports, to prevent inadvertent runway incursions.

Enhanced Technology

The FAA has invested heavily in technology improvements to solve runway safety problems. Because many problems arise when controllers cannot readily see the aircraft and vehicles they are controlling, typically in fog, snow, or dark conditions, beginning in the early 1990's, contracts were issued for the development of a ground-scan radar system. This project combined what is essentially a land-oriented version of air traffic control radar with a sophisticated software system called the Airport Movement Area Safety System (AMASS). The system was designed to be used at large airports to automatically alert controllers to impending conflicts in enough time for corrective actions to be taken. Initial results were disappointing. The system was labeled as being over budget, over schedule, and ineffective, criticisms leveled at the FAA on a number of projects during this period. The first AMASS unit was installed at San Francisco, California, in September, 2001, with thirty-three other airports to follow. A simpler and less costly version, ASDE-X, was to be provided to smaller airports, but most U.S. airports would not benefit from either program.

Runway Incursion Awareness

The FAA has long recognized that training and education are effective ways to address human-factors issues, and that policy was extended to the runway collision problem. Reaching air traffic controllers was relatively easy, because they are almost all FAA employees and could thus be scheduled for training as necessary. Controllers received training on new equipment, were educated about the scope and scale of the runway safety problem, and were taught new techniques to address specific issues, especially those involving communication and clarity.

Addressing human-factors issues with the 600,000 pilots utilizing U.S. airports was a more difficult task. Airline pilots could be provided relevant education by their corporate training departments, but teaching general aviation pilots, who constitute the bulk of active aviators in the United States, was more challenging. Taking advantage of the requirement that pilots obtain refresher training every two years, the FAA encouraged flight instructors to promote heavily runway safety awareness. Student pilots received similar instruction as part of their initial training. Through newsletters, safety seminars, and booths at aviation conventions, the FAA spoke directly to pilots on the subject of runway safety. The FAA was aided in this effort by nonprofit aviation organizations, such as the Air Safety Foundation and the Flight Safety Foundation, whose missions are to improve the safety of all forms of air transportation.

Part of the FAA's agenda was to step up enforcement actions. Increasingly, pilots found there was no such thing as an inconsequential runway incursion. Violations were met with fines, pilot certificate suspensions, or mandatory retraining. Repeat or flagrant offenders could expect more than one of the aforementioned actions.

Specific Runway Safety Instruction

The FAA, flight instructors, and the nation's aviation schools identified a number of steps that pilots could take to reduce the possibility of a runway safety compromise.

The first step was to increase visibility. It was recommended that pilots use rotating beacons, landing and taxi lights, and strobe lights while operating on the airport surface, even in the daytime. The degree of illumination should be based on environmental conditions.

A second step involved communications. Unclear or ambiguous instructions should be clarified so that both pilots and air traffic controllers achieve a shared mental model of the situation. Critical elements of information must be repeated back to the controller to ensure that a message has not only been heard but also understood. A sterile cockpit, that is, one in which no extraneous conversation takes place in the presence of the crew, is vital for keeping a cockpit free of distractions.

A third step recommended that pilots taxi accurately. This is best achieved by the pilot having in hand an airport diagram, essentially a road map of the airfield, while the taxi is underway. If a diagram is not available or uncertainty still exists, a "progressive taxi," involving turn-by-turn sequential instructions from a ground controller, may be requested.

Pilots should also know and abide by taxiway and runway markings and signs. Airport signs and markings are standardized throughout the United States, making this job easier.

Pilots should always confirm runway alignment. More than one pilot has landed or taken off on the wrong runway, creating an obvious safety hazard. This error can be remedied by confirming the runway number and cross-checking with the compass.

Lastly, a pilot's most important actions should always be to look, listen, and talk. Communication helps all flight participants achieve a shared mental model that is vital to situation awareness.

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Runways

Definition: Facilities on airfields that accommodate aircraft takeoff and landing operations.

Significance: Runways are the last part of the airport that an aircraft uses before reaching the sky and the first part of the airport an aircraft uses upon landing at its destination.

Design Characteristics

The earliest runways were nothing more than small grass or dirt strips that provided room for small aircraft to land or take off. Although thousands of small runways used by small and light aircraft still exist, the heavier aircraft employed by commercial air carriers require large paved runways for their operations. The design of airport runways involves many factors that allow aircraft to perform takeoff and landing operations within aircraft performance specifications and local environmental conditions.

Runway Length

One of the most important characteristics of a runway is its length. Runways must have sufficient length to accommodate aircraft takeoffs and landings. Larger and heavier aircraft tend to require longer distances and, thus, longer runways, in order to accelerate to a speed high enough for liftoff. Small aircraft may require only 500 feet of runway length, whereas the largest commercial aircraft may require nearly 12,000 feet, more than 2 miles, of runway to take off. In addition to aircraft specifications, runways located at higher elevations and in warmer climates tend to be longer, as aircraft need longer distances to take off in the thinner air of hot climates and high elevations. In addition to greater runway length requirements, larger aircraft tend to require runways of greater width, so that landing gear wheels can fit on the runways. Runway widths range from as few as 50 feet to more than 200 feet. Runways are also built with shoulders, similar to those of roads, and safety areas to make sure that there are no obstructions that will be in the way of any aircraft operations.

Runway Orientation

The direction, or orientation, in which a runway is located is another important characteristic. Aircraft perform better when taking off or landing into a wind, called a headwind, than when taking off with a tailwind, with the wind behind the aircraft, or with a crosswind, with the wind blowing across the side of the aircraft. Therefore, runways are oriented so that aircraft can take off or land into the preferred wind direction. Runways that are oriented in the direction of the prevailing winds are called primary runways. Runways that are oriented in the direction of less frequent winds are called crosswind runways. Because smaller aircraft are more sensitive to crosswinds, airports that accommodate smaller aircraft tend to have multiple crosswind runways, oriented in several different directions. Airports serving larger aircraft tend to have more primary runways all oriented in the same direction, called parallel runways.

Runway Pavement

The type and amount of surface material, called pavement, used to build the runway is yet another important runway characteristic. Runways accommodating heavier aircraft tend to be constructed out of thick, rigid pavements, such as concrete. Runways accommodating smaller aircraft tend to be built out of more flexible pavements, such as asphalt. If a runway pavement cannot support the weight of an aircraft, the aircraft will not be able to perform a smooth takeoff or landing.

Signage, Lights, and Markings

Runways may be operated with a variety of associated lights, signs, and markings. A runway is named by the numbers painted on each runway end. The numbers on each end of a runway describe the direction relative to magnetic north. For instance, an airport runway named 09-27 is a runway that runs east 90 degrees from magnetic north to west 270 degrees from magnetic north. Other markings on runways include centerlines and lines that help pilots make accurate landings. Some runways also have electronic landing aids that aircraft use to make precision landings in inclement weather. These runways are called instrument runways. Depending on the type of landing aids and the type of markings on the runway, the runway may either be a precision-instrument or a non-precision-instrument runway. Runways are often also equipped with edge lights, centerline lights, and approach lights, to help pilots make accurate landings at night.

The runway threshold is defined as the beginning of the usable part of the runway for aircraft landing. Often, runways have displaced thresholds, identified by white arrows, before the threshold, to provide extra runway length for aircraft departures. Sometimes, runways have relocated thresholds, identified by yellow chevrons, which provide extra runway length for emergency landings. Relocated thresholds are not for use during normal aircraft takeoff and landing operations.

Runway Capacity

Airports often have more than one runway to handle the large numbers of aircraft that land over a period of time. Both government rules and the physical properties of flight limit the number of aircraft that can use a runway during a given period of time. The typical capacity, or maximum number of aircraft that can use a runway, is approximately sixty operations per hour. At busy airports, where more than sixty aircraft depart or land over the course of an hour, parallel runways are often operated. Government rules dictate how far apart these runways must be for them both to be used simultaneously. In cloudy, or instrument flight rules (IFR), conditions, for example, parallel runways must be 4,300 feet apart, or nearly three-quarters of a mile, in order to be used simultaneously. This is one reason why the world's largest airports take up a large amount of land.

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See also: Airports; Commercial flight; Landing procedures; Pilots and copilots; Runway collisions; Safety issues; Takeoff procedures; Taxiing procedures; Training and education; Vertical takeoff and landing

Russian space program

Date: Beginning in 1945

Definition: The Russian space program was one of two successful attempts to travel into outer space. Starting in 1945, the Soviet Union developed sophisticated scientific and technological expertise that allowed it to make significant accomplishments in space exploration.

Significance: The Russian space program played an important role in extending humankind's knowledge of outer space. The technological and scientific accomplishments of this great endeavor also had a significant impact on the international struggle known as the Cold War.

Russia has had a long and significant role in the history of space exploration. Most historians of science designate Konstantin Tsiolkovsky as the father of modern spaceflight. In the first decade of the twentieth century, Tsiolkovsky produced a ground-breaking theoretical study on the possibilities of traveling in space. The essay, "Issledovanie mirovykh prostanstv reaktivnymi priborami" (1903; exploration of cosmic space with reactive devices), published in the journal *Naootchnoye Obozreniye* (scientific journal), described the methods to be employed to develop vehicles that would carry human beings into outer space.

Tsiolkovsky was both a technological visionary and a social utopian. He perceived spaceflight as the instrument to free humankind from the drudgery of earthly existence. He viewed the power to conquer the law of gravity as a metaphor for the human race's ability to liberate itself by embarking on a new historical epoch of limitless possibilities. The connection among science, technology, and political and social philosophy within Russian culture played an important role in the development of Soviet technological policy.

Unfortunately, Tsiolkovsky's ideas were constrained by the autocratic regime of Czar Nicholas II and the economic, political, and social instability it fostered. This cultural turmoil led to Russia's disastrous defeat in World War I and the subsequent Bolshevik Revolution. The modern history of Russian spaceflight begins in this politically explosive era. From the ascension of Lenin to the construction of the Soviet space station Mir, the Russian space program would be linked to and directed by changes in the accepted political doctrine of Communist totalitarianism.

Early Communism and Space Theory

The intellectual foundation of communism was laid on the philosophy of Karl Marx, who did not consider himself a political philosopher in the classical sense but insisted that his ideas were based upon scientific principles. Technology would be the instrument used to establish Marx's new utopian society. In 1917, Vladimir Ilich Lenin, the leader of the Communist Party, accepted these ideas in the abstract, but the practical problems of reconstructing a wartorn nation drove Lenin to compromise his adherence to strict Marxist-Leninist theory in favor of economic recovery. Lenin's famous statement, "Electrification plus Soviet power equals socialism," set the tone for his national recovery program.

From this emphasis on science and technology, a technological elite developed whose expertise was used to create a new socialist order. Many of these technologists were influenced by the works of Tsiolkovsky, especially by his utopian vision based upon space travel. The Soviet scientific community during the 1920's adopted a research and development program focusing upon the possibilities of space exploration, and two influential works were published during this decade. Yuri Kondratyuk's book *Zavovevanie mezhplanetnykh prostorov* (1929; *The Conquest of Interplanetary Space*, 1997) and Nikolai A. Rynin's work *Mezhplanetye Soobschchicheniia* (1927-1932; *Interplanetary Flight and Communication*, 1970-1971) had a significant impact on the technologists around the world who were working on the possibilities of spaceflight.

Technology Under Stalin

Soviet society drastically changed with the death of Lenin and the ascension of Joseph Stalin to power. In Stalin's purges, technological expertise became secondary to ideological purity, and he launched a nationwide attack against the "elite experts"; many of them suffered the same fate as their military and political counterparts. Stalin's concentration on making socialism safe in Russia had an important impact on Soviet space research. The utopian vision of a socialist cosmos was declared unimportant at a time when the Soviet Union needed to construct a competitive industrial and military sector in order to protect its borders from both its fascist and democratic rivals.

The aeronautical expertise that had been focused on spaceflight during the 1920's was now directed toward the construction of a world-class air force. During the 1930's, the Soviet Union made great strides in aeronautical engineering, generating a confidence among Russia's military leadership that its air force was among the best in the world. This optimism was shown to be unfounded when the German Luftwaffe soundly defeated the Soviet air force during the Spanish Civil War.

Stalin reacted with reprisals against the Russian aeronautical engineering establishment. Many of the Soviet Union's finest rocket scientists were sent to the gulag (a series of camps for political prisoners) and released only after the German invasion of 1941. Among these prisoners was Sergei Korolev, who became the driving force behind the postwar Soviet space program, working on the development of military rockets for the defense of the Soviet Union.

World War II and the Early Cold War

Two major scientific developments of World War II had a lasting impact on the Russian space program. In the last months of the war in the European theater of operations, the Nazis attempted to change the strategic direction of the conflict by introducing a new super weapon, the V-2 rocket. The German industrial sector was too damaged to mass-produce this weapon in the numbers needed to change the outcome of the war, but all of the Allied nations, including the Soviet Union, recognized the potential of this revolutionary new delivery system. The Russians expended considerable resources and energy to capture as many German rocket scientists as possible. The new technology became even more important after the United States successfully used two atomic bombs to force the Japanese to surrender in August, 1945.

The breakdown of the wartime alliance due to Soviet expansion in Eastern Europe brought on the Cold War. Once again, Stalin focused upon the defense of the "Motherland," but this time he accepted the connection between rocket science and the protection of the Soviet Union. A new generation of Soviet rockets was produced through the combined efforts of German and Russian scientists. With the successful detonation of an atomic bomb in 1949 and a hydrogen bomb in 1953, the Soviets accelerated their research in an attempt to create an accurate, uncrewed delivery system for these new weapons of mass destruction. After Stalin's death in 1953, the direction of Russian rocket technology once again focused on space travel.

The Sputnik Era

The Khrushchev era catapulted the Soviet Union into a position of prominence in the area of space exploration. Nikita Khrushchev was a true intellectual child of Marxist-Leninist thought and believed in the compatibility of socialist and scientific truth. Like Tsiolkovsky, he envisioned a utopian state that would reap the benefits of increased productivity based upon science and technology. He extended this idea of universal brotherhood to the entire universe when the Soviet Union successfully launched Sputnik, the first artificial satellite, on October 4, 1957. Khrushchev believed this great scientific and technological accomplishment confirmed both the power of Russian science and the inevitability of communism because it showed that the communist system had created the conditions and the environment for great scientific advancement.

Sputnik had an impact on Khrushchev's foreign policy that went far beyond the technological strategic implications of United States-Soviet relations. This dramatic event also captured the attention of the newly independent nations of Africa, Asia, and the Middle East. An important aspect of the Cold War was the struggle between the democratic and communist camps to win the allegiance of this important segment of the world community. When Sputnik went into orbit, most of the leading nations of the Third World issued press communiqués praising the achievements of the Soviet scientific community. Many seemed convinced that the socialist model, based upon the universal ideal of a one-world community sharing equally the benefits of human knowledge, was responsible for such great accomplishments.

Khrushchev also used the image of Soviet scientific prowess to challenge the theory that war was inevitable between the capitalist and communist nations. Russia's seeming ability to accurately target the United States helped to create the reality of mutual assured destruction, which Khrushchev believed would reduce the likelihood of a third world war.

Khrushchev's confidence in this new strategic doctrine established a sense of security among the nations of Western Europe that bordered the Soviet Empire, and it upset an already strained relationship between the Soviet Union and the ultraradical People's Republic of China. Mao Zedong embraced the Leninist doctrine that power would have to be taken from the capitalist nations through the use of force. As a result of Sputnik, the Chinese believed that the Soviet Union had the ability to bring down the capitalist West. Mao was not deterred by the possibility of widespread death and destruction. He believed a new socialist order would rise from the dust and inaugurate a utopian epoch. He had no concept of the fact that the dust of the old civilization would contain deadly levels of radiation with a half-life of ten thousand years. Khrushchev refused to adopt Mao's radical strategy, an attitude that helped create the Sino-Soviet split.

The success of the Russian space program also caused considerable tension between Khrushchev and the Soviet military establishment. Khrushchev believed that a new strategic doctrine that reflected recent accomplishments in space technology was necessary if the Soviet Union was to reach the ultimate economic goal of universal material prosperity. Khrushchev desperately wanted to reduce the size of the military in order to redirect money and resources into the domestic economy. He created a Seven-Year Plan that proposed increasing both agricultural and industrial output. The military perceived these cuts as unwarranted and dangerous, and it vigorously opposed his plan. At the same time that the Soviet leader proposed massive cuts in conventional forces, he approved a large budget for important research into the development of spy satellites. Khrushchev knew the United States was far more advanced in this field; he recognized that if the Soviet Union hoped to maintain some sort of military parity, significant progress would have to be made in this all-important area. This action exacerbated his problems with the military, which recognized that introducing this new technology could also mean a further reduction in the military budget.

The Space Race

Khrushchev's plan to reduce both world tensions and the size of the Russian military rested upon the image of Soviet scientific and technological superiority. A potentially dangerous aspect of this situation was the absolute importance of staying one step ahead of the accomplishments of the United States.

On November 4, 1957, the Soviet Union launched Sputnik 2; this spacecraft carried Laika, a Russian dog that was the first living creature to be placed into orbit. These successes set the stage for the greatest era of human space exploration. Russia's first crewed project, Vostok, had to reflect both Soviet scientific strength and the proposed egalitarian nature of the communist system. Yuri Gagarin had all the attributes necessary for this space spectacular. He was a highly intelligent, handsome test pilot from one of Russia's elite units. Politically, Gagarin was made to order. He was born in the Russian hinterland, grew up in a log cabin, and was the son of a poor artisan. The success of his magnificent flight on April 12, 1961, seemed once again to validate the inherent strength of the Soviet system.

The Russian space program soon scored another propaganda victory on June 16, 1963, by launching the first woman into space, and like Gagarin, she fit the Marxist model perfectly. Valentina Tereshkova was a simple factory worker whose lack of scientific training and expertise would be emphasized to show once again the power of Soviet science. Soviet propaganda would describe how the innate strength of the socialist model based upon the power of technology would one day create a utopian society.

When intelligence reached the Soviet Union that the United States was planning to launch two astronauts into space, Khrushchev reacted by pressuring Sergei Korolev to strike first by launching a capsule containing three men. The Russian space program had already started to develop plans for a vessel that could carry more than one cosmonaut. Initially the program was designated Soyuz, but in 1961 it was only in the earliest stages of development. To meet the deadline set by Khrushchev, the Russians had to modify the Vostok capsule at great risk to the three cosmonauts. All but essential equipment was removed, and they had to fly without the protection of their outer spacesuits as well, in order for three men to fit inside what was supposed to be a one-person vehicle. On October 12, 1964, Voskhod 1 was launched and placed into orbit. It returned the three cosmonauts safely to earth in what was perceived to be the next example of Soviet dominance of outer space. On March 18, 1965, the crew of Voskhod 2 again impressed the world when Aleksei Leonov made the first space walk, remaining outside his capsule for twelve minutes while orbiting 128 miles above the surface of Earth.

The Soviet Moon Program

Sergei Korolev had developed a plan to land cosmonauts on the lunar surface that consisted of three major stages. The Vostok and Soyuz programs were to provide the Soviets with the necessary experience and information concerning both the effect of spaceflight on human beings and the skills needed to successfully complete a sophisticated lunar mission. This would be followed by a program designated Luna, which would consist of a series of reconnaissance missions to familiarize the cosmonauts with the surface of the moon. Finally, the N-Program would be the Russian equivalent of the American Apollo Program, which would transport three cosmonauts to the moon.

Two important events occurred in the mid-1960's that would forever change the direction of the Soviet lunar program. On January 14, 1966, Sergei Korolev died of complications resulting from his years as a prisoner in Stalin's gulag. Korolev's great intelligence, formidable power, and universal respect among Russia's scientific elite had enabled him to push his fellow space scientists to achieve at levels unmatched by any other members of the space establishment. The problems that resulted from his death were compounded by the political demise of Nikita Khrushchev. In pursuit of his new socialist order, Khrushchev had alienated too many powerful interest groups, especially the Soviet military. When widespread agricultural and industrial failure was combined with the military and political embarrassment of the Cuban Missile Crisis, Khrushchev was removed from office.

Khrushchev was replaced by Leonid Brezhnev, a Stalinist hardliner whose political philosophy was far more practical than that of Khrushchev. He inherited a very inefficient economy that already had to balance the military expenditures of the world's largest army with the growing consumer expectations of Soviet society. Brezhnev's strategic view differed significantly from that of Khrushchev. He believed that if the Soviet Union continued an extensive military buildup, the United States by the early 1980's would find it necessary to begin to accommodate to Russian international demands.

The Soviet Space Program in Decline

On September 12, 1970, after the success of the Apollo Program, the Russians attempted to salvage some international respect by landing an uncrewed vehicle on the lunar surface. Luna 16 extracted soil samples to be studied back on Earth. A second moon mission on November 17, 1970, saw a Soviet Lunokhod lunar rover explore the surface of the Moon. However, these two missions actually reflected the underlying weakness of the Russian space program.

In the 1980's, the United States established its clear supremacy in outer space. The year 1981 saw the successful flight of the space shuttle that displayed a level of space technology decades beyond the capabilities of the Soviet Union. The Soviet Union attempted to maintain some respectability by concentrating its resources on an extensive space station program. Instead of competing against the United States in the arena of space travel, the Soviets decided to focus on creating a permanent working environment that would provide space-based laboratories for scientific research.

Soviet premier Mikhail Gorbachev attempted to institute a series of reforms that would revitalize the Soviet economy and provide an economic foundation for the development of a new generation of technology that would allow the Soviet Union to once again compete in space with the United States. Instead of reinforcing the communist system, *glasnost* and *perestroika* set in motion a chain of events that brought down the Soviet Union. Initially there was great optimism about a future democratic Russia operating within a structure where both material goods and ideas flowed freely. Unfortunately, this dream was not realized, and Russia fell into economic and political chaos. In 1996, the new Russia ranked eighteenth out of the top twenty nations in expenditures on space technology. By the turn of the century, a series of disasters ravaged the space station Mir and in the end turned the broken spacecraft into a metaphor for the collapse of the Russian space program.

Richard D. Fitzgerald

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See also: Astronauts and cosmonauts; Crewed spaceflight; Yuri Gagarin; Spaceflight; Sputnik; Valentina Tereshkova; Konstantin Tsiolkovsky; Uncrewed spaceflight

Burt Rutan

Date: Born on June 17, 1943, in Portland, Oregon

Definition: The best known, most creative, most prolific, and most influential late twentieth century aircraft designer.

Significance: Rutan revolutionized aircraft design with his tail-first, canard airplanes and his all-composite homebuilt and commercial aircraft. His best-known design, the *Voyager,* was the first aircraft to fly around the world without refueling, in December, 1986. Mostly through his Scaled Composites firm, he has designed forty new types of aircraft as well as a catamaran, a space-load launcher, a gondola, and a car body. His futuristic-looking prototypes have been used in a number of Hollywood motion pictures.

Born into an airplane-involved family, Elbert Leander "Burt" Rutan began to design and build award-winning model airplanes while still a teenager. He made his first solo flight at sixteen years of age, and his ability to look at aircraft design from a pilot's viewpoint has been an important factor in the success of his many airplane designs.

In 1965, Rutan received a bachelor of science degree in aeronautical engineering from California Polytechnic University, where his thesis won a national award from the American Institute of Aeronautics and Astronautics. After graduating from college, he took a job as a civilian flight test project engineer at the Air Force Flight Test Center at Edwards Air Force Base, California, and began working on his first homebuilt, the VariViggen, inspired by the canard XB-70 bomber and the canard Saab Viggen fighter.

In 1972, Rutan left the Air Force to work in development and flight testing for a homebuilt kit manufacturer. Two years later, in June, 1974, he established the Rutan Aircraft Factory to develop and sell homebuilt aircraft plans. Rutan's second homebuilt design, the VariEze, introduced in 1975, was a very efficient canard homebuilt that revolutionized homebuilding. The VariEze's moldless composite construction of fiberglass-covered foam did not require specialized skills or tools to build and produced smooth, sculpted surfaces. The longer-range follow-up, the Long-EZ, set many distance records, including for around-the-world flights, and remains one of the most popular homebuilt aircraft. A powered glider, the Solitaire, and a push-pull, twin-engine canard, the Defiant, were his last designs for homebuilders.

In April, 1982, Rutan founded the Scaled Composites firm to develop research prototypes for government and industry. Scaled Composites firm has produced such well-publicized aircraft as the *Voyager,* the Pond Racer, the AD-1 skew-wing aircraft for NASA, the Beechcraft Starship prototype, the Advanced Technology Tactical Transport, the Triumph business jet, the Ares close air support airplane, the *Proteus* high-altitude aircraft, and the Boomerang. The firm is competing in the first private race to space: a race to develop a practical, reasonably inexpensive, reusable flight vehicle for short flights out of the atmosphere for future space tourists.

Over the course of his career, Rutan has received many awards, including Outstanding Design Awards from the Experimental Aircraft Association, the Presidential Citizen's Medal, the Collier Trophy, the Chrysler Award for Innovation in Design, and the British Gold Medal for Aeronautics. In 1995, he was inducted into the National Aviation Hall of Fame.

W. N. Hubin

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See also: Airplanes; Experimental aircraft; Military flight; Model airplanes; National Aeronautics and Space Administration; Test pilots

S

Safety issues

Definition: Aspects of the airline industry that affect the number of accidents and incidents, as well as the continuing effort to reduce this number as much as possible.

Significance: Because millions of people travel every year for both business and pleasure, safe air travel is vital to passengers, businesses, and economies of the world.

Statistics

The aviation industry has a remarkable safety record. The total number of fatalities on board commercial jets in the years from 1959 to 1999 is less than one-half the annual U.S. automobile fatality rate. However, because so many people can be affected by one incident, aviation accidents make headline news. Although the airlines' safety record is impressive, continuous efforts by the aviation industry, the federal government, and the airlines are aimed at reducing the accident rate to zero.

Statistics from the Boeing Company show that the ten-year commercial jet airplane accident rate from 1990 to 1999 was less than one accident per one million departures of scheduled air carriers. Even this statistic does not tell the whole story, however, because fatal injuries were not present in all of those aircraft accidents. Although accidents are very rare occurrences, reducing the accident rate remains important. If the number of departures doubled from ten million to twenty million annually and the rate of accidents remained the same, there would be an increase in the number of aircraft accidents.

Many organizations, both public and private, are actively involved in research to prevent safety problems before accidents occur. The National Aeronautics and Space Administration (NASA) is very involved in funding basic research into new technologies and cockpit displays to prevent accidents both on the ground and in flight. The NASA Aviation Safety Program is a partnership with the Federal Aviation Administration (FAA), the Department of Defense (DOD), aircraft manufacturers, airlines, and universities. Their collective efforts have contributed significantly to the reduction of the number of aircraft accidents.

Human Factors

Research reveals that more than 70 percent of all airline accidents can be attributed to human error, including that of pilots, air traffic control personnel, airport employees, and others. Government and industry officials have been implicated in some accidents because of delays in implementing certain safety warning devices. However, flight crews are ascribed with the majority of the errors that result in accidents. Aviation researchers are actively involved in determining how best to relieve this problem.

The discipline of human factors in aircraft operations has become focused not only on the causes of accidents but also on the best ways to incorporate lessons learned from them into the aviation system. Rarely does a single event result in an aircraft accident. Research has shown that most accidents can be blamed on a series of uncorrected errors, intervention at any point in which would likely have disrupted the pattern and prevented the accident. Although aircraft operations attempt to make corrections based on lessons learned, the implementation of such procedures remains a complex issue involving many personalities, agencies, airlines, manufacturers, and governments.

Human Performance

Accidents are rarely caused by a deliberate disregard of procedures. They are more generally caused by a series of uncorrected mistakes or by the development of a situation in which people become overwhelmed or find their capabilities are inadequate for the situation. Human performance in an accident or serious incident should be measured in terms of what could normally be anticipated and under what circumstances could a reasonable degree of correct performance have been expected from the persons involved.

Many aspects of human performance must be considered when evaluating crew behavior. Work experience, working conditions, skill, fatigue, low blood sugar, reduced oxygen, and use of medicines, drugs or alcohol can all affect a person's capabilities. Environmental conditions, such as noise, vibrations, motion, and visual cues may also affect a person's ability to perform. The least measurable aspect of one's capability is one's psychological state. At any given time, one's emotion, awareness, memory, attention, complacency, boredom, judgment, perceptions, and attitude are all significant contributors to an individual's psychological capability. The level and quality of interaction with others associated with the flight will affect the tenor of the entire experience.

Crew Resource Management

Research into an aircraft accident reveals the specifics of the event and most often assigns the blame to the flight crew. Nevertheless, the question of why qualified, demonstratively competent, highly trained, medically fit, well-paid professionals failed to perform the job correctly, resulting in an accident, continues to demand an answer. In 1983, the National Transportation Safety Board (NTSB) established its Human Performance Division to place an emphasis on answering that question.

Investigations into crew behavior and organizational cultures reveal that the personalities of the individuals involved have a direct bearing on the flight crew's general attitude. In the early days of commercial flight, the captain was considered the indisputable boss, and the other crewmembers were required to follow the captain's orders. Although this hierarchical approach was the norm and expected, especially because most of the airline pilots at the time had been retired from the military, post-accident analysis revealed that if a subordinate crewmember had been more assertive, the accident chain might have been disrupted.

A new concept of crew interaction was adopted by United Air Lines in the 1980's and became known as crew resource management (CRM). CRM challenged the paradigm of the captain-as-boss and introduced the concept of teamwork for decision making. It was a revolutionary idea at the time, and airlines holding the traditional view of cockpit authority were reticent to embrace this concept.

In 1989, United Air Lines Flight 232, whose pilot was able to land a hopelessly crippled DC-10 and saved the lives of half the passengers, forever changed the perception of CRM training from an interesting concept to an indispensable part of crew training. The crew's remarkable teamwork was identified by the captain as the result of the CRM training that he and his fellow pilots received.

The CRM concept is now the accepted norm and required by federal regulations. Airline management uses CRM training as an opportunity to intervene in a broad class of poorly defined problems. Line-oriented flight training (LOFT) is a curriculum of real-time simulator exercises that introduce situations to flight crews that enable them to practice their CRM skills and receive comments on their performance from the instructor. This broad-scale approach to social communication-based behaviors and attitudes is in marked contrast to the previous norm of a top-down captain-copilot relationship. CRM teaches the value of using all members' experience to solve a problem, even though the captain maintains the legal authority to make final decisions.

The success of CRM training has extended beyond cockpit crews. Airlines have discovered that cabin crews can also play a significant role in enhancing flight safety. Flight attendants, when included in preflight briefings by the captain, feel that their role in the safety of the flight is recognized. This inclusion contributes to the healthy tone of the flight and increases the likelihood that cabin crews would intervene in instances where communication between the cabin and cockpit was necessary.

Training

Training is the single best method of ensuring airline safety. Airlines spend millions of dollars each year to evaluate pilot performance and to teach corrective actions and procedures based on current research.

Training instructs pilots how to perform their tasks. Procedures are designed to dictate the manner in which tasks are implemented by the flight crew, ground crew, and others with direct input to the flight. Training programs, standardization of procedures, quality control, and printed materials such as manuals and checklists are used by all airlines for the safe operation of flight. The prevention and elimination of human error through successful training programs is a vital safety step.

Checklists

The purpose of checklists has been to alleviate the burden of pilots from trying to remember all the steps necessary to configure the aircraft for various flight regimes. The use of standardized checklists began about the time of the U.S. Airmail Service and evolved to a complex written list of actions to be performed, a system which has not changed in concept from those early days despite the modern computerized checklists.

The checklist is a critical tool for ensuring safe and consistent flight operations. Consistent, accurate use of the checklist is a safeguard to ensure that the aircraft is properly configured, operations are completed sequentially and efficiently, and the aircraft is prepared for flight.

The FAA's Federal Aviation Regulations (FARs) require the checklist to include a starting engines check, a takeoff check, a cruise configuration check, an approach check, an after-landing check, and a shutdown check. The FARs also require a checklist for the emergency operations of fuel, hydraulic, electrical, and mechanical systems and instruments and controls, as well as engine inoperative procedures and any other emergency procedures necessary for a safe flight.

Significant research has been conducted in the area of checklist design and usage. The determination of which items should be included, their sequence, redundancy, action and verification, and by whom the checking should be done, is complex. Checklist presentation—on paper, electronically, or mechanically—will vary among airlines and aircraft types.

Role of Technology

Since the 1950's, continuing improvements in aircraft and engine design have significantly reduced the number of accidents based on these factors. High-bypass engine reliability, aircraft design, warning devices, and automation have all had a significant effect on reducing the airline accident rate.

Several major improvements in aircraft systems and technology contribute to the safety record of the industry. These include ground proximity warning devices, traffic alert and collision avoidance systems (TCAS), and new cockpit computers and displays that provide updated weather and flight status information directly to the cockpit.

Ground Proximity Warning System

The introduction of the ground proximity warning system (GPWS) has significantly reduced the number of accidents involving controlled flight into terrain since its introduction in the 1970's. Controlled flight into terrain occurs when an airworthy aircraft, under the control of the flight crew, is flown unintentionally into terrain, obstacles, or water, usually with no prior awareness by the crew. Because controlled flight into terrain accidents represent the leading cause of aircraft hull losses annually, this safety device is particularly relevant. The GPWS system uses radar altimeter and aircraft configuration information to alert the flight crew of impending terrain. An advanced design, enhanced GPWS (E-GPWS) takes advantage of satellite Global Positioning System (GPS) technology and cockpit computer technology in third-generation aircraft to combine traditional GPWS with terrain mapping and GPS location information. E-GPWS is expected to reduce or eliminate the number of controlled flight into terrain accidents attributable to the flight crew's loss of situational awareness.

Traffic Alert and Collision Avoidance Systems

In the decades following World War II, the steady increase in the number of flights by airlines and general aviation aircraft increased the likelihood of midair collisions, especially in the congested airspace over cities. In 1978, a Pacific Southwest Airlines Boeing 727 collided with a single-engine Cessna 172 over a populated area of San Diego, California, resulting in many deaths. In 1986, an Aeromexico DC-9 collided with a single-engine Cherokee over Cerritos, California. The aftermath of this accident and the memory of the 1978 midair accident motivated the FAA and the airlines to develop a technology to augment vision and assist pilots in detecting and avoiding other aircraft. This research led to the development and implementation of traffic alert and collision avoidance systems (TCAS). This system displays other transponder-equipped aircraft within a specified radius. TCAS II, implemented a few years later, gives pilots resolution advisories (RA) either to descend or to climb in order to avoid a collision. Since 1993, TCAS II has been required on all passenger aircraft with more than thirty seats. Commuter aircraft with from ten to thirty seats are required to be equipped with TCAS I.

Pilots widely and readily accept TCAS, finding it an indispensable cockpit tool. TCAS enhances pilots' situational awareness and assists the visual location of aircraft advisories issued by air traffic control.

Weather

Because weather is such an integral part of aviation, improvements in severe weather information, prediction, and depiction have a significant relevance to improving the safety and comfort of flight. Thunderstorms, although easy to detect, have associated hazards, such as lightning, turbulence, heavy precipitation, icing, wind shear, and microbursts, that are more difficult to see and predict. These hazards are most dangerous when the aircraft is low to the ground, as in takeoff and landing. On-board weather detection systems enable pilots to see the thunderstorm and avoid its associated hazards.

Turbulence

Aircraft encounters with turbulence result in upsets and injuries every year. Turbulence accounted for 103 injuries on board commercial aircraft in the period from 1990 to 1999. Although turbulence is not uncommon in flight, the severity of turbulence ranges from uncomfortable to fatal. Types of turbulence include convective turbulence, mountain range turbulence, and clear-air turbulence.

Convective turbulence occurs in localized, vertical air movements. The most hazardous types are usually associated with thunderstorms. Mountain range turbulence, as the name implies, occurs when wind blows across rugged hills or mountains, creating updraft on the windward side and strong downdrafts on the lee side. Lenticular clouds that form on the lee side of a mountain range and cumulus-looking rotor clouds that form parallel to the ridge line of a mountain are indicators of strong winds and occasionally severe downdrafts and associated turbulence.

Clear-air turbulence is rough, bumpy air that sometimes buffets an airplane in a cloudless sky. It is usually found above altitudes of 15,000 feet and is often located near the jet stream winds. It is associated with a drastic change in wind direction, speed, air temperature, and horizontal or vertical wind shear. Research into the detection and avoidance of clear-air turbulence is important to reduce the injuries and fatalities on board aircraft.

Microburst and Wind Shear

Microburst and wind shear are atmospheric phenomena that have been implicated in several major airline accidents. Investigations into these crashes and computer simulations of the events have led to specific training procedures for pilots to escape from these extremely hazardous winds.

Low-level wind shear alerting system (LLWSAS) is a system of anemometers implemented in select airports to give air traffic tower controllers information on wind direction and speed at different locations on the airport. If the wind direction and velocity exceed a predetermined parameter, an alarm will sound in the tower. Timely dissemination of the wind directions and velocities to the pilots help them prepare for or avoid encounter with a wind shear.

Runway Incursions

Crowded skies inevitably lead to crowded airports. Increased congestion at major airports has consequences on the ground as well as in the airspace above. Although it is a rare occurrence, the ground collision of aircraft accounts for the worst aviation disaster in history: that which occurred between two fully loaded Boeing 747 jumbojets in Tenerife, Canary Islands, in 1977. From 1995 to 2000 there was a 60 percent increase in near-collisions on the ground, according to the NTSB.

The FAA places a high priority on the reduction of the number of runway incursions. New methods for pilots to determine their exact location on the airport in low-visibility or night situations are being researched. Improved airport markings, assessing new technologies, strategic plans for foreign air carrier pilot awareness, training, and review of pilot/controller communications phraseology are among the issues being explored to mitigate this safety problem.

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See also: Accident investigation; Air carriers; Air traffic control; Airline industry, U.S.; Avionics; Cockpit; Communication; Federal Aviation Administration; Flight attendants; Instrumentation; Landing procedures; National Aeronautics and Space Administration; National Transportation Safety Board; Pilots and copilots; Runway collisions; Runways; Takeoff procedures; Taxiing procedures; Training and education; Weather conditions; Wind shear

Antoine de Saint-Exupéry

Date: Born on June 29, 1900 in Lyons, France; died on July 31, 1944, near Corsica

Definition: The literary voice of early aviation and an inspiration for many would-be fliers.

Significance: Saint-Exupéry, through his writing, reflected the romance and mystery of aviation and promoted flying among his early twentieth century readers.

Image Not Available

Antoine de Saint-Exupéry was the eldest son of a provincial, aristocratic family. His father's early death in 1904 made the family dependent on relatives. This background shaped Saint-Exupéry's character to an enormous extent. The commanding French lead in early aviation during his formative years was the primary external influence on his life.

At age twelve, Saint-Exupéry experienced his first airplane flight and began taking flying lessons in 1921. By 1922, he had become a second lieutenant and pilot in the French army reserves. In 1926, he began flying airmail from France to Spain, before the airmail service rapidly expanded into Africa and South America. Becoming an industry legend, Saint-Exupéry was soon in charge of operations, first in Morocco and then in Argentina.

The Great Depression of the 1930's and events in France caused the collapse of the airmail business in 1932. To support himself financially, Saint-Exupéry turned increasingly to writing, flying only sporadically. He worked briefly as an industrial test pilot and then made an abortive attempt to set a record by flying to Saigon. He crashed in the Libyan desert and walked for four days before encountering a camel caravan. French newspapers made much of the story and its hero. A later goodwill tour of the Americas likewise ended in a crash, this time in Guatemala.

Saint-Exupéry was in the United States when France fell to the Nazis, but he returned to his army reserve position and began flying reconnaissance. His unit was demobilized after Dunkirk (1940), and Saint-Exupéry spent the next three years in New York. When the unit was remobilized in Africa, he was reassigned to it, this time flying the new Lockheed P-38 Lightnings in reconnaissance. With the successes of the Allied landings at Normandy on D day, June 6, 1944, operations moved to Corsica, and it was from Corsica that Saint-Exupéry made his last flight. The Cape Corse radar tracked him into southern France but never spotted his return. Nothing more is known of his death.

Saint-Exupéry was much more than a pilot. He held several patents for aviation improvements, but his writings are remembered as his main achievements. His first book, *Courrier sud* (1929; *Southern Mail*, 1933) was published just before he went to Argentina. It was followed by *Vol de nuit* (1931; *Night Flight*, 1932) and *Terre des hommes* (1939; *Wind, Sand, and Stars*, 1939). These two books won major prizes and a reputation for their author as a major literary talent. *Pilote de guerre* (1942; *Flight to Arras*, 1942) and *Le petite prince* (1943; *The Little Prince*, 1943), probably his best-known work, followed. All but the last drew heavily on tales from his life as a pilot. *Vol de nuit* proved to be a major factor in recruitment for the French air force early in the war.

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See also: Airmail delivery; Airplanes; Military flight; Pilots and copilots; World War II

Alberto Santos-Dumont

Date: Born on July 20, 1873, in Palmira, Brazil; died on July 24, 1932, in Guarujá, Brazil

Definition: The designer and pilot of the first truly dirigible balloon and the first airplane in Europe.

Significance: A flamboyant early twentieth century advocate of lighter-than-air flight, Santos-Dumont built and flew airships in Paris before mastering heavier-than-air flight and becoming the first European builder of airplanes.

Alberto Santos-Dumont was born in an outlying district in Brazil in 1873, the seventh and last child of a civil engineer and his wife, who soon afterward became the nation's most wealthy coffee plantation owners. The death of his father in 1892 left Santos-Dumont financially secure, allowing him to pursue an eclectic scientific and technical education in Paris while indulging his passion for automobiles. After reading a book about a famous aerial expedition to the North Pole that had ended in tragedy, the mechanically gifted young man turned his attention to ballooning. Seeking out the book's authors, two Parisian balloon manufacturers, he persuaded them to build a small vehicle to his specifications, and he rapidly became expert in handling free spherical balloons. By 1898, however, he was experimenting with powered lighter-than-air craft, building, testing, and often crashing successively more sophisticated models that were designed to be far more maneuverable than Henri Giffard's steam-powered dirigible of almost a half-century earlier. For nearly fifty years, advances in dirigible technology had been nonexistent. Santos-Dumont became single-minded in his desire to overcome all obstacles, using his financial resources, assembling a talented group of mechanics, and taking upon himself all the physical risks involved with testing his concepts.

Winning the Deutsch Prize

In April, 1900, the financier Henri Deutsch de la Meurthe announced a prize of 100,000 francs to go to the first person who could navigate an aerial trip from the Parc d'Aérostation of the Aéro Club de France in St. Cloud, near Paris around the Eiffel Tower and back to the Parc d'Aérostation in less than thirty minutes without landing, a feat which would require an average speed of 14 miles per hour. Santos-Dumont alone was in a position to accept the challenge. On July 13, 1901, his airship number 5 flew the circuit in forty minutes before sinking into a tree. Two weeks later, the repaired vehicle met a similar fate in an encounter with a hotel facade. On October 19, 1901, a new airship, 33 meters in length and equipped with a 20-horsepower engine, completed the task in a few seconds over the stipulated time, but was fast enough to garner the prize.

Santos-Dumont was already a familiar, if solitary, figure in Paris, a fastidious dresser whose somber visage, slight frame and nerves of steel augmented his status as premier conqueror of the air. His mastery of powered ballooning had gained him international fame, and during a visit to the United States in 1902, he was sought out by Thomas Edison and Samuel P. Langley.

The Airplane Builder

Over the next few years, Santos-Dumont continued to design new airships, building his own station for them at Neuilly St. James. In 1904, however, he became interested in heavier-than-air flight. The following year, he teamed up with Gabriel Voisin to build an ungainly looking "canard-type" airplane, with a rectangular, fabric-covered fuselage and tail unit forward of the main wing with its propeller in the rear. Its wings, which resembled large box kites, were attached at a pronounced dihedral angle, providing lateral stability. A 50-horsepower engine propelled the craft through the air. Attached to the leading end of the fuselage was a small boxlike device that pivoted both vertically and horizontally, the sole means of control during flight. The pilot stood in a wicker basket directly in front of the engine. On October 23, 1906, the craft flew for a distance of some 60 meters, the first successful European airplane flight. On November 12 of the same year, it flew 220 meters, managing to stay aloft for more than 20 seconds.

To a Europe that knew nothing of Orville and Wilbur Wright's triumph at Kitty Hawk three years earlier, Santos-Dumont's new accomplishment was heralded as another technological first, rivaling his previous feat in controlled aerial navigation in 1901. Soon, former associates such as Henri Farman and Louis Blériot were breaking Santos-Dumont's records, but only Wilbur Wright's flying exhibitions in a biplane during a 1908 visit to France finally disabused objective observers of Santos-Dumont's claim to the first flight. Yet the Brazilian aeronaut continued to contribute to the airplane's evolution: His lightweight *Demoiselle* (dragonfly), first tested in 1909, could attain a speed of 70 miles per hour and was easy to control.

In 1910, Santos-Dumont suddenly gave up designing and flying and sold his entire fleet of vehicles. In March of that year, he was diagnosed with multiple sclerosis, and its inevitable sentence of gradual physical debilitation often tempted him to despair. His dark moods were further exacerbated during World War I by a sense of responsibility for the deaths caused by aerial warfare. He lectured on three continents about the use of aircraft in peace and war, often sounding a distinctly pacifist note.

The last two decades of Santos-Dumont's life offer few milestones beyond the occasional honors bestowed on him—particularly by the country of Brazil, which idolized him as its most famous citizen—for his pioneering work and a chronicle of rootless travel between Europe and South America. His efforts at invention, notably with proposed ornithopters, were only parodies of his former audacious triumphs, and he gradually receded from public view. Even a planned festive trip to Brazil in 1928 ended in disaster when a seaplane sent out to greet his arriving ocean liner plunged into the sea in front of his eyes, killing all passengers, among whom were many of the nation's leading intellectuals.

In 1931, Santos-Dumont returned permanently to Brazil, but the country's descent into civil war hastened his physical and mental decline. On July 23, 1932, after witnessing an aerial bombing raid carried out by government forces against fellow Brazilians, he took his own life.

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See also: Airplanes; Balloons; Buoyant aircraft; Dirigibles; Heavier-than-air craft; History of human flight; Kites; Lighter-than-air craft

SAS

Also known as: Scandinavian Airlines System

Date: Founded as a consortium in 1946

Definition: SAS, a major international airline, was formed by three national Scandinavian air carriers.

Significance: SAS is a unique major airline in that it is a consortium of three airlines under one brand. SAS has a global route network and a good reputation for safety, technical standards, and service.

History and Organization

Scandinavian Airlines System (SAS) is a major international airline. Its headquarters are in Stockholm, Sweden. Three national Scandinavian air carriers, through a consortium agreement, established the airline. The carriers were Det Danske Luftfartselskab (DDL), the Danish airline; Det Norske Luftfartselskab (DNL), the Norwegian air carrier; and AB Aerotransport (ABA), the Swedish airline. On September 17, 1946, *Dan Viking*, the first DC-4 painted in SAS's colors, made its premier flight from Stockholm's Bromma airport to New York via Copenhagen, Prestwick, and Gander. The flight took twenty-seven hours. By November 30, SAS had inaugurated its second route, to Rio de Janeiro and Montevideo.

In 1947, SILA (from Sweden), DDL, and DNL operated to North and South America under SAS's colors. DDL, DNL, and ABA operated their own domestic and European services and all three had plans to open routes to the Middle East, Asia, and Africa. The three airlines had difficulties in developing their traffic, hampered by heavy restrictions on travel and how much currency people were allowed to bring with them. The three carriers often offered parallel services, and passengers were few.

In 1948, on the initiative of the Swedish government, privately owned SILA and state-owned ABA were merged on a fifty-fifty ownership basis and named ABA. An agreement was made with DDL and DNL to coordinate European traffic. The cooperation agreement was called ESAS (European SAS) and Copenhagen was made the operational center. All aircraft used by ESAS were painted in SAS colors, and offices abroad were merged. ESAS did not provide the economies of scale that had been anticipated and the three companies struggled with major financial problems.

In September, 1949, the Norwegian Department of Transport urged DNL to withdraw from ESAS. Instead of a complete collapse of the cooperation, a new SAS Consortium comprising the total traffic of the three companies was established. On February 8, 1951, ABA, DDL, and DNL ceased to exist as independently operating airlines. Their share of the new consortium remained three-sevenths, two-sevenths, and two-sevenths, respectively. Ownership of each of the three companies was distributed fifty-fifty among government and private interests.

Corporate Activities

SAS as of 2001 operated scheduled passenger, freight, and mail flights between nearly one hundred cities in about fifty countries. The company also offered tour and catering services, and operated hotels in Scandinavia, Greenland, and the rest of the world under the SAS Radisson brand. Since 1990, SAS has owned and operated its own flight academy as a subsidiary company. The SAS Flight Academy is headquartered at Arlanda Airport in Stockholm and is responsible for training pilots, cabin attendants, and mechanics for SAS and other airlines. SAS Media, founded in 1972, is also a subsidiary of SAS. The company has offices in Stockholm and Oslo employing forty-one people, with an annual turnover in 2001 of $10 million.

The airline operates a fleet of several types of aircraft, most of them made in the United States. In addition to the Boeing B-767-300 ER, which is used for its long-haul flights, SAS operates for its short- and medium-haul flights the Boeing B-737-600, 700, and 800 series, the McDonnell Douglas (Boeing) MD90-30, the McDonnell Douglas (Boeing) MD-81-82 and -83, the McDonnell Douglas MD-87, the McDonnell Douglas DC-9, the Dutch-made Fokker F-50 and F-28, the Swedish-made SAAB 2000, and the Canadian De Havilland Q-400.

The SAS route system is built around nonstop flights to and from the Scandinavian capitals and offers its customers a global traffic system. This is a hub-and-spoke network, which attempts to provide customers with convenient and efficient travel connections between continents, countries, and towns.

A notable first in flight operations for SAS took place on February 24, 1957, when a SAS DC-7C took off from Copenhagen to Anchorage and Tokyo. Simultaneously, another SAS DC-7C departed from Tokyo. At 9:10 P.M. the two aircraft met over the North Pole. By tying together the southern route and the polar route, SAS was the first airline to fly over the pole and around the world.

Events in SAS History

1946: SAS, a consortium of three Scandinavian airlines, AB Aerotransport (ABA), Det Danske Luftfartselskab (DDL), and Det Norske Luftfartselskab (DNL), is formed for the purpose of joint transatlantic service.

1947: Daily flights are scheduled between Stockholm, Sweden, and New York City.

1952: SAS introduces tourist class fares costing 25 percent less than previous standard fares.

1957: With the inauguration of SAS's pioneering Copenhagen-Anchorage-Tokyo polar route, flying time to Japan is reduced from fifty-two to thirty-two hours.

1965: SAS introduces its SASCO electronic airline reservations system.

1971: The airline takes delivery of its first Boeing 747.

1979: SAS inaugurates business-class service on its transatlantic flights.

1980: SAS takes delivery of its first Airbus A300.

1988: SAS establishes a cooperative agreement with Continental Airlines.

1991: With delivery of its fiftieth MD-80 aircraft, SAS becomes the world's largest MD-operating airline carrier outside the United States.

1996: SAS forms an alliance with Lufthansa.

1997: SAS joins the Star Alliance with Lufthansa, United Air Lines, Air Canada, and Thai Airways. All SAS flights are made nonsmoking flights.

1999: SAS presents a new corporate image, with redecorated aircraft and redesigned uniforms.

Alliances

In an attempt to solve some of the problems connected with SAS's geographic position in the far north, in an area with a relatively sparse population, SAS entered into agreements with a number of airlines having strategically better locations as early as the 1950's. Among those were Austrian Airlines, Thai Airways International, and Gamsa of Mexico. In order to keep down the costs for training, maintenance, and equipment for their newly acquired Boeing B-747's, SAS entered into the KSS (for the initial letters of each partner) agreement with Swissair and KLM in 1971.

In May, 1995, a strategic alliance with Lufthansa was signed, and implemented on February 1, 1996. This agreement was the impetus for Scandinavian Airlines System to found, along with Lufthansa, Air Canada, Thai Airways International, and United Air Lines, the Star Alliance in 1997. In subsequent years, membership grew to include Air New Zealand, ANA (Japan), Ansett Australia, Austrian Airlines, British Midland, Lauda Air (Austria), Mexicana Airlines, Singapore Airlines, Tyrolean Airways (Austria), and Varig Brazil. The Star Alliance grew significantly and by mid 2001 it encompassed fifteen airlines and a network of 130 countries and 815 destinations, making it the world's largest alliance.

In addition to its Star partners, SAS has cooperated with several other airlines. The cooperation encompasses, among other things, code-share flights and the participation in each other's frequent flier programs. In the Scandinavian market, SAS offers a comprehensive network together with its regional partners Cimber Air, Widerøe, Skyways, Air Botnia, and Maersk. SAS is also regional partners with Estonian Air in the Baltic and Spanair in Spain. All in all, SAS can offer more than eight thousand departures daily to over 815 destinations in 130 countries. SAS has proven that through cooperation, three relatively small nations are able to create an airline of international magnitude.

Triantafyllos G. Flouris

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See also: Air Canada; Air carriers; Fokker aircraft; Lufthansa; MD plane family; Singapore Airlines

Satellites

Definition: Objects gravitationally bound to and orbiting about larger bodies.

Significance: Artificial satellites permanently stationed in space perform many important economic, military, and scientific missions. Uncrewed artificial satellites are the chief instrument of space exploration and provide the only means of obtaining permanent utilization of space.

Virtually all objects in space are satellites of one body or another. Satellites range in size from galaxies such as the Large and Small Magellanic clouds in orbit about the Milky Way to microscopic flakes of paint in low-Earth orbit that have eroded from artificial spacecraft. In practice, the word satellite is reserved for uncrewed spacecraft in Earth orbit. Crewed spacecraft are usually referred to individually by name, such as the International Space Station. Nonfunctional objects of artificial origin are regarded as orbital debris. Natural satellites of stars are more properly referred to as planets, while natural satellites of planets are more properly referred to as moons.

Satellites travel on elliptical trajectories called orbits, which are freely falling paths determined by the local gravitational field. Although satellites are indeed falling, they are also traveling sideways at extremely high speeds, on the order of 7 kilometers per second (5 miles per second) at 200 kilometers altitude (130 miles). The combination of free fall and high lateral velocity creates a closed trajectory that carries the satellite around Earth repeatedly.

The point on the orbit nearest to the earth is called the perigee; it is also the point at which the satellite has the greatest velocity. The point farthest away is called the apogee. That is also where the satellite velocity is least. If space were a perfect vacuum, satellites would orbit forever, but the atmosphere has no distinct end, and gradually fades away with altitude. Satellites orbiting at altitudes from 200 to 600 kilometers (130 to 400 miles) encounter enough residual atmosphere to create significant aerodynamic drag. Over the months, these low-Earth-orbit satellites lose energy and decrease in apogee until the apogee equals the perigee and the orbit is a circle. The satellites then drop closer to Earth on a spiral path, accelerating as they do so. Eventually, they enter regions where the atmosphere is too thick for them to continue in orbit. Aerodynamic drag becomes so strong that all of the satellite's energy is converted into heat in a matter of minutes. The air around the satellite becomes hot enough to glow, and exposure to the heat burns up the satellite.

Satellites orbiting below 200 kilometers (130 miles) reenter Earth's atmosphere in a matter of months. Those orbiting above 600 kilometers (400 miles) seldom reenter.

Satellites are classified according to user (commercial, military, or scientific) and according to mission (communications, remote sensing, or experimentation and measurement). Commercial satellites belong to private businesses. Military satellites support military operations. Scientific satellites perform experiments or make measurements in support of scientific research.

A satellite is only one part of a space mission's architecture, an assembly which consists of the satellite, the launch system necessary to place it in orbit, the ground support system necessary to control the satellite and communicate with it, and a data analysis and information management system to exploit the data gathered by the satellite.

The Satellite Design Process

The satellite design process begins with the delineation of the satellite mission. A mission to photograph Earth from space, for example, might be expressed in terms of the goal that all areas of Earth between 45 degrees north latitude and 45 degrees south latitude be photographed with sufficient clarity that objects as small as 10 meters across can be imaged clearly. This requirement immediately eliminates all orbits of less than 45 degrees inclination and makes the orbital altitude of the satellite heavily dependent on camera quality: high-resolution cameras will be able to fulfill the requirement from greater altitudes than low-resolution cameras. In this way, the mission is expressed in the form of a set of requirements for orbital altitude, inclination, life span, launch date, and other needs which the satellite must fit.

A satellite is composed of the payload and the support bus. The payload consists of those components which perform the primary mission of the satellite. Component choice is driven by the best fit of available hardware to mission requirements. The components chosen will in turn determine payload parameters such as mass and volume, and payload demands such as power consumption, data storage and transmission, and attitude control.

The bus contains various systems to support the payload and provide electric power, thermal control, attitude control and propulsion, communications, and structural support. Bus components must be chosen that are capable of filling all of the payload demands as well as supporting the bus itself.

Total mass and volume are determined once payload and bus design are complete. Total mass and volume together with orbit requirements determine the choice of launch vehicle.

No satellite design process is complete without the development of ground sites. Ground sites monitor the status of the satellite and issue commands as necessary to maintain proper function or to correct anomalies in function. Ground sites receive data sent down by the satellite, process the data into a form intelligible to the user, and deliver it. Ground site personnel continually track the satellite, noting inevitable changes in orbit and issuing predictions for future passes within range of the ground site.

Power

The power system provides the electric power needed to operate electrical and electronic components. Solar cells are usually the primary source of power, converting sunlight to electricity. What is not immediately required for satellite operations is stored in rechargeable batteries for later use. The power requirements of the payload and bus together determine the size of power system components. Solar cells must have enough area to collect all the power needed by the satellite plus more to provide a margin of safety. Because solar cells degrade over time in the harsh space environment, they must be built larger than initially required to guarantee that enough capability remains after years of degradation to continue operating the satellite. The number and size of batteries must be sufficient to meet the voltage and current demands of the payload and bus.

Power consumption must be carefully managed on board satellites. Consumption of electricity inevitably generates heat, which cannot easily escape in the vacuum of space and becomes a challenge for the thermal control system. Batteries build up internal pressure when charging and are in danger of bursting and destroying the satellite if overcharged. On the other hand, batteries that discharge too deeply are in danger of dying completely. Also, electronic components that lose power or receive too little voltage (an undervoltage condition) may cease operating or undergo an uncommanded reset when normal conditions return. Power system conditions such as voltage, current, and temperature are monitored at critical locations with the results transmitted to satellite operators on the ground.

Thermal Control

The thermal control system maintains proper temperature throughout the satellite. It removes heat from components in danger of overheating from electric power consumption or exposure to the Sun, and provides heat to components in danger of freezing from exposure to the cold vacuum.

Attitude Control and Propulsion

The attitude control system maintains the satellite in the proper orientation required for the satellite to fulfill its mission. Communications satellites must have antennas permanently pointed toward Earth's surface, for example, while the Hubble Space Telescope must be constantly looking at the object being photographed.

The simplest type of attitude control system is none at all; the satellite is allowed to tumble uncontrollably. This requires the use of antennas that broadcast in all directions at once, so that communication with the ground is never interrupted. This also means that most of the broadcast power is wasted on transmissions into empty space and that only a small fraction of the power reaches the ground. This is acceptable only for the simplest types of low-Earth-orbit satellites.

Oblong satellites can be oriented so that the long axis points toward Earth and couples to tidal gravitational forces to provide gravity gradient stabilization. Once gravity gradient stabilization is achieved, the satellite will permanently present one face toward Earth, where cameras, remote sensing instruments, and communications antennas may be advantageously mounted. Gravity gradient stabilization is usually achieved by building a telescoping boom into the satellite structure, which deploys when the proper orientation is obtained. When extended, the end of the boom closest to Earth feels the strongest gravitational field and is continually pulled downward. That continuous downward pull keeps that end pointed toward Earth.

Active attitude control systems include momentum wheels and control moment gyroscopes. Momentum wheels are spun up in one direction so that the satellite will spin in the opposite direction in reaction. Three momentum wheels mounted in three perpendicular directions provide attitude control about any rotation axis. When the spin axis of a control moment gyroscope is altered, complicated reaction forces are created that may be used to rotate the spacecraft. Both of these systems have the virtue of reorienting the satellite without consuming propellant.

Active attitude control requires the satellite to have some knowledge of its orientation with respect to the outside world. The location of the Sun can be determined through the use of sensors that respond to visible light to indicate which side of the spacecraft is facing the Sun and which is in shade. Earth sensors respond to infrared radiation from the comparatively warm Earth. Star sensors look for the light from very bright stars. Stable platforms controlled by gyroscopes maintain a constant orientation regardless of the rotation of the spacecraft.

Communications

The communications system keeps the satellite in contact with the ground support system and moves data and commands to and from the satellite. The communications system includes transmitters and receivers, data encoders and decoders, data storage and retrieval elements (memory), and antennas. High-gain directional antennas carry the maximum amount of data with the minimum amount of power, but must be accurately pointed toward the reception site. This requires additional equipment to control the pointing of the antenna and maintain communications lock. The antenna may move itself, or the attitude control system may be tasked to reorient the entire satellite.

Orbital speeds of the order of 7 kilometers per second (5 miles per second) create significant shifts in the frequency of radio waves transmitted or received by satellites. Frequency goes up as the satellite approaches a ground site and falls as the satellite recedes, a phenomenon known as the Doppler shift. The ground site must continuously adjust frequency of both transmission and reception so that communication is continuous and no information is lost.

Most satellites are in range of a ground site for only ten minutes or less at a time and only during the infrequent occasions when their orbit takes them over the ground site location. Data collected at other times must be stored on board for relay to the ground during the next pass.

Structure

The structural system holds the parts of the satellite together and protects the components of the satellite from the high accelerations and intense vibrations experienced during launch. Structures range from simple frames to hold the components of the satellite in place to complicated mechanical systems folded and stowed during launch that must unfold and extend instruments upon deployment. The structure must not respond resonantly to vibrations generated by the launch vehicle or the satellite will shake itself to destruction. Special composite materials and honeycomb construction keep structural members lightweight without sacrificing strength.

Satellite Construction and Testing

The high costs of launch and the inability to make repairs on malfunctioning satellites demand high reliability and long operational lifetimes. Both are expensive and difficult to achieve. Altogether, these requirements force satellite designers and builders to make every attempt to make the satellite perfect the first time and every time. Components are extensively tested individually, and each system is tested and retested as new components are added. Complete systems are tested individually, and then tested and retested as they are linked into the final satellite assembly. Finally, the complete satellite is tested and retested under conditions simulating spaceflight as closely as possible.

The quest for perfection begins at the component level. Items for use in satellites must meet rigorous requirements. Materials cannot emit water vapor or volatile organic compounds in a vacuum. They must not chemically break down, degrade, or darken under exposure to ultraviolet light or atomic oxygen. Electronic parts and components must not be susceptible to ionizing radiation. Electrical systems must not be susceptible to the build-up and discharge of static electricity.

The space shuttle deploys a satellite by means of a robotic arm. (NASA)

Complete satellite assemblies must survive a harsh launch environment. Launch vehicle accelerations can produce the equivalent of eight to ten times normal weight in the satellite. Rocket exhaust plumes generate strong vibrations and intense noise that can vibrate poorly constructed assemblies to destruction. Satellites therefore undergo vibration testing on massive shake tables that realistically simulate the launch vibration environment. After vibration testing, the satellite is placed in a vacuum chamber and run through heating and cooling cycles that mimic what the satellite will encounter in space.

All stages of satellite construction are extensively documented. Even after all this testing, satellites fail on orbit. Since a failed satellite cannot be retrieved for study, the only way to analyze what went wrong is to review the documentation and deduce the cause of the failure. A complete and thorough record of the design and construction process is essential.

Tracking Satellites

The U.S. Space Command (USSPACECOM) catalogs and tracks every object in Earth orbit greater than 10 centimeters (4 inches) in length with ground-based radar and electro-optically enhanced telescopes. Continuous space surveillance allows U.S. Space Command to predict when and where a decaying space object will reenter Earth's atmosphere in order to prevent an innocent satellite or inert piece of debris from triggering missile-attack warning sensors of the United States or other countries upon reentry. It also charts the present position and anticipated motion of space objects, detects new manmade objects in space, and determines their country of origin. An extremely important function of space surveillance is to inform the National Aeronautics and Space Administration (NASA) of the identity and path of objects that may endanger the space shuttle.

End-of-Life Operations

Space is becoming crowded. The Soviet Union launched Sputnik 1, the first artificial Earth satellite, in October, 1957. The United States launched its first satellite, Explorer 1, in January, 1958. Both have long since decayed and burned during reentry. The oldest satellite still in orbit is Vanguard 1, launched in March, 1958. As of June 6, 2001, U.S. Space Command reported 2,728 satellites in orbit, while 2,569 other satellites had undergone orbital decay and burned on reentry since 1957.

Satellites still in orbit degrade in the harsh space environment, shedding small particles of debris, such as paint flecks and pieces of thermal blanket. In extreme cases, old satellites are completely destroyed when aging batteries burst or leftover propellant spontaneously explodes. As of June 6, 2001, U.S. Space Command reported 6,150 pieces of debris in orbit that were 10 centimeters or greater in length. Satellites in low-Earth orbit run a significant risk of collision with a piece of orbiting debris. At collision velocities on the order of 10 kilometers per second (about 7 miles per second) even a tiny fleck of paint can do significant damage.

In an effort to slow the rate at which new debris is being created, satellite designers routinely include end-of-life planning in the satellite design process. At end-of-life, batteries are disconnected from solar panels to prevent destructive overcharging, and any unused pressurized liquids or gases are vented into the vacuum. The last few gallons (or pounds) of propellant are consumed in an orbital adjustment burn which either forces low-Earth-orbit satellites to reenter the atmosphere and burn up, or moves higher-altitude satellites to disposal orbits where they do not present a hazard to other spacecraft.

Observing Satellites

Satellites shine by reflected light and are visible to the naked eye for a short time just before sunrise and just after sunset. During these periods, the background sky is dark enough for dim objects to be seen by observers on the ground, but satellites passing overhead are still illuminated by the sun. There are so many satellites in orbit that every morning and evening, several pass over virtually every location on Earth. Satellites of the Iridium group of communications satellites have large, highly polished solar panels that can be extremely bright when the sun is reflected in them. Sightings of so-called Iridium flares are extremely common.

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See also: National Aeronautics and Space Administration; Orbiting; Propulsion; Spaceflight; Sputnik; Uncrewed spaceflight; Vanguard Program

Saturn rockets

Date: First flight (SA-1) on October 27, 1961; last flight (SA-210) on July 15, 1975

Definition: A family of heavy-lift rockets that culminated with the Saturn V Moon rocket used in the Apollo Program.

Significance: The Saturn rockets were the first U.S. rockets truly designed from their inception as space rockets and not as adaptations of existing intercontinental ballistic missiles. The Saturn V rockets were the largest and most powerful rockets ever built.

History

In the late 1950's, adaptations of existing intercontinental ballistic missile (ICBM) technology led to the development of the Atlas and Thor missiles and the Juno and Jupiter rockets. These rockets could be adapted to launch small payloads into Earth orbit, as demonstrated when a Jupiter C rocket developed by rocketry pioneer Wernher von Braun at the U.S. Army Ballistic Missile Agency (ABMA) successfully launched the United States' first Earth-orbiting satellite, Explorer 1, on January 31, 1958.

Even before Explorer 1 was launched, it had become apparent that existing rockets could only orbit fairly small payloads. Development was underway for the Atlas rockets, but von Braun foresaw a need for a launch vehicle designed to lift heavy payloads into space. This new rocket was to be a successor to the Jupiter rocket and was tentatively designated as the Jupiter V, though it was often referred to as the "super Jupiter."

The Jupiter V project was approved in part because the Soviet Union had already developed very large rockets capable of lifting into orbit payloads far larger than those of any U.S. rocket at that time. Soon after ABMA began development of the Jupiter V at its site near Huntsville, Alabama, it became apparent that the new rocket would be of a totally new design and not merely an adaptation of the Jupiter rocket. Von Braun proposed that the name of the new rocket be "Saturn," because that was the next planet from the Sun after Jupiter. The name was agreed to, and so from then on, the Jupiter V rocket under development was called the Saturn I rocket. The Saturn rocket would be able to lift into Earth orbit payloads far greater than those of any other U.S. rocket. Von Braun, however, was planning ahead. He proposed a new rocket, based on existing technology, that would be able to boost a payload to the Moon and back. The tentative name for this proposed new rocket was Nova. The Nova rocket, von Braun reasoned, would need nearly 12,000,000 pounds of thrust. This would require a first stage with more than fifty of the then-most powerful rocket engines.

The Advanced Research Projects Agency (ARPA), associated with ABMA, began test-firing of the engines for the first stage of the Saturn rocket in late 1958. The Saturn project was nearly canceled in June, 1959, when the U.S. Department of Defense decided that it did not really need a heavy-lift vehicle after all. ABMA was told to stop working on both Saturn and Nova. The initial proposed need for the development of the Saturn had been to launch orbiting communications satellites. It was found that such satellites would not be as heavy as had been thought. However, the National Aeronautics and Space Administration (NASA), the civilian space agency created in 1958, was very interested in both the Saturn and Nova rockets. Eventually, a deal was worked out to transfer von Braun, his rocket development team, and most of ABMA to the jurisdiction of NASA. The ABMA site in Huntsville became the Marshall Space Flight Center.

Work began immediately on the first of the Saturn rocket family, the Saturn I. During development of Saturn I, new engine technology was being developed that allowed modifications to the Saturn I. The improved rocket, designated the Saturn IB, was capable of lifting far heavier payloads. The Saturn I was never used except as a technological development stage toward later rockets.

The exact design of the Nova rocket would depend upon the mission characteristics and requirements of a crewed Moon program. In 1962, NASA's Office of Manned Space Flight decided to use a lunar orbit rendezvous mission, in which a small lander, rather than the entire rocket, would descend to the lunar surface and then return to a mother ship orbiting the Moon. This method would require a rocket slightly smaller than von Braun's proposed Nova rocket. It became apparent that the Saturn rocket program could be adapted and significantly enhanced to yield a rocket of specifications nearly like those of Nova. This new rocket, which was ultimately built, was designated the Saturn V rocket.

Saturn I

The Saturn I rocket was designed as a two-stage rocket. The upper stage would use liquid hydrogen as fuel and liquid oxygen as oxidizer. The first stage used kerosene (RP-1) and liquid oxygen. Liquid hydrogen is more energetic as fuel than kerosene but is harder to handle. Furthermore, hydrogen is lighter than kerosene, making it ideal for the upper-stage fuel. Kerosene, however, requires less storage space than does liquid hydrogen. Additionally, the rocket would be more stable with a heavier first stage, so kerosene was deemed the best fuel for first stage use.

The first stage of Saturn I, designated S-I, used eight H-1 engines, developed by the Rocketdyne Division of North American Aviation. Each engine provided 188,000 pounds of thrust. The four inboard engines were fixed in position, and the four outer engines were gimbaled, or suspended, to change direction slightly in order to steer the rocket. A decision was made to use existing Mercury and Jupiter propellant tanks to save development costs. The larger Jupiter tank was used for liquid oxygen. Clustered around it were four Redstone rocket oxygen tanks and four Redstone fuel tanks filled with kerosene. This clustering approach ensured that the fuel would not slosh around inside the large tank but made the plumbing of the system difficult. Although the first few S-I stages were constructed in-house by ARPA, the sheer magnitude of the project led to the selection of the Chrysler Corporation's Space Division as a contractor to build the remaining S-I stages.

The Saturn I upper stage, designated S-IV, was constructed by Douglas Aircraft. Nearly two thirds of the S-IV was used by the liquid hydrogen tanks. Liquid hydrogen and liquid oxygen must be kept extremely cold, and so the propellant tanks were heavily insulated. This insulation, however, would be very heavy, and the lighter the stage, the higher the payload that could be delivered to orbit. North American Aviation devised a honeycomb aluminum insulation that was both very light and very strong. The honeycomb aluminum actually became stronger when cooled, so it was used to boost the strength of the propellant tanks, allowing the tank walls to be made thinner so that the tanks could be lighter. To power the S-IV stage, six Pratt & Whitney RL-10 engines were used, each providing 15,000 pounds of thrust.

Ten successful missions, beginning on October 27, 1961, were flown with Saturn I rockets. The first three involved the first stage only, with a dummy payload in place of the second stage. The last Saturn I rocket was launched July 30, 1965.

Saturn IB

The Saturn IB was essentially an upgrade of the Saturn I. Rocketdyne upgraded the H-1 engines to 200,000 pounds of thrust for the Saturn IB first stage, designated S-IB. Additionally, the dimensions of the first stage were slightly altered to couple with the redesigned upper stage. The S-IB had onboard computers and guidance systems intended to be used on the later Saturn V rockets. The rocket's computers were constructed by International Business Machines (IBM). Although they were used for only a few minutes, they had to monitor a very large number of operations of the rocket.

The Saturn IB's second stage, the S-IVB, was completely redesigned. The S-IVB used a liquid hydrogen and liquid oxygen propellant system and was powered by a single J-2 engine developed by Rocketdyne. The J-2 engine, with 200,000 pounds of thrust, provided the S-IVB with more than double the thrust of the S-IV used on Saturn I. The S-IVB was also configured to receive a collar on its top end to mate with payloads expected of the Apollo Program.

The first Saturn IB flew on February 26, 1966. Only four test flights were made with Saturn IB before the first crewed flight, Apollo 7, on October 11, 1968. Apollo 7 demonstrated the effectiveness of the Apollo spacecraft in an Earth-orbital mission. From this time until 1973, when the Apollo Program was canceled after the Apollo 17 mission, all remaining Apollo missions would use the Saturn V rocket. The Saturn IB, however, was used for three more missions in 1973 to launch Apollo capsules. The final launch of a Saturn IB was on July 15, 1975, when an Apollo capsule was launched to rendezvous with a Soyuz spacecraft launched by the Soviet Union.

Saturn V

In order to achieve the necessary thrust for a lunar mission, Rocketdyne developed the F-1 engines used in the Saturn V first stage. The F-1 engines burned 40,000 gallons of kerosene per second and provided a thrust of 1,600,000 pounds each. Each F-1 engine provided about the same thrust as the entire Saturn IB first stage. The Saturn V first stage was designated S-IC, and it was a complete redesign of the earlier first stages. Five F-1 engines were used. The center engine was fixed, and the outer four engines were gimbaled to steer the rocket. No other rocket had ever been constructed to match the 8,000,000-pound thrust of the S-IC. The S-IC, constructed by Boeing, was 33 feet in diameter and 138 feet in length. It contained enough kerosene and liquid oxygen in two giant tanks to fill more than fifty railroad tank cars.

The second stage of the Saturn V was a new design, designated the S-II. The S-II used five Rocketdyne J-2 engines. The S-II, constructed by North American Aviation, was also 33 feet in diameter and 81.5 feet in length. The S-II used liquid hydrogen and liquid oxygen as a propellant. The upper part of the S-II mated with a flared collar that fitted the more narrow third stage of the Saturn V.

The Saturn V's third stage was the venerable S-IVB stage that had been used as the second stage to the Saturn IB. On top of the S-IVB was the payload for the Saturn V. For the Apollo missions, the payload had consisted of the Lunar Module, the Command Module, and the Service Module. The Service Module contained power systems for the Command Module and a rocket designed to return the Apollo spacecraft back to Earth from the Moon. On top of the Command Module was an escape tower that held rockets designed to lift the Command Module off of the Saturn V in the event of a catastrophic failure during launch. The total height of the rocket was 364 feet, and its total weight was more than 6,000,000 tons when fully fueled and ready for liftoff.

A total of fifteen Saturn V rockets were constructed. The first two launches on November 9, 1967, and April 4, 1968, were unmanned test missions. December 21, 1968, however, a Saturn V launched Apollo 8 on a trip around the Moon and back to Earth. On July 16, 1969, a Saturn V rocket, designated SA-506, launched Apollo 11, which was the first manned landing on the Moon. The last lunar mission was rocket SA-512, which launched Apollo 17. Only one other Saturn V rocket was launched. On May 14, 1973, SA-513 launched a modified S-IVB as Skylab, the first U.S. space station. The two remaining Saturn V rockets were never used, and became displays at the Kennedy Space Center and at the Johnson Space Center.

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See also: Apollo Program; Wernher von Braun; Crewed spaceflight; Robert H. Goddard; Johnson Space Center; Missiles; National Aeronautics and Space Administration; Orbiting; Rocket propulsion; Rockets; Spaceflight; Uncrewed spaceflight

Seaplanes

Also known as: Float planes, flying boats

Definition: Aircraft that are capable of taking off and landing on bodies of water.

Significance: Seaplanes allowed aircraft to fly across large bodies of water, allowing for transoceanic passenger and freight service.

History

The development of water-based aircraft, or seaplanes, as they are called, was a natural outgrowth of the development of flight. In the early years of aviation, almost the only places where sufficiently long "runways" for takeoff and landing existed were along various bodies of water. Because almost one-half of the populations of the United States and Western Europe lived within close proximity to the coastline, the development of water-based flight became important.

Over the years, long over-water, or transoceanic, flights became a natural part of the transportation infrastructure. Yet, in many cases aircraft did not have the range to fly across the entire ocean nonstop. The development of seaplanes allowed for craft that could stop at islands or other harbors to refuel, do maintenance, or wait for improved weather before continuing on their way. Seaplanes also opened remote areas to travel, as they could land or take off on lakes, rivers, or harbors without requiring shore-based facilities.

The military, by the 1930's, had taken a great interest in seaplanes. Naval vessels used catapult-mounted planes as forward scouts and observers. They could be landed on the sea and recovered back aboard ship for reuse. Seaplanes were also used for search and rescue by the military. They not only had long over-water flight capability, but also could set down on the water's surface to pick up people. Some of these planes were also armed and used to hunt submarines, to lay mines, or to bomb torpedoes.

These uses, coupled with the dramatic increase in the number of flight passengers and the opening of regular transatlantic and transpacific mail routes in the years prior to World War II, led to the development of a number of different seaplane designs. Designers at Dornier, Sikorsky, Martin, Boeing, Grumman, and Consolidated all contributed to the variety of seaplanes available for both military and civilian use.

Types

Seaplanes have been designed and built as two distinctly different types of aircraft. The first type, float planes, are essentially land-based aircraft modified for water takeoffs and landings. Float planes could be fitted with a single float under the fuselage and wingtip floats under the wings. Other aircraft manufacturers adapted their plane designs with twin floats under the hull. Manufacturers such as Cessna, DeHavilland, Grumman, and others have successfully adapted their aircraft to the rough conditions of water takeoffs and landings. These aircraft are prized for their ability to give access to remote areas. They are used for search and rescue and backcountry expeditions and as supply planes and tourist vehicles. Some are twin-engine planes, and others are single-engine planes. Due to the conditions of rough water, spray, and low visibility, however, all float planes have high-wing designs.

The second type of seaplanes, flying boats, have the rounded hull shape of a boat. The fuselage is designed so that it floats in, and not above, the water like float planes. This type of aircraft may also be equipped with wing floats. Flying boats are generally multiengined aircraft, with either two, three, or four engines. The number of engines depends upon the size of the plane and the range it is designed to fly over water. Flying boats also have a high-wing design, required not only by rough water, spray, and low visibility, but also by the fact that these planes land on their hulls in the water.

Commercial Aviation

The interwar years and, to some degree, the years during World War II, were a time of great success for commercial enterprises operating flying boats. One of the first companies to undertake long-haul, transoceanic service was Imperial Airways, formed in 1924 by the merger of four small companies, Handley Page Transport, Instone Air Line, Daimler Airway, and British Marine Air Navigation. Imperial's goal was not only to unite the British Empire through air travel, but also to carry mail throughout the empire. Imperial Airways flew a number of different craft on its routes. In the early years, it flew small Supermarine Sea Eagle craft of the biplane style, with two wings placed one above the other and a single engine in between, with the propeller facing the rear. Sea Eagles were about 37 feet long, with a single Rolls-Royce 350-horsepower engine capable of flying at 93 miles per hour for all of its 200-mile cruising range.

Imperial Airways eventually expanded its service to include routes from England to Egypt, Australia, India, Kenya, South Africa, and Hong Kong. By the late 1930's, Imperial was flying Short S-23 flying boats. These were known as C-class boats, and all had names beginning with the letter "C," such as Cabot, Clio, Canopus, Coorong, and Cambria. C-class boats were very large vessels with a takeoff weight of nearly 40,000 pounds. They had four 910-horsepower engines, which gave them a top speed of almost 200 miles per hour over their 1,500-mile cruising range.

During this same period, another airline was establishing seaplane service in the United States also using flying boats. In 1927, Juan Terry Trippe merged a number of small airlines to create Pan American Airways, known as Pan Am. The airline flew primarily from the United States to points of call in Central and South America. When in 1928, the Foreign Air Mail Act, also known as the Kelly Act, began to allow U.S. commercial air carriers to be paid to carry United States mail overseas, Pan Am seized this opportunity to enlarge its fleet. The first vessels added were S-38 flying boats built by Sikorsky Aero Engineering Corporation.

As business expanded, Pan Am became America's "official" airline. Although the U.S. government did not have financial investments in any airline, it was able and willing to help Pan Am compete against foreign state-run airlines such as Air France or Lufthansa. By 1931, Pan American had added the larger S-40 series to their fleet. These were the first of the Pan Am "Clippers" and carried thirty-two passengers.

By 1932, the S-42 series of vessels had begun to appear, and Pan American was looking to fly not only North, Central, and South American routes but also transatlantic and transpacific routes. S-42 aircraft were powered by four

Boeing's 314A Clipper was one of the most famous seaplanes, carrying seventy-four passengers and a crew of ten. (Library of Congress)

700-horsepower Hornet radial engines and were capable of a 1,200-mile range. Although these craft turned out to be effective on the transatlantic run, they could not get all the way to Hawaii.

In 1935, the first of the real long-range flying boats were delivered to Pan Am for their Pacific service. The Martin 130 "China Clippers" were powered by four 950-horsepower Wasp engines, giving them a speed of 160 miles per hour and a cruising range of more than 4,000 miles. The first transpacific trip, from San Francisco, California, to Manila, the Philippines, took approximately 60 hours of flying.

By 1939, Pan Am had started to take delivery of the Boeing 314A, with a length of 106 feet, a wingspan of 152 feet, and a takeoff weight of 84,000 pounds. The four 1,600-horsepower Wright Cyclone engines could push the aircraft at 180 miles per hour for a cruising range of 3,700 miles. The first of these planes to fly was the "Dixie Clipper," capable of carrying seventy-four passengers and a crew of ten. The Boeing 314A did not have wingtip floats for stability but instead had sponsons on the lower portion of the hull.

Military Aviation

Imperial Airways and Pan American Airlines were not the only beneficiaries of the new types of flying boats. The militaries of numerous countries were also involved in the design and manufacture of a variety of seaplanes.

German manufacturers designed and built a number of aircraft during this period. The Heinkel and Blohn und Voss companies both designed float planes and flying boats for the German military. Another successful designer and manufacturer of flying boats was Dornier. The Wal was a workhorse for Lufthansa in the 1920's and 1930's. In 1929, the Dornier DO-X made its maiden voyage from Lake Constance in Switzerland. It was the largest craft ever built at the time, with a wingspan of 157 feet, a length of 131 feet, and a weight of 48 tons. It was powered over a 1,000-mile range by twelve 600-horsepower engines.

During this time both Italy and France produced a number of flying boats. Both the Italian Macchi company and the French Latecoere company produced a number of designs. British companies such as Felixstowe, Sea Eagle, Iris, and Short all produced a number of designs for the Royal Navy during this period. Short, in particular, produced the Sunderland series, 85-foot-long craft with a 112-foot wingspan. The four 1,050-horsepower engines pushed the vessel's 58,000-pound takeoff weight at 205 miles per hour over its 2,700-mile range.

In the United States, the Consolidated, Grumman, Sikorsky, Martin, and Boeing companies all contributed designs to the U.S. Navy's flying boat fleet. Some of these designs, such as the Martin Mariner (PBM-3D), were used primarily as submarine hunters because of their 2,400-mile range.

During World War II, more than six thousand flying boats and float planes were produced by the United States, Russia, England, and Germany. This is a very large number of aircraft, but of the total, 3,290 of those were of one series, the Consolidated PBY series. The PBY-5 became known as the Catalina. The Catalina was 63 feet long with a wingspan of 104 feet. The twin 1,200-horsepower Pratt & Whitney engines drove the 34,000-pound aircraft at 190 miles per hour over its 4,000-mile range. These were some of the most versatile aircraft built for military service. They served as submarine hunters, coastal patrols, mine layers, search-and-rescue craft, and personnel carriers. They were built in a number of nations throughout the war.

The war years marked the end of an era for flying boats. The development of a large number of long-range aircraft and the building of the large number of airfields with runways capable of handling these planes made most flying boats obsolete. Some navies, including that of the United States, continued to develop flying boat prototypes for a number of years, but none of these were deployed to the fleet.

Contemporary Uses of Seaplanes

There remain places in the world so remote and with so little infrastructure that they are still serviced by seaplanes such as the Grumman Widgeon. The Widgeon is small, with a 31-foot length, a 185-mile-per-hour top speed, and a 1,00-mile range.

More recently, flying boats have made a comeback of sorts. They are not used for passengers or freight. Instead they are used, with special scoops attached, as firefighting aircraft. These vessels swoop down low over a lake or other body of water and scoop up a large volume of water and then return to the fire site to drop their water "bomb" on the fire.

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See also: Airplanes; Firefighting aircraft; Manufacturers; Military flight; Rescue aircraft

707 plane family

Definition: The dominant family of passenger planes made in the twentieth century.

Significance: The Boeing 707 was the first U.S. commercial jet airplane to be introduced. It was followed by eight more advanced airplanes, and by the end of the twentieth century the 707 family dominated the commercial jet aircraft market.

The Boeing 707 Family

The family of jet commercial transport planes developed by the Boeing Company began in 1952, when the company gambled nearly $16 million on a prototype airplane. It was a success and led to a family that grew to over eight thousand airplanes by the turn of the century. By the year 2000, about 65 percent of the world's commercial jets were members of the 707 family.

The first 707 was not a pioneer. The British Comet, built by the De Havilland Aircraft Company, blazed the trail of commercial jet travel. With a prototype built in 1949 and a first production plane in 1951, the Comet took advantage of the experiences learned by the aircraft industry during World War II. These experiences were not good enough, however. A series of disastrous crashes brought production of Comets to an end in the 1950's. Most of the Comet crashes were traced to design faults, especially with respect to the integrity of the fuselage covering.

The Comet crashes had damaged the public's and the airlines' confidence in jet travel and Boeing realized that it would have to reestablish that enthusiasm before being able to successfully introduce its 707. An extensive period of testing and publicity about safety eventually led to public acceptance, and soon jet travel became the mode of preference, especially for long-distance flights where the jet's extra speed was important to passengers. The 707 jets succeeded in cutting travel time approximately in half compared to even the fastest propeller planes, such as the Douglas DC-7, the last of the great prop planes.

By the year 2000, the 707 family had grown to nine different named models, most of which had several different versions. The evolution was driven by two considerations: the different requirements of short-range, medium-range, and long-range markets, and the need for improved performance in terms of load capacity, fuel efficiency, noise abatement, and passenger convenience.

The Dash 80

First conceived in 1952, the prototype of the 707 was completed in 1954 and had its first flight that summer. Nicknamed the "Dash 80," this plane was never sold by the company but was kept for demonstrations and various tests. It was eventually retired in 1972, when it was presented to the Smithsonian Air and Space Museum. It spent several years parked in Arizona and then was returned to the Boeing Company. In 2000, it was still to be seen on the tarmac at Boeing Field in Seattle, waiting for the construction of a new Museum of Flight facility to allow it to be on public display.

The Dash 80 still looks like a modern airplane. Its design formed the pattern that dominated the commercial aircraft industry for fifty years, a remarkable record. With its swept-back wings, sleek nose, and numerous small windows, its appearance was a hit with both passengers and airlines. Its performance was also impressive. It broke a long series of records for both speed and distance. In 1957, for instance, the Dash 80 flew from Seattle to Baltimore nonstop in just 4 hours and 48 minutes, with an average speed of 612 miles per hour. Its logbook records three thousand hours of flying, all of it for testing and demonstration.

The 707's

After the extensive and well-publicized test flights of the 707 prototype, the public and the world's airlines were ready for the first 707's to fly. Pan American World Airways, then one of the premier intercontinental carriers, ordered the 707 early and began its inaugural flights in 1958. Its first flight, between New York and Paris, was such a success that 707's were put into service by most large airlines as soon as the planes could be delivered. In the following year, Pan American introduced the first scheduled around-the-world jet service with its 707's, and the jet age had begun. The first 707 model, called the 707-120, was an excellent plane for medium to long flights, but with a range of only about 4,000 miles, it was considered better for transcontinental flights than for intercontinental. In the late 1950's, 707's were scheduled by several airlines for coast-to-coast service. For the Los Angeles-to-New York route, for example, 707's could cut travel time from more than ten hours to only about five hours. Their use for longer distance travel, however, was restricted by their limited range, which necessitated intermediate stops for such flights as from San Francisco to Tokyo.

In response to this special need, Boeing developed a longer-distance model of the 707 called the 707-320 series, popularly known as the 707 Intercontinental. With a range of 6,000 miles, a larger fuselage, and more powerful engines, the Intercontinental quickly became the most commonly used airplane for long flights, especially transoceanic ones. Many national airlines of the Western world adopted the Intercontinental for its longer flights, and its familiar sleek outline was graced by the insignias of dozens of airlines, such as Air France, Lufthansa, BOAC (later renamed British Airlines), and Qantas.

It was almost impossible to fly in a 707 at the beginning of the twenty-first century. Most of them have been retired or converted to freighters. An example of an especially long-lived 707 is the plane that was used by Air Zimbabwe until well into the 1990's. It was a favorite of tourists to Victoria Falls until it was replaced by newer Boeing airplanes.

The 720

The 1960's saw the Boeing 707 and its Douglas rival, the DC-8, take over most of the long-distance air routes of the Western world. Shorter routes, however, still saw smaller planes in common use, especially because the 707 had a large capacity and required a long runway. For that reason, a new model of the 707 was introduced that was somewhat smaller and that was efficient for use on medium-range flights. Called the 720, it had essentially the same design as the 707 and offered passengers the same comfort and speed as its larger sibling.

The 720 was used, for instance, for the north-south routes along the West Coast by Western Airlines, where its characteristics were well matched to the needs.

The 727

The popularity of the 707 and its similarly sized competitors, the Douglas DC-8 and the Convair 880, demonstrated passenger preference for jet travel. However, these big planes demanded long runways and large airports. In spite of attempts to expand airport facilities rapidly, most commercial airports were just too small to handle the jets. In response to this problem, the 727, a smaller, three-engine jet, was developed. With newly designed wing flaps, the 727 could take off remarkably steeply and could land slowly, fitting onto smaller runways. The first 727 was put into service in 1964 by United Air Lines, which flew that one plane continuously for twenty-seven years. The last 727 was built in 1984, at which time 727's were being used by nearly one hundred different air carriers and were carrying 150 million passengers per year. Near their peak in 1995, the 727's had flown over four billion passengers on short- to medium-range commercial flights.

As wide as the 707, the 727 began as a much shorter and lighter airplane. Early models had a gross weight of 170,000 pounds, which increased to 210,000 pounds for the later versions. The cabins were roomy and, with the engines behind almost all passenger seats, the interior was relatively quiet, both features that helped the plane's popularity. A total of 1,832 of the 727's were built.

Although the 727 had several variants, there were only two main models, the 727-100 series and the 727-200 series. Included was a convertible version that could carry passengers, freight, or a combination of the two. The 727-200F, for instance, carries nearly 60,000 pounds of freight. As the 727's aged, many were converted to freighters, carrying considerable amounts of mail and express packages.

The 737

By the end of the twentieth century, the Boeing 737 had become the most popular commercial airplane of all time. It had been delivered to airlines throughout the world, including Eastern Europe and Asia, which previously had not been notable customers of American airplane companies. By the year 2000, this airplane had carried over six billion passengers, equivalent to the total population of the world.

The 737 started as the "little cousin" of the 727, intended for shorter flights and even smaller airports. The first planes were delivered in 1967 to Lufthansa, and thirty-five years later, the 737 was still being built and delivered to airlines over the world. As in the case of the 727, Boeing used high-lift devices to provide steep takeoffs and slow landings, making the 737 a particularly versatile plane as far as runways were concerned. It had two wing-mounted engines and thus used less fuel than three- or four-engine planes. It soon became the workhorse of many commercial airlines, making frequent and fuel-efficient short hops to serve a wide range of communities.

As an example of the common use of 737's, Aloha Airlines of Hawaii has an all-737 fleet, most of which are devoted to the short (less than an hour) trips between the islands. In the year 2000, Aloha 737's flew more than one thousand flights per week, carrying about five million passengers in the year.

As of 2001, there were nine different models of the 737. The first, the 737-100, carries ninety-nine passengers when used as a one-class airplane, with six-abreast seating and a central aisle. It has an 87-foot wingspan and a fuselage only 95 feet long, giving it a squarish appearance. Each engine can develop 14,000 pounds of thrust for a maximum takeoff weight of 110,000 pounds. Its cruising speed at 35,000 feet is 575 miles per hour and its range is 2,160 miles, although it is primarily used for much shorter flights.

Responding to airline requests, Boeing soon introduced the 737-200 series, with a fuselage that is 6 feet longer than that of the 737-100 and a carrying capacity of 124 passengers when used as a one-class airplane. This series was followed by the 737-300, which was longer yet and had a wingspan of 95 feet. Its range is 2,595 miles. Improvements in fuel efficiency, noise abatement, and speed led to the introduction of the 400 and 500 series, and then Boeing made several additional design changes and introduced the Next Generation 737's, the 600 to 900 series. The 737-900, introduced in 2001, can carry 189 passengers, almost twice as many as the 737-100. The plane, originally designed for short-haul flights, was by 2001 being used for transoceanic flights, as between California and the Hawaiian Islands. It has a 274,200-pound takeoff weight and a range of 3,160 miles. In wingspan and fuselage length, the 900 is about 30 feet bigger than the 100.

The 747

In the mid-1960's, the aircraft industry realized that the potential of commercial jet transport included scales of plane size and capacity that would be vastly different from past experience. Pan American World Airways conceived of planes that could carry at least twice as many passengers as the 707 and could travel nonstop over twice the distance. Working with Boeing engineers, Pan Am promoted the idea of the "superjet." It took nearly five years to bring that idea to fruition.

Under the leadership of chief engineer Joseph Sutter, Boeing designers put together a plan for an airplane that could carry over four hundred passengers and that could fly nonstop for more than 5,000 miles. To ensure the building of such a revolutionary new craft, Pan Am ordered twenty-five of them in 1966. As no existing facility could hold such a giant airplane, Boeing had to build an entire new plant, choosing a site north of Seattle near the small city of Everett, Washington. This plant was said to be the largest building in the world.

The first superjet, named the 747-100, was completed in 1968. It was first shown to the aviation world at the Paris Air Show in 1969. This plane, named the *City of Everett*, is still in service, being used by the company for various tests of new equipment, and is destined for the Museum of Flight in Seattle, Washington. The characteristic look of the 747, with its forward hump, was the result of a two-deck design in which the cockpit and a passenger cabin were located above the main floor. This idea was not entirely new; Boeing's pre-jet-era passenger plane, the Stratocruiser, had two decks, incorporating a lower passenger deck, usually used as a passenger lounge, below the main cabin.

The first commercial flight of the 747 occurred in January, 1970, when Pan American flew its first 747 nonstop from New York to London. In the next thirty years, over 1,200 747 superjets were built, flying 33 billion miles in airline service. Most were delivered to non-U.S. airlines for service on long-range international flights. By the year 2000, over 2.2 billion passengers had flown on 747's.

Four different versions of the 747 were developed in the first thirty years, called versions 100, 200, 300, and 400. Each of these included various special versions, such as freighters, combis carrying both freight and passengers, and convertibles, which allowed airlines to convert from freight to passengers depending on needs such as seasonal demands. The freighters were given hinged noses to allow large objects to be loaded easily. Each version incorporated new features, including increased capacity, better fuel efficiency, and more modern (digital) avionics. For example, the 747-300, introduced in 1982, added about forty-four passenger seats by having an extended upper deck.

The 747-400 has a wingspan of 211 feet and a length of 232 feet, making it about as large a plane as airports can handle. Its tail rises above the tarmac as high as a six-story building. The interior of the cabin is 20 feet wide, making room for ten economy class seats abreast. In a two-class configuration, the 747-400 can carry 524 passengers over a range of 8,430 miles. Each of its four engines develops about 63,000 pounds of thrust so that it can take off with a gross weight of nearly one million pounds.

The 757

The Boeing 757 is a medium-range airplane that was designed to take the place of older jets, such as the 727, by providing a plane that could serve airline hubs efficiently, being capable of flying either short or medium-range flights. It has two engines and a single-aisle interior, with six-abreast seating in the main cabin. With a larger capacity than the 727 (it can carry 239 passengers in a two-class configuration), its improved aerodynamical design and high-bypass-ratio engines mean a quieter aircraft and a fuel savings of about 40 percent per seat.

The cockpit is fully digital, with a flight management control system that provides automatic control and guidance of the plane from just after takeoff to final approach. This system is designed for maximum efficiency, taking into account all flight and aircraft conditions en route. The cockpit design is the same as that of the 767, so that pilots certified for one can fly the other.

By the end of 2000, more than one thousand of the 757's had been built. Included was a freighter version that had no passenger windows or doors, but instead a large cargo door on the starboard side of the cabin.

The 767

In 1978, United Air Lines expressed the need for a modern wide-body jet that would be highly fuel-efficient for long-distance flights but smaller than the 747 when it ordered thirty of the not-yet-built Boeing 767 airplanes. The first 767 was finished in 1981. It had longer, thicker, and less swept-back wings compared to earlier jets, and it introduced a new feature, raked wingtips, all of which increased the plane's flying efficiency. With two aisles, it could accommodate seven-abreast seating in economy class, with a passenger count in the two hundred to three hundred range, depending on seating arrangements. The 767 became popular for intercontinental flights, as it was approved for two-engine flights that would take it as far as three hours from the nearest runway. In the year 2000, the 767 was the most common airplane flying the busy North Atlantic route, outnumbering all other jets combined.

In 2001, there were three 767 models: the 200, 300, and 400 series. The 200 is 159 feet long, the 300 is 21 feet longer, and the 400 has an overall length of 201 feet. Combined, more than eight hundred of the three models had been built by 2001.

The 777

During the final decades of the twentieth century, the airplane industry's emphasis turned to issues of efficiency and passenger comfort. Manufacturers worked to develop more spacious cabins, more fuel-efficient engines, and more lightweight construction materials. At the same time, computers were extensively employed to control both operations and performance monitoring, while modern communication and navigation systems were installed as well. The Boeing 777 became that company's best example of a plane ready for the twenty-first century. There are five different models of the 777, a two-engine plane that was intended to bridge the gap between the 747 and the 767. The first, the 777-200, was certified in 1995. It has a passenger capacity of four hundred in a two-class configuration. Its two-aisle cabin is designed to give passengers more room than earlier jets. There is built-in flexibility in the cabin: lavatories, overhead storage units, and galleys can be moved readily when configuration changes are needed.

The 777-200 is a large plane. Its wingspan is a full 200 feet and its length is 209 feet. It has a maximum takeoff weight of 545,000 pounds and a maximum range of 5,600 statute miles, allowing it to fly, for example, from San Francisco to Tokyo nonstop. There is an extended-range model that has the capability to fly almost 8,500 statute miles. The 777 was certified to fly as far as three hours from the nearest airport.

The 777-300 model was introduced by Cathay Pacific Airways in 1998. It is thirty-three feet longer than the 777-200 and can carry 479 passengers in a two-class configuration. Its range is 6,600 statute miles. Two new models, the Longer Range 777-200 and 777-300, will be introduced in 2003. The LR777-200 will have a range of 9,750 statute miles, the longest distance that any two-engine passenger plane can fly nonstop.

The 717

Not originally part of the 707 family, the Boeing 717's ancestor was the popular Douglas DC-9, a fuselage-mounted twin-engine jet designed for short- and medium-range flights. Completely redesigned by Douglas's successor, McDonnell Douglas, in 1995, the plane was first called the MD-95. When Boeing merged with McDonnell Douglas in 1997, the plane's name was changed to the Boeing 717. It has a usual capacity of 106 seats and a range of 1,500 statute miles.

Paul Hodge

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See also: Airplanes; Boeing; Jet engines; Jumbojets; Manufacturers; Tail designs; Wing designs

Alan Shepard

Date: Born on November 18, 1923, in East Derry, New Hampshire; died on July 21, 1998, in Monterey, California

Definition: The first American astronaut to fly in space.

Significance: Shepard flew the first U.S. manned space flight in 1961 and became the only Mercury astronaut to walk on the Moon.

Alan Bartlett Shephard, Jr., was born to Colonel Alan B. Shepard and his wife in East Derry, New Hampshire. He graduated from Pinkerton Academy in Derry and spent a year studying at Admiral Farragut Academy in Toms River, New Jersey, prior to his acceptance into the United States Naval Academy.

Shepard pursued flight training after World War II, earning his wings in 1947. Completing U.S. Naval Test Pilot School training in 1950, he remained at the school, participating in high-altitude research, flight operations development for a naval in-flight refueling system, F2-H3 Banshee testing for carrier deployment, and angled carrier-deck development.

After two tours of duty in the Pacific aboard the USS *Oriskany,* Shepard returned to the Naval Test Pilot School to fly F-3H Demon, F-8U Crusader, F-4D Skyray, F-11F Tiger, and F-5D Skylancer aircraft. Shepard achieved instructor status there, but five months later entered the Naval War College in Newport, Rhode Island, graduating in 1958.

After the National Aeronautics and Space Administration (NASA) began screening military files for potential astronauts, Shepard's test-pilot career singled him out as a prime candidate. In April, 1959, Shepard was one of the seven astronauts selected for Project Mercury. The Mercury astronauts worked cooperatively on all aspects of Project Mercury but competed for flight assignments. In 1960, NASA picked Shepard, John Glenn, and Virgil "Gus" Grissom to train for a suborbital Mercury-Redstone mission.

Alan Shepard undergoes a flight simulation test preparatory to his Mercury flight in 1961. (NASA)

Although the Soviets had beaten the Americans into space by launching Yuri Gagarin into orbit on April 12, 1961, NASA moved forward with Project Mercury. Shepard lifted off on May 5, 1961, inside his *Freedom 7* spacecraft strapped atop a Redstone missile. Shepard was exposed to high g forces and five minutes of weightlessness. The spacecraft achieved a 116-mile altitude before splashing down in the Atlantic 302 miles from Cape Canaveral.

Three years later, Shepard was grounded by Meniere's syndrome, an inner-ear condition capable of inducing nausea, ringing ears, and vestibular disturbances. He was reassigned to Astronaut Office management. In 1969, Shepard underwent surgery that corrected his condition, and, within six months, he had gained command of Apollo 14.

The Apollo 14 mission launched on January 31, 1971, with Shepard, Stuart Roosa, and Edgar Mitchell. Shepard and Mitchell touched down Lunar Module *Antares* in the Fra Mauro region, deployed scientific instruments on the lunar surface, and collected samples during two moonwalks. Shepard hit two golf balls before leaving the surface. After 33 hours, Shepard and Mitchell lifted off the Moon to rejoin Roosa. Apollo 14 splashed down in the Pacific on February 9.

In 1974, Shepard retired from the Navy and NASA. He enjoyed subsequent success in the business world, helping found the Astronaut Scholarship Foundation. Diagnosed with leukemia in 1997, Shepard valiantly fought the disease and expected to join the other surviving Mercury astronauts to witness their colleague Glenn fly aboard space shuttle *Discovery* in late 1998. However, Shepard's condition worsened, and Shephard died on July 21, 1998, three months before Glenn's mission.

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See also: Apollo Program; Crewed spaceflight; Yuri Gagarin; John Glenn; Mercury project; National Aeronautics and Space Administration; Navy pilots, U.S.; Spaceflight; Test pilots

Igor Sikorsky

Date: Born on May 25, 1889, in Kiev, Russia; died on October 26, 1972, in Easton, Connecticut

Definition: Russian-American aeronautical engineer, aircraft manufacturer, and inventor best known for developing the helicopter.

Significance: Sikorsky's introduction of controlled-pitch rotor blades was instrumental to the development of the modern helicopter.

Igor Sikorsky was born in 1889 to educated parents who were both physicians, although his mother did not practice professionally. His formal training began in 1903, when he enrolled at the Russian Naval Academy in St. Petersburg. His interest in education led him to leave the service in 1906 and to enroll at the Polytechnic Institute in Kiev. At the age of twenty, Sikorsky built his first helicopter, which would not leave the ground. In 1911, he set a record by flying for thirty minutes at 70 miles per hour in the S-5, a plane he had designed himself. In 1913, at the request of the Russian Army, he designed and built the world's first four-engine, dual-controlled airplane, which served as a bomber in World War I.

A strong anti-Bolshevist, Sikorsky left Russia after the Revolution of 1917 and made his home in the United States. He became a U.S. citizen in 1928. He originally joined in business with a group of Russian immigrants building airplanes, but the business failed. In 1923, he started over, forming the Sikorsky Aero Engineering Corporation, which built "flying boats" for Pan American's transoceanic flights and fifty-six "aerial yachts" for wealthy clients. After the stock market crash of October, 1929, his once-wealthy clients could no longer meet their payments, ending his independent company, which became a division of the United Aircraft Corporation. Sikorsky continued to head the division until his retirement.

In 1939, Sikorsky developed the VS-300, the first helicopter with controlled-pitch blades. This innovation turned out to be instrumental in making helicopters practical. Although early helicopter models were used in World War II after 1944, they came of age during the 1950's. Sikorsky also designed a patrol bomber, known as the Flying Dreadnought, for the U.S. Air Force's use in World War II. Sikorsky continued to be a vital part of the company even after his 1957 retirement at the age of 68. He consulted on design and on business matters and was at his desk the day before his death at 83 years of age.

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See also: Helicopters; Manufacturers; Military flight; Rotorcraft; Vertical takeoff and landing

Singapore Airlines

Also known as: Singapore International Airlines, Malayan Airways

Date: Founded in 1947 as Malayan Airways

Definition: A major international airline and the national flag carrier of Singapore.

Significance: Singapore Airlines is internationally recognized as one of the world's leading carriers. The company has achieved record growth and financial health through careful planning and management.

History

Singapore International Airlines is a major international airline headquartered in Singapore. It is owned by the state of Singapore (54 percent) and private investors (46 percent). Singapore Airlines was formerly known as Malayan Airways. Malayan Airways was founded in May, 1947, at which time it first operated a twin-engine Airspeed Consul between Singapore, Kuala Lumpur, Ipoh, and Penang. As passenger demand grew, so did the airline. By 1955, the airline had a fleet of Douglas DC-3's. The creation of the Federation of Malaysia in 1963 prompted two name changes for the airline, first to Malaysian Airways and then, three years later, to Malaysia-Singapore Airlines (MSA). The second name change was in deference to the carrier's joint shareholders, the governments of Malaysia and Singapore.

MSA came to an end in October, 1972, giving birth to two new airlines: Malaysia Airline System (now called Malaysia Airlines), headquartered in Kuala Lumpur, and Singapore Airlines, headquartered in Singapore. In 1972, Singapore Airlines operated a fleet of ten aircraft and commanded a route network that covered twenty-two cities in eighteen countries. It began immediately to modernize its fleet of aircraft and improve customer service standards for its customers. By 2001, the airline was internationally recognized as one of the world's leading carriers, frequently wining customer service awards in international competitions. The route network spans over ninety cities in more than forty countries. The company has pioneered some of the flight service amenities that have become standard throughout the industry, such as complimentary headsets and free drinks, and their amenities are some of the best available, such as their revolutionary interactive entertainment system.

Fleet

In 2001, Singapore Airlines operated an all-wide-body fleet of modern aircraft. It is the world's largest operator of Boeing 747-400 aircraft. It also operates the Airbus A340-300E and has placed firm orders for the A340-500, the Airbus A310-300, and Boeing 777-200 and 300. Singapore Airlines has placed firm orders with Airbus and has taken options on the Airbus A380-800 double-deck super transporter. Silk Air, a wholly owned subsidiary of Singapore Airlines also based in Singapore, operates a fleet of Boeing 737's. Silk Air has an extensive regional network to some of Southeast Asia's resorts and lower-load-factor cities. Other subsidiaries of Singapore Airlines include SIA Engineering Company and Singapore Airport Terminal Services.

Alliances

Singapore Airlines has been a member of the Star Alliance since 1999. Lufthansa, along with Air Canada, SAS, Thai Airways International, and United Air Lines founded the Star Alliance in 1997. In subsequent years, membership grew to include Air New Zealand, ANA, Ansett Australia, Austrian Airlines, British Midland, Lauda Air, Mexicana Airlines, Tyrolean Airways, and Varig Brazil. As of 2001, the Star Alliance encompassed fifteen airlines and a network of 130 countries and 815 destinations, making it the world's largest airline alliance.

Safety

Singapore Airlines and its subsidiary, Silk Air, have had one hijacking, which took place in 1991, as well as two significant accidents. On December 20, 1997, Silk Air Flight MI185, a jetliner heading from Jakarta to Singapore, crashed outside the southern Sumatran city of Palembang. On board the Boeing 737-300 were ninety-seven passengers and seven crew, all of whom died. The reason for the crash remained unclear for a long time as there was apparently nothing wrong with the aircraft, the weather was clear, and the aircraft crashed while in cruise, without reporting anything out of the ordinary. After more than a year of investigation, it was concluded that the plane had crashed as a result of "unlawful interference," possibly a murder-suicide on the part of the captain.

Singapore Airlines Flight SQ006, carrying 159 passen-

Events in Singapore Airlines History

1947: Singapore Airlines' predecessor, Malayan Airways, flies between Singapore and the Malayan cities of Kuala Lumpur, Ipoh, and Penang.
1955: The airline develops a fleet of DC-3 aircraft.
1963: In response to national political changes, Malayan Airways is renamed Malaysian Airways.
1966: The airline's name is again changed, to Malaysia-Singapore Airlines (MSA) to reflect its governmental owners.
1972: After MSA ceases operations, Malaysia Airlines and Singapore Airlines continue as individual national flag carriers.

gers, crashed soon after takeoff at Taipei's Chiang Kai Shek Airport, on October 31, 2000. Taiwanese authorities investigating the crash released a factual data report concluding that airport officials had not properly marked a closed runway. The Singapore Airlines jumbojet mistakenly tried to use the closed runway and slammed into construction debris, bursting into flames and killing eighty-three people. In addition, one runway light was broken and another was not bright enough when the Los Angeles-bound plane tried to take off during a fierce rainstorm caused by an approaching typhoon. The captain's decision to continue with the takeoff despite the weather and his commencing the takeoff on the wrong runway were contributing factors to the accident.

Triantafyllos G. Flouris

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See also: Accident investigation; Air carriers; Lufthansa; Safety issues

Skydiving

Definition: Recreational and competitive sport parachuting, which arose from early twentieth century barnstorming and military parachuting. Skydivers jump from aircraft, high buildings, or cliffs, or are towed by speedboats

Significance: Skydiving is excellent recreation, lowering tension and providing good exercise. It is also a highly appreciated spectator sport.

Parachuting, originally conceptualized in the fifteenth century by Leonardo da Vinci, became skydiving (or sport parachuting) using steerable parachutes about five centuries later. The first parachute was developed in the eighteenth century by Louis-Sébastien Lenormand. It was a canopy, strengthened at the edge and using rigging to hold an underslung passenger basket. It was tested with animal passengers. At the end of that century the first human parachutist, André-Jacques Garnerin, used a modified Lenormand chute. Nineteenth century barnstorming parachutists used Garnerin's modified chutes to parachute from balloons. To hone the thrills for spectators, folded and packaged canopies were developed. An outstanding chute was the Broadwick coat pack, worn attached to jackets and held to balloons by static lines designed so that, as parachutists fell, their weight pulled against the line and caused the canopy to open.

In 1912, in Ohio, the first aircraft parachute jump—from 1,500 feet—was made by Captain Albert Berry. High aviator mortality in World War I led Leslie Irvin and Floyd Smith to design a parachute escape system for the U.S. Air Force. Because aircraft that were falling out of control were unsuitable platforms for static-line systems, Smith and Irvin built free-fall packs with ripcords that let pilots control the chute opening. By the end of World War II, 100,000 aviators had been saved by parachutes, and paratroopers were routinely sent into battle.

Basics of Sport Parachuting

In the 1950's, parachute modifications led to steerable chute canopies and people began to parachute for fun. Soon, changes in chute shape allowed good horizontal movement, fine motion control, and soft, precise landings. In 1954, "blank gore" modification removed a panel (gore) from the hemispherical parachute canopy and used escaping air to provide some thrust and direction via pulled steering lines attached to the gore bottom. Then, placing L-shaped slots in the rear of the canopy increased ability to "hold" the wind.

In 1961, Pierre Lemoigne designed the first really steerable parachute, leading to ram-air chutes, inflatable flying wings which hugely increase canopy control. They are rectangular, and inflation of their double surfaces (skins) produces the wing shape. Control is obtained by means of low-porosity canopy material; devices enabling the maximum use of canopy air; steering toggles to turn, brake, and control descent rate; and useful shroud-canopy connection systems at the front and rear of the chute. Overall venting arrangements of sport parachutes thus allow skydivers to fine-tune their descents after the canopy opens.

In skydiving, a jump is usually made from a slow-moving plane flying at altitudes from 10,000 to 12,000 feet. "Free fall" is sustained down to 2,000 to 2,500 feet above the ground before opening the parachute. Free-fall maneuvers are accomplished by controlling body position.

Skydiving events include jumping for style, landing accurately, and performing in teams. Early contests in the 1930's involved only accuracy in landing on a target. The first world championship in skydiving was in Yugoslavia in 1951. It involved contestants from five countries. After this event, world championship contests were scheduled every two years, under the auspices of the Fédération Aéronautique Internationale (FAI). Currently, thirty-five countries participate in world championship contests. The U.S. Federal Aviation Administration (FAA) regulates all skydiving in U.S. competitions. Governance is by the International Parachuting Committee of the FAI, as represented by the U.S. Parachute Association. American competitive skydiving events occur every year.

In jumping for style, the parachutists are required to perform their stunts (called aerobatic maneuvers), such as back turns, in the shortest time possible during free fall, and are judged on their aerobatic form, not on landing site. In accuracy jumping events, competing parachutists seek to land as close as possible to the center of a circular target, set on the ground. In team events, members perform maneuvers such as baton passing or forming circles or other geometric figures (all called "relative work"). Each competing team attempts to form the largest number of patterns in the time available to them. In "canopy relative work," team members link together and perform figures after their parachutes have opened.

In all competition jumping, the sport parachute is opened at an altitude designated by FAI judges. The way in which contestants leave the delivery aircraft is likewise predetermined. In most recreational skydiving, jumpers carry an altimeter, which indicates rate of descent and tells them when to open the chute. Two new forms of sport parachuting are BASE (an acronym for building, antennae, span, Earth) and parasailing. In BASE jumping, the parachutist leaps from a very high structure such as a building or a cliff. In parasailing, the parachute is linked to and towed by a long line attached to a moving speedboat. The boat's forward motion both lifts and tows the parachutist.

Sport Parachute Construction and Use

A skydiving parachute is manually opened with a ripcord after free fall, and the jumper rides it down to the ground. Each parachute is contained inside a knapsacklike harness container (a rig). In addition to the rig, other equipment includes altimeters, jumpsuits, helmets, and goggles. Most parachutes used are ram-air chutes, named for the way in which they open and fly. The first commercial ram-air canopies, developed in the 1970's, and more modern canopies use the same flight theory. The canopy leaves the rig and the weight of the jumper causes it to inflate into a shape resembling an aircraft wing or airfoil. The canopy holds its airfoil shape because of two-skin (two-layer) construction, with the top and bottom skins joined at the rear (trailing edge) and ends.

The front, the parachute's leading edge, is open to the air. The canopy is divided into pockets or cells. Suspension lines between the skydiver and the canopy are shorter at the leading edge than at the trailing edge, causing the airfoil to tilt forward and move downward. Air is thus rammed into the cells and, as the jumper and chute move forward, the leading edge divides the air it meets so that air moves over the top skin faster than the air flowing under the lower parachute skin. This leads to lower pressure on the top surface than the bottom and creates lift force, the mechanics that create flight. The canopy flies enough to make descent to the ground relatively slow. However, the lift is not large enough to allow for ascent.

Canopy materials have changed frequently during the history of skydiving. Early canopies, later modified for sport parachute use, were made of silk. This gave them a small rig volume compared to the cotton or linen used by nineteenth century parachutists, while providing the strength and elasticity needed for fast opening. Silk was replaced with more durable and damp-resistant nylon soon after nylon was discovered in the 1930's. Most nylon in contemporary skydiving is the "ripstop" used in many garments. Ripstop resists tears because it is woven as many tiny squares, so that damage in any single square is contained within it. Shrouds (lines) that attach the jumper to the canopy need to combine strength and elasticity. Dacron, Kevlar, and zero-porosity (ZP) nylon are used to increase strength and reduce total rig weight for skydiver comfort. The greater the canopy porosity, the faster air passes through and the faster the chute falls. Use of ZP nylon slows fall by allowing little air through the canopy.

Vertical (straight-ahead) ram-air flight is achieved by means of steering toggles situated above the chutist's right and left shoulders, into which the hands are inserted. The toggles connect to shrouds (suspension lines) in the canopy's trailing edge and act like ailerons. Equal downward pull on both toggles distorts the trailing edge to slow the canopy's vertical movement and descent rate, if the pull is not too radical. If, however, both toggles are depressed to waist level, full braking occurs, airspeed becomes negligible, and descent rate increases as the canopy loses its ability for lift. Turning a chute also uses the steering toggles.

With one toggle depressed and the other unmoved, a full turn is produced in the direction of pull because the side of the canopy that is pulled slows down while the other side remains flying at speed. To land, a sport parachutist faces into the wind because opposing airflow slows the parachute somewhat, making it easier to land on one's feet. However, it does not affect descent rate, and this must be reduced if a hard landing is to be avoided. In order to slow descent rate and forward speed, a parachutist identifies the wind direction and turns directly into the wind by smoothly and quickly pulling down both toggles. This converts the canopy's forward speed, for an instant, to lift, during which time the sport parachutist steps down onto the ground. Maneuvering is complex and takes practice. However, student skydivers usually have the basics down after four to six hours of individual instruction.

Sanford S. Singer

Gravitation, Gravity, and Parachutists

Gravity is the force of attraction Earth exerts upon objects on or near it. Gravitation is one of the four basic forces that control the interactions of matter. The law of gravitation was formulated by the English physicist Sir Isaac Newton in 1684. Newton's law states that the gravitational attraction between two bodies is proportional to the product of the masses of the bodies ($mass_1 \times mass_2$) and it is inversely proportional to the distance between them. The force of gravitation is tiny. For example, between two spherical objects each of mass 1,000 grams and separated by 1 meter, the gravitational force is only 3.3 millionths of a gram. (For these purposes, the terms mass and weight have equivalent meanings.)

The force of gravity, measured as the amount of acceleration that the force of gravitation gives to an object falling to Earth's surface, is 9.8 meters (32 feet) per second squared. Thus, neglecting air resistance, a body falling freely toward Earth's surface increases its speed of fall at a rate of about .5 mile per minute squared. It is this deadly acceleration due to gravity that a parachute counters. The parachute canopy uses the pressure difference across it to maintain the necessary inflated parachute shape for this purpose. The pressure difference is caused by a mass of air trapped inside the canopy and the movement of the air outside of the canopy. The shape of the parachute causes it to experience tension forces only. Hence, the very strong fabric (such as nylon) of which parachutes are made maintains parachute integrity during use.

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See also: Air shows; Barnstorming; Parachutes; Wingwalking

Skywriting

Definition: An aviation technique in which an oil-based liquid is added to an airplane's exhaust system, creating words or images with the resulting bright white smoke against a clear blue sky.

Significance: In the days before television, advertisers used skywriting to promote their products to a wider audience. Skilled pilots created mile-high messages against a clear blue sky over racetracks, fairgrounds, and any other place where a large number of people were expected to gather.

History

British war pilot J. C. Savage was the first to write an aerial message in the skies over England, in 1922. In the fall of that year, Captain Allen J. Cameron brought skywriting to the United States when he wrote “Hello U.S.A.” in the sky over New York City. An advertising executive for the American Tobacco Company saw the message and signed Cameron to a $1,000-per-day contract to promote the cigarette company.

Image Not Available

Since the early days of aviation, one of skywriting’s biggest advertising advantages has continued to be the attention it attracts. After people on the ground see a skywriting message begin to form, they are driven by curiosity to stop and watch. Advertisers hire skywriters to create messages over beaches, fairgrounds, racetracks, and anywhere else they are guaranteed a large audience for their messages.

Method

In skywriting, both timing and planning are crucial. Paraffin or some other nonpolluting oil-based fluid is vaporized in the 1,500-degree heat of the aircraft engine to create white smoke, which is then discharged under pressure. Letters are drawn at slightly different altitudes, which allows pilots to see what they have already drawn as they proceed. This method also allows pilots to complete their message without disrupting the letters already in place. Pilots will often use roads or railroad tracks to ensure that their skywriting follows a straight line. Letters average 1 mile high, and, on a clear day, they can be seen from a distance of up to 30 miles away. Depending on the weather conditions, skywriting messages will remain in the sky for up to twenty minutes.

Skywriting is performed at altitudes ranging from 7,000 to 17,000 feet, depending on temperature. On warm days, skywriting must be done at higher altitudes, because the temperature drops 3.5 degrees for every 1,000 feet of altitude. Each letter takes approximately twenty seconds to create. Skywriting works best in a cloudless sky with no more than a moderate wind.

A modern version of skywriting is called skytyping, in which five to seven planes fly in parallel across the sky in perfect unison. The message is written as smoke generators in each plane produce short, sharp puffs that expand after they are released, leaving a continuous line of dots in the sky. Using a master control panel in the lead plane to synchronize the smoke generators, the vapor is released in specific sequences, creating the letters in much the same manner in which dot-matrix printers create images on paper.

P. S. Ramsey

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See also: High-altitude flight; Weather conditions

Sopwith Camels

Date: First entered combat in 1917

Definition: A leading British fighter plane of World War I, the Camel was a rotary-engined, single-seat fighter biplane.

Significance: The Sopwith Camel was one of the most successful British fighter planes in World War I, and one of the war's most successful fighters of any nationality. More enemy aircraft were downed by Camels than by any other Allied airplane during the war. The air forces of Australia, the United States, France, Belgium, and the British Navy flew the Camel.

The Air War in France

The air war over the western front in France during World War I saw the development of military aircraft from unreliable observation and artillery-spotting platforms to specialized attack and defense systems. Fighter aircraft soon were developed from existing planes or designed from scratch to bring down enemy observation, spotting, and bombing craft. Great Britain was, in 1917, in need of an effective fighter plane to combat several superior German aircraft, as well as to overcome the losses from the so-called Bloody April of 1917, a period in the air war that had seen many German fighter airplanes preying successfully on slower and less effective Allied fighter and observation planes.

Predecessors

Sopwith had a number of aircraft in World War I, many of them quite successful. The Sopwith Tabloid, an early single-seat tractor-engine design, was employed early in the conflict and became famous for bombing German zeppelin sheds at Cologne and Düsseldorf. Later planes, such as the Two-Seater, nicknamed the "1½ Strutter," for the formation of the wing struts, saw combat in 1916. Sopwith also built a triplane (similar, but not identical, to the popular German Fokker triplane, which was supposedly based on the Sopwith design) and later the popular Sopwith Pup, which gave decent performance (more than 90 miles per hour) with a very low-powered engine (an 80-horsepower Le Rhone). The Pup was a stable aircraft and pilots enjoyed flying it. The Camel, which entered service in mid-1917, was considered by some to be a refinement and improvement of the Pup. If so, it was an extensive one.

The Camel

The Camel's distinguishing characteristics were the humplike sheet metal covering the two machine guns directly in front of the pilot, which gave the craft its nickname, and the pronounced dihedral (the angle away from horizontal) of the lower wings. In addition, it had a much more powerful engine and more powerful armament: two machine guns either both in front of the pilot, synchronized to shoot through the propeller blades, or, in some cases, one synchronized gun and another machine gun mounted on the upper wing above the pilot. Compared to modern warplanes, the Camel was rather small. The wingspan was only 28 feet; the length of the craft was almost 19 feet. From the ground to the top of the upper wing was only 9 feet. Fully loaded with pilot and ammunition, the plane weighed about 1,500 pounds. In an era when the ability of the craft to stay in the air was measured in terms of endurance rather than a specific range of miles, the Camel could spend 2.5 hours in the air, and traveled at a maximum speed of 113 miles per hour—a very good speed for that time. Like most World War I aircraft, it was built of a wooden framework for the fuselage and wings, with fabric stretched over the plane and then stiffened and tightened with airplane dope. The wings were braced to the body with wooden struts and rigging wires. Like all World War I aircraft, it had fixed landing gear carrying inflatable rubber tires. The cockpit was small and cramped. Over 5,700 Camels were built, including marine versions that could take off from launching ramps erected on large warships; these versions had a folding fuselage for stowage aboard ship.

The Reputation

Two things are said of the Camel today: it was an effective "killer" of enemy aircraft, and it also had a bad habit of killing its own inexperienced pilots. As for the latter, the Camel's bad reputation was partially deserved and difficult for it to shake. The powerful Bentley, Le Rhone, or

Image Not Available

Clerget rotary engine, which was mounted only a few feet ahead of the pilot, created from 110 to 150 horsepower, as well as a great deal of torque in the direction that the engine and propeller were spinning. As the craft still weighed less than a ton when loaded, such a significant amount of weight (guns, pilot, and engine) at the front of the plane meant that turns in the direction of the engine's spin were considerably faster than turns in the opposite direction. Novice pilots could quickly find themselves out of control, especially when turning immediately after takeoff. Eventually, pilots became used to (and were warned of) this tendency and the Camel went on to great success; however, given that mishaps unrelated to combat cost the lives of over three hundred Camel pilots, the problem was more than passing.

The Result

Even with its early reputation, the Sopwith Camel was eventually to become, along with other British fighters such as the SE-5A and the two-seat Bristol Fighter, one of the distinguishing aircraft of the British aerial forces during World War I. Difficult to learn to fly, yet very capable in the hands of a competent pilot, the Camel helped the British forces achieve domination of the skies over the western front during the final years of World War I. Pilots flying the Camel in British and other air services shot down 1,294 enemy aircraft, while just over four hundred pilots died in combat while flying the Camel. This is a very high kill ratio, made even more impressive when it is realized that this was all accomplished from July, 1917, when the Camel entered service, to the end of the war in November, 1918—only sixteen months. The structural and design elements that made the Camel hard to learn to fly also made it extremely maneuverable, and it was especially fast in turns.

Famous Camel Pilots

Many pilots flew the Camel, and many became extremely effective, becoming aces—denoting that they had shot down five or more enemy aircraft. Perhaps the most famous was Canadian William Barker, who, while flying for the Royal Flying Corps and later the Royal Air Force, downed fifty enemy planes, forty-six of them in the same Sopwith Camel, and who eventually won the Victoria Cross. Kenneth Unger was the highest-scoring American ace who flew the Camel, with fourteen victories, and American Field Kindley, who also flew the Camel, shot down twelve. No list of Camel pilots would be complete without mentioning Canadian Roy Brown, who flew a Sopwith Camel and shot down ten aircraft; his last victory being over the "Red Baron," German ace Manfred von Richthofen.

Aftermath

Within a few years after the war, most Camels were scrapped; very few survive. One, which was flown by Field Kindley, is on display in the United States at the Aerospace Education Center in Little Rock, Arkansas. Interestingly, in the 1960's, the Camel again reached the world's attention with the cartoon character Snoopy, the big-nosed beagle in Charles M. Schulz's *Peanuts* comic strip, whose fantasy exploits in his Sopwith Camel fighting the "Red Baron" delighted millions.

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See also: Airplanes; Biplanes; Dogfights; Fighter pilots; Manufacturers; Military flight; Manfred von Richthofen; Royal Air Force; World War I

Sound barrier

Definition: A wall of superimposed sound waves along the leading edge of an aircraft traveling at the speed of sound in air.

Significance: When an aircraft punches through the sound barrier and travels at supersonic speeds, it creates a continuous pressure wave that reaches the ground as a sonic boom.

Doppler Effect

The Doppler effect, discovered by Austrian physicist Christian Johann Doppler in 1842, is the change in the observed frequency of a wave, of sound or light, for example, due to relative motion between the observer and the wave source. When observer and source approach each other, the emitted frequency of the waves is measured to be higher, due to the velocity of approach; the greater the relative speed, the greater the frequency shift. When the source and observer are receding from each other, the emitted frequency is measured to be lower, in direct proportion to the velocity of recession.

Although the Doppler effect applies to all types of waves, it is particularly noticeable for sound waves. When an ambulance speeds by, for example, the pitch, or frequency, drops noticeably. The effect is most easily explained by considering water waves on a placid pond created by a small insect jiggling its legs. The insect's movement creates a pattern of equally spaced concentric rings; each ring represents the crest of a wave traveling outward from the insect at constant speed. If the insect is traveling toward the left while jiggling its legs, the wave pattern is distorted; the rings are no longer concentric, but the centers of consecutive waves are displaced in the direction of motion. Although the insect has not changed the frequency with which it jiggles its legs, an observer at a position toward the insect's left encounters a higher frequency of waves because the waves are compressed in the direction of motion. An observer at a position to the insect's right perceives a lower frequency of waves. The waves are spread farther apart because the insect is moving away from the observer.

Although sound waves are invisible and spread into three dimensions, the same principle applies. When a source of sound approaches, the perceived frequency, or pitch, is higher than the emitted frequency, and the opposite is true for a receding source.

Wave Barrier

If the insect discussed above were to swim across the water at the same speed as the velocity of water waves while continuing to jiggle its legs at a constant frequency, the wave crests would be superimposed on one another directly in front of the insect rather than moving ahead of it. This wall of water may be considered a wave barrier, because the insect would have to exert considerable effort to swim over this barrier in order to travel at a speed greater than the wave velocity. However, after the insect had surmounted the barrier by exceeding the wave velocity, the water ahead would be smooth and undisturbed.

When an aircraft travels at the speed of sound in air, it also encounters a barrier of superimposed sound waves. The compression waves are stacked up along the leading edge of the aircraft, requiring some additional thrust for the aircraft to punch through. After the plane exceeds the velocity of sound, however, there are no further barriers to inhibit additional acceleration; the airplane may travel at supersonic speed.

Shock Waves

As the jiggling insect travels through water with a speed greater than the wave velocity, it produces the pattern in which each consecutive wave crest, represented by a circle, is located outside the previous crest. The wave crests overlap to form larger crests. This small wall of water, called a bow wave, has a solid "V" shape.

When an aircraft flies at a supersonic speed, the overlapping spherical sound waves form a cone of air pressure that grows in size until intercepted by the ground. This thin conical shell of compressed air is termed a shock wave. Just as a person floating in a tranquil lake will be hit by the bow wave of a speed boat traveling faster than the speed of water waves, people on the ground will be struck by the shock wave of a supersonic aircraft. This wave, called a sonic boom, is heard as a sharp cracking thunderclap.

Sonic Booms

The sound of a subsonic aircraft is perceived by a listener on the ground as a continuous tone. The shock wave produced by a supersonic airplane, consisting of many superimposed waves, occurs like an explosion in a single burst. Both processes consist of a burst of high-pressure air that creates a loud, unpleasant noise. In actuality, the shock waves produced by supersonic aircraft create a double sonic boom; the shock wave from the bow of the plane is a pulse of increased pressure that is followed a fraction of a second later by a negative-pressure pulse from the trailing edge of the aircraft. Overall, the pressure wave has the general appearance of the letter "N." This pressure shock wave is produced during the entire course of a supersonic flight and not only during the time when it passes the sound barrier, as is mistakenly believed. Because the width of the sonic boom trail is about 20 miles, and its length is the flight path, sonic booms can create considerable problems. First, there is the annoyance factor of people being startled or awakened by the loud, explosive noise. Because of sonic booms' intense and rapid pressure changes, sonic booms can destroy property in inhabited areas. Broken windows and structural damage are not uncommon. Finally, sonic booms can be problematic even in uninhabited regions; they have been known to topple rock structures in national parks.

Brief History of Supersonic Flight

The speed of sound at sea level is 760 miles per hour. The speed of sound decreases with increased altitude, so that at 50,000 feet, sound travels at 660 miles per hour. Because the wall of pressure termed the sound barrier differentiates subsonic from supersonic flight, the speed of sound is defined as a velocity of Mach 1. Mach 2, then, would be twice the speed of sound, and so on.

Although several attempts were made in the early 1940's to exceed the sound barrier, early jet planes of the period were not powerful or sturdy enough to succeed. When an aircraft reaches Mach 1, strong local shock waves form on the wings, and the flow of air around the plane becomes unsteady. As a result, the airplane is subjected to severe buffeting that interferes with the plane's stability and renders it difficult to control. In 1943, U.S. aeronautical engineers began working on the first airplane specifically designed to surmount these problems and withstand the tremendous air pressure of Mach 1 in order to obtain supersonic flight. This goal was realized on October 14, 1947, when Captain Charles E. "Chuck" Yeager of the U.S. Air Force smashed through the sound barrier in a Bell X-1 rocket plane. Although many supersonic flights at ever-increasing speeds were made over the next decade, the speed never exceeded Mach 2.5, because friction caused by the rapidly moving air overheated the outer shell of the airplanes.

Using jet engines specifically designed for supersonic flight, the North American F-100 Super Sabre jet fighter became the first jet capable of flying at supersonic speeds in level flight. The first supersonic bomber, the Convair B-58 Hustler, became operational in 1956. By 1963, the

X-15 rocket plane was able to fly 67 miles above the earth's surface at a speed exceeding Mach 6. The world's first supersonic transport (SST) plane, the Tupolev Tu-144, was tested by Soviet pilots in 1968. Britain and France jointly constructed the Concorde SST, which was designed to fly at Mach 2 and began commercial service in 1969. Since that time, however, the number of supersonic flights has been limited due to the high cost of fuel and the problems of sonic booms. In the United States, commercial supersonic flights are now restricted to transoceanic flights.

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See also: Aerodynamics; Aerospace industry, U.S.; Concorde; Doppler radar; High-speed flight; Hypersonic aircraft; Mach number; Supersonic aircraft; Andrei Nikolayevich Tupolev; X planes; Chuck Yeager

Southwest Airlines

Date: Founded in 1971
Definition: A major U.S. carrier.
Significance: Southwest is a leading short-haul, low-fare carrier in the southwestern United States.

In the early 1970's, Herb Kelleher and Rollin King were growing frustrated with short-haul flights in Texas and the Southwest. Kelleher and King believed that flights were not only too expensive but also not frequent enough to accommodate the needs of business travelers. The two decided to target this niche, and Southwest Airlines was born. On June 18, 1971, Southwest inaugurated service with flights between Houston, Dallas, and San Antonio. Southwest has since grown into a major U.S. carrier, with revenues in excess of $1 billion yearly, employing more than thirty thousand workers and operating more than 2,700 flights a day.

History

In 1971, Southwest Airlines inaugurated service among three Texas cities: Dallas, Houston, and San Antonio. At this time, Houston flights took off and landed in Houston Intercontinental Airport (now called Bush Intercontinental). Many passengers disliked Houston Intercontinental because it was located 23 miles north of downtown, entailing a 40-minute drive to take a 45-minute flight. Because of passenger frustration, Southwest in 1972 transferred all flights originating or terminating in Houston to Houston's Hobby Airport, a mere 7 miles from downtown.

The next year, 1973, marked Southwest's first profitable year. At this time, Southwest applied to the Texas Aeronautics Commission (TAC) for permission to extend service to the Rio Grande Valley.

During 1974, Southwest carried its one-millionth passenger. This year also marked a capital outlay for the company as it remodeled its Houston terminal by adding two new boarding gates and departure lounges, at a cost of $400,000.

The TAC did not approve Southwest's request to provide service to the Rio Grande Valley until 1975. The commission permitted four roundtrips to the valley via the Harlingen Airport each business day. The TAC must have been satisfied with Southwest's flights because in 1976, the commission gave Southwest clearance to fly to Austin, Corpus Christi, El Paso, Lubbock, and Midland/Odessa.

Several milestones for Southwest occurred in 1977: the airline carried its five-millionth passenger, and Southwest stock was listed on the New York Stock Exchange as "LUV."

Several organizational changes happened during the following year. After Lamar Muse stepped down as president, Herb Kelleher filled in as interim president, CEO, and chairman of the board. Later in the year, Howard Putnam was unanimously elected president and Chief Executive Officer. Kelleher stayed on as permanent chairman of the board.

Southwest Airlines continued to grow, and in 1979, the airline extended service to the first city outside of Texas: New Orleans, Louisiana.

In 1980, Southwest purchased its twenty-second Boeing 737. This plane was the first 737 in the fleet to be completely owned by Southwest Airlines.

In 1982, Kelleher took command as permanent president, CEO, and chairman of the board. Under his leadership, Southwest expanded its service area, spreading its wings to San Francisco, Los Angeles, San Diego, Las Vegas, and Phoenix. Southwest's next big expansion came in 1985, when the airline extended service to St. Louis, Missouri, and Chicago's Midway Airport. In 1989, service began from International Airport in Oakland, California.

In 1990, Southwest passed the billion-dollar revenue mark and became a major airline. With major airline status came an ever-widening geographic reach: in 1993, the company expanded to the East Coast and began service to Baltimore/Washington International Airport. Reaching out not only to the East Coast but also the Pacific Northwest, during the next year, 1994, Morris Air merged with Southwest. Service began to Seattle, Spokane, Portland, and Boise.

During this time, Southwest decided to take advantage of emergent technology to deliver better service to customers. Ticketless travel (travel with an electronic rather than a paper ticket) became available systemwide in January, 1995.

In 1996, Southwest started service into Florida: Tampa Bay and Fort Lauderdale in January, and Orlando in April. In October, Southwest inaugurated service from Providence, Rhode Island. Southwest started out 1997 with service to Jacksonville, Florida, its fiftieth city. Service to Jackson, Mississippi, was added in August. The following June, Southwest Airlines added service to Manchester, New Hampshire. In 1999, Southwest Airlines broadened service on the East Coast to include Islip, New York, in March and to Raleigh-Durham International Airport, in North Carolina, in June. Service to Hartford, Connecticut's Bradley International Airport

Events in Southwest Airlines History

1971: Southwest Airlines inaugurates service within Texas, between the cities of Dallas, Houston, and San Antonio.

1973: Southwest applies to the Texas Aeronautics Commission (TAC) to extend service to the Rio Grande Valley and completes its first profitable year.

1974: Southwest carries its one-millionth passenger.

1975: The TAC approves four roundtrips to the Rio Grande Valley via the Harlingen Airport each business day.

1976: Southwest gets clearance from the TAC to fly to Austin, Corpus Christi, El Paso, Lubbock, and Midland/Odessa and places its sixth Boeing 737 into service.

1977: The airline carries its five-millionth passenger, and its stock is listed on the New York Stock Exchange as "LUV."

1978: After Lamar Muse steps down as president, Herbert D. Kelleher fills in as interim president, chief executive officer, and chairman of the board. Later in the year, Howard Putnam is unanimously elected president and chief executive officer, and Kelleher remains as permanent chairman of the board.

1979: The airline extends service to the first city outside of Texas: New Orleans, Lousiana.

1980: Southwest purchases its twenty-second Boeing 737, the first 737 in the Southwest fleet to be completely owned by Southwest Airlines.

1982: Kelleher takes command as permanent president, chief executive officer, and chairman of the board. Southwest spreads its wings to San Francisco, Los Angeles, San Diego, Las Vegas, and Phoenix.

1985: Southwest extends service to St. Louis, Missouri, and Chicago, Illinois.

1989: Service begins from Oakland's International Airport.

1990: Southwest passes the one-billion dollar revenue mark, becoming a major airline.

1993: Southwest expands to the East Coast and begins service to Baltimore/Washington International Airport.

1994: After Morris Air merges with Southwest, service begins to the Pacific Northwest cities of Seattle, Spokane, Portland, and Boise.

1995: Southwest introduces "Ticketless Travel," or travel without a paper ticket, systemwide and adds service to Omaha.

1996: Southwest inaugurates service into Florida and from Providence, Rhode Island.

1997: Southwest initiates service to Jacksonville, Florida, the airline's fiftieth city, and later to Jackson, Mississippi.

1998-2000: Southwest Airlines continues to expand throughout the Northeast, with new service to Manchester, New Hampshire; Islip, New York; Hartford, Connecticut; Albany, New York; and Buffalo-Niagara, New York.

began on October 31, 1999. New service to New York's Albany International Airport began in May, 2000, and to Buffalo-Niagara International Airport in October.

Financial Information

Southwest's common stock is traded under the symbol "LUV" on the NYSE. Net income for 2000 totaled $625.2 million, a result of having carried 63.7 million passengers. Southwest flights in 2000 were 70.5 percent full, on average. The company took in a total operating revenue of $5.6 billion.

An important component of Southwest's revenue is its World Wide Web site (www.Southwest.com). In 2000, Southwest reported that $1.7 billion, or approximately 30 percent of its 2000 revenue, was generated from online bookings. Southwest's World Wide Web site saves the company money, because having customers make reservations over the Internet is approximately ten times less expensive for the company than having to pay travel agents to book reservations.

Fleet

As of January 24, 2001, Southwest operated 346 Boeing 737 jets. On average, planes in the company's fleet were 8.2 years old. Southwest's flights average 492 miles in length and last 1.5 hours. Each aircraft makes eight flights per day on average, spending about twelve hours a day in the air.

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See also: Air carriers; Airline industry, U.S.; Boarding procedures; Overbooking; Ticketing

Space shuttle

Date: Beginning on January 5, 1972

Definition: A reusable space launch vehicle developed by the United States to launch astronauts and large satellites into Earth orbit.

Significance: The space shuttle was the first reusable launch vehicle to carry humans into space.

Planning the Space Shuttle

The space shuttle program was initially conceived in the 1960's, when the National Aeronautics and Space Administration (NASA) began planning a comprehensive program for a permanent American presence in space. The plan included three components: a permanently crewed space station, a reusable vehicle to carry astronauts from Earth to orbit and back, and a space tug to move satellites around in orbit. However, the need to fund other national priorities resulted in cuts to the NASA budget at the end of the Apollo Program. Because this new space effort's cost far exceeded its budget, it was scaled back to include only the reusable launch vehicle, which was called the space shuttle. On January 5, 1972, President Richard M. Nixon officially announced the inauguration of the space shuttle program. NASA's ambitious schedule called for suborbital tests by 1977 and the first orbital tests by 1979. The shuttle was scheduled to begin regular launchings by 1980.

The Shuttle Vehicle

The space shuttle consists of three major components: a reusable, winged orbiter that carries the crew; a large external tank that holds fuel for the main engines; and two solid rocket boosters that provide most of the shuttle's lift during the first two minutes of flight. The space shuttle is designed to reach orbits ranging from about 115 miles to 400 miles high. Normally, space shuttle missions range from five to sixteen days in orbit. The smallest crew to fly on the shuttle was composed of two people, on the first few test flights, but the shuttle normally carries crews ranging from five to eight people, depending on the flight objectives. At liftoff, the space shuttle weighs about 4,500,000 pounds.

The orbiter, manufactured by the Space Division of Rockwell International, carries the crew, the payload, and the main propulsion system. The empty weight of the orbiter is about 150,000 pounds, approximately the same as that of a DC-9 jet aircraft. The crew compartment of the orbiter has three levels: the flight deck, the middeck, and a lower level equipment bay. The crew compartment is pressurized to 14.7 pounds per square inch with a mixture of 80 percent nitrogen and 20 percent oxygen, similar to the air pressure and composition at the earth's surface. The volume of the crew compartment is 2,325 cubic feet, about the equivalent of a 15-by-15-by-10-foot room.

The uppermost level of the crew compartment is the flight deck. The mission commander and the pilot are seated side-by-side in the forward portion of the flight deck. The mission commander and the pilot sit at workstations that contain the controls and displays used to guide the orbiter throughout the flight. Two seats for mission specialists are located directly behind the seats of the mission commander and the pilot. At the rear of the flight deck there are two overhead- and aft-viewing windows for observing orbital operations.

The middeck, which is directly beneath the flight deck, provides accommodations for additional crewmembers and contains three avionics equipment bays. Depending on the mission requirements, bunk sleep stations and a galley can be installed in the middeck. In addition, three or four seats of the same type as the mission specialists' seats on the flight deck can be installed in the middeck.

An airlock, located in the rear of the middeck, provides access to the payload bay. Normally, two extravehicular mobility units (EMUs) are stowed in the airlock. The EMU is an integrated spacesuit assembly and life-support system that enables flight crew members to leave the pressurized orbiter crew cabin and work outside the cabin in space. Removable panels in the middeck floor provide access to the equipment bay that houses the major components of the waste-management and air-cleaning and recirculating systems. This compartment has space in which to stow lithium hydroxide canisters, used to clean the air, and five separate spaces for crew equipment stowage. When on the ground, astronauts enter and exit the crew compartment through a side hatch in the middeck.

The payload bay, measuring 15 feet wide and 60 feet long, holds large payloads being carried to orbit. Two payload bay doors, each 60 feet long, are hinged at each side of the fuselage. The payload bay doors expose the payload bay to space when they are opened along the centerline. The back surface of the doors, which have a combined area of approximately 1,600 square feet, contains radiators that exhaust the heat generated by equipment on the orbiter. Seals on the doors provide a relatively airtight payload compartment when the doors are closed and latched.

The crew compartment of the orbiter does not contain sufficient space for experiments, and the payload bay is not pressurized, so astronauts working in the payload bay must wear spacesuits. To provide space for experiments, the European Space Agency (ESA) designed the Spacelab, a large, pressurized module that can be carried in the orbiter's payload bay. Astronauts enter the Spacelab through the airlock at the rear of the middeck of the crew compartment. The Spacelab provides electrical power and a pressurized working environment for astronauts to perform a variety of experiments.

The orbiter also contains the three liquid-fueled main engines. These engines burn liquid hydrogen and liquid oxygen, which is carried in the external tank attached to the orbiter. The top surface of the orbiter is covered with white silica material that protects the surface during reentry from temperatures of up to 1,200 degrees Fahrenheit. The bottom of the orbiter and the leading edge of the tail are covered with black silica heat-shield tiles, having very low thermal conductivity, which protect those surfaces from temperatures of up to 2,300 degrees Fahrenheit.

The orbiter's external tank, which was designed by Martin Marietta and built at NASA's Michoud Assembly Facility in New Orleans, Louisiana, contains all of the fuel, liquid hydrogen, and the oxidizer, liquid oxygen, for the orbiter's main engines. At the top of the external tank there is a conical nose cone that reduces the air drag on the vehicle and serves as a lightning rod. The oxygen tank, located beneath the nose cone, has a volume of 19,563 cubic feet. A 17-inch-diameter fuel line carries the oxygen to the orbiter with a maximum flow rate of 17,592 gallons per minute. The liquid hydrogen tank, which is located below the liquid oxygen tank, has a volume of 53,518 cubic feet. The 17-inch fuel line connecting the hydrogen tank to the orbiter has a maximum flow of 47,365 gallons per minute. Just before the shuttle reaches orbital velocity, the external tank is jettisoned, and it burns up on atmospheric entry.

The two solid-fueled rocket boosters are attached to the main tank. The solid rocket boosters are the largest solid-propellant motors ever flown and the first that were designed to be reused. The propellant mixture in each motor consists of ammonium perchlorate as the oxidizer, aluminum as the fuel, iron oxide as a catalyst, and a polymer binder that holds the mixture together. The fuel is shaped so that each rocket provides a high thrust at ignition and then reduces the thrust by approximately one-third after 50 seconds to prevent overstressing the vehicle during the time when it experiences maximum dynamic pressure. Because the solid boosters were too long to manufacture as a single unit, each booster consists of four segments. These segments are joined together using a system of clamps and O-ring seals, which are made of compressible material that fills the space in the joints to prevent leakage of high-pressure gas through the joints. Each solid booster weighs 1,300,000 pounds at liftoff and 192,000 pounds after the fuel has been burned. At liftoff, each of the solid boosters develops approximately 3,300,000 pounds of thrust. The solid rocket boosters also contain a parachute system, which allows them to descend into the Atlantic Ocean after use. They are recovered by ship and returned to the manufacturer for refurbishment and reuse.

The orbiter returns to Earth as a glider, using conventional flight controls and wings that provide lift. The wingspan is 78 feet. Each wing, constructed of aluminum alloy with a multirib-and-spar arrangement, has a maximum thickness of 5 feet and is approximately 60 feet long where it is attached to the fuselage. The main landing gear is stored in the wings and is extended only a few seconds before landing.

The Space Shuttle Flight Profile

The space shuttle is launched vertically from a transporter-launching pad that was modified from a Saturn V launching pad after the end of the Apollo Program. The shuttle can carry a crew of up to eight astronauts and can deliver a payload of up to 65,000 pounds into low-Earth orbit.

The space shuttle Columbia *is brought to Launch Pad 39B at the Kennedy Space Center in preparation for liftoff.* (NASA)

The liquid-fueled main engines ignite about seven seconds before the planned liftoff. A computer checks the performance of the main engines, which can be shut down if a problem is detected. If no problems are detected, the solid rocket boosters, which must burn until their fuel is exhausted, are ignited. At liftoff, the three main engines and the two solid-fueled booster rockets develop a total of more than 6,800,000 pounds of thrust. The solid rocket boosters, which provide most of the thrust to lift the space shuttle off the pad and up to an altitude of about 150,000 feet, burn for approximately two minutes. At an altitude of about 28 miles, just after they burn out, the solid boosters are jettisoned from the external tank by pyrotechnic separation devices. Eight small rockets on the solid boosters fire to carry them well clear of the orbiter. A parachute system slows the descent of the solid boosters, which are recovered from the ocean, about 170 miles from the launch site.

The external tank continues to provide fuel for the orbiter's three main engines until about eight minutes after liftoff. The main engines shut down at a speed just below orbital speed, and the external tank is jettisoned. After a short period of coasting, two small maneuvering engines, fueled from tanks on the orbiter, fire to place the orbiter in Earth orbit.

Environmental control and life-support system radiators, used to cool the orbiter's systems, are located on the interior of the payload bay doors. Once the orbiter has achieved orbit, the payload bay doors are opened to allow proper cooling of the spacecraft.

During the mission, the path of the orbiter can be adjusted using the maneuvering engines. Once the mission is completed, the maneuvering engines serve as retrorockets, firing opposite the direction of the orbiter's motion and slowing the orbiter so that it reenters the earth's atmosphere.

Space Shuttle Missions

The first space shuttle orbiter, named *Enterprise*, was unveiled to the public on September 17, 1976, when it was rolled out of the Rockwell International hangar in Palmdale, California. Initially, the *Enterprise* was used for a series of ground tests. During 1976 and 1977, the *Enterprise* was carried aloft by a specially modified Boeing 747 aircraft, allowing engineers to study the aerodynamics of the orbiter. On August 12, 1977, the *Enterprise* separated from the Boeing 747 at an altitude of 22,800 feet, allowing the flight crew, Gordon Fullerton and Fred Haise, to perform approach and landing maneuvers at Edwards Air Force Base in California. After a series of unpowered flight tests, the *Enterprise*, which was never intended for powered flight, was retired. A fleet of four shuttles, *Columbia*, *Challenger*, *Discovery*, and *Atlantis*, was built for orbital operations.

The space shuttle *Columbia* was launched from NASA's John F. Kennedy Space Center at Cape Canaveral, Florida, on its first flight on April 12, 1981. John W. Young, a veteran of NASA's Gemini and Apollo Programs, was the commander, and Robert L. Crippen was the pilot. This was a test flight, and the only payload carried on the mission was a Development Flight Instrumentation Package, which contained sensors and measuring devices to record orbiter performance and the stresses that occurred during launch, ascent, orbital flight, descent, and landing. Post-flight inspection of *Columbia* revealed that an overpressure wave that occurred when the solid rocket boosters ignited resulted in the loss of 16 heat shield tiles and damage to 148 others. However, *Columbia*'s first flight demonstrated that the shuttle could perform a safe ascent into orbit and return to Earth for a safe landing.

The first five space shuttle missions were flown by *Columbia*, while the other space shuttle orbiters were under construction. The sixth shuttle flight, launched on April 4, 1983, was the first mission of *Challenger*. This mission deployed the first Tracking and Data Relay Satellite (TDRS), part of the satellite network used to relay shuttle communications to the ground. A malfunction of the inertial upper stage booster, which moves the satellite from the low orbit of the shuttle into the higher orbit required for global communications, resulted in an improper but stable orbit. Propellant aboard the satellite was used over the next several months to move the TDRS into the proper orbit.

Between April, 1981, and January, 1986, the space shuttles completed twenty-four missions. On June 18, 1983, the shuttle *Challenger* carried the United States' first woman astronaut, Sally K. Ride, into orbit and deployed two communications satellites, Anik C-2 for Telesat Canada and Palapa-B1 for Indonesia. During the *Challenger* mission launched on February 3, 1984, the first untethered space walk took place. Astronauts Bruce McCandless II and Robert L. Stewart used the Manned Maneuvering Unit (MMU) to fly in space unconnected to the orbiter. This mission also launched three satellites, but two, the Westar-VI and Palapa-B2, were placed into a low, elliptical orbit when the Payload Assist Module rocket motor, which should have boosted them into a high, circular orbit, failed. The shuttle *Challenger* carried the Long Duration Exposure Facility (LDEF) into orbit on April 6, 1984. The LDEF, whose purpose was to expose various materials to the space environment to monitor their stability or degradation in space and to determine the flux of micrometeorites and orbital debris, was supposed to be retrieved and returned to Earth after about two years.

The orbiter *Discovery* made its first flight on August 30, 1984, on a mission that launched three communications satellites. This mission also deployed a 102-foot-long, 13-foot-wide solar wing, which tested several different types of solar cells being considered for future space missions and demonstrated that very large structures could be deployed in space. The Spacelab space laboratory flew three times: carried into orbit by *Columbia* on November 28, 1983, and by *Challenger* on April 29, 1985 and July 29, 1985. The shuttle *Atlantis* made its first flight on September 20, 1985.

On January 28, 1986, the twenty-fifth space shuttle mission was launched from the Kennedy Space Center. The space shuttle *Challenger*, after a night of below-freezing temperatures, lifted off on its tenth mission into space at about 10:40 A.M. eastern standard time, carrying a crew of seven astronauts: Francis R. Scobee, the commander; Michael J. Smith, the pilot; Judith A. Resnik, Ellison S. Onizuka, and Ronald E. McNair, all mission specialists; Gregory B. Jarvis, a payload specialist; and America's first Teacher in Space, Sharon Christa McAuliffe. Seventy-four seconds after the launch, *Challenger* was destroyed, killing all seven crew members. A subsequent investigation established that the previous night's low temperature had hardened the O-ring seals between the segments of the solid-fueled rocket boosters. One joint in the right solid rocket booster had developed a leak, and the hot gases cut through metal on the shuttle to cause the disaster.

NASA immediately suspended the space shuttle program while the shuttle's overall safety was evaluated. The solid-fuel rocket booster joints were redesigned and the shuttle orbiter underwent more than two hundred modifications before the shuttle fleet returned to service. An escape system was added to the orbiter to allow astronauts to escape from a crippled shuttle and parachute to Earth. Construction began on a new shuttle, named *Endeavour,* to replace *Challenger.*

Shuttle flights resumed on September 29, 1988, when the shuttle *Discovery* carried a crew of five astronauts, commanded by Frederick H. Hauck, into orbit. This mission placed another TDRS communications satellite into orbit. Subsequent shuttle flights performed a variety of functions. On April 24, 1990, the shuttle *Discovery* placed the Hubble Space Telescope (HST) into orbit. The Hubble was designed to be serviced in orbit by future space shuttle missions. The first Hubble-servicing mission, flown by *Endeavour* and launched on December 2, 1993, accomplished its three primary objectives: restoring the planned scientific capabilities of the Hubble by installing a corrective lens designed to compensate for the incorrect shape of the mirror; restoring the reliability of Hubble's guidance system; and validating the concept of servicing while in orbit. The shuttle *Columbia* was launched on January 9, 1990, to place the SYNCOM IV-F5 defense communications satellite in orbit and to retrieve the Long Duration Exposure Facility (LDEF), which had been stranded in orbit after the *Challenger* accident.

The space shuttles have launched several interplanetary spacecraft. On May 4, 1989, the shuttle *Atlantis* launched the Magellan spacecraft, which went into orbit around Venus and performed radar mapping of its surface. On October 18, 1989, the shuttle *Atlantis* launched the Galileo spacecraft, which went into orbit around Jupiter, exploring that planet and its moons. On October 6, 1990, the shuttle *Discovery* launched the joint ESA/NASA Ulysses spacecraft, which was placed on a trajectory to pass Jupiter, where its orbit was altered to explore polar regions of the Sun.

In 1984, the U.S. government decided to build a space station, similar to the one that had been in the original 1960's plan. In preparation for this new space station, NASA began a series of space shuttle missions to Mir, the Russian space station. As part of this project, Russian cosmonaut Sergei Krikalev, the first Russian to be a crew member on an American spacecraft, flew on the space shuttle *Endeavour* in March, 1995. In June, 1995, the space shuttle *Atlantis* carried out the first mission to dock with the Mir Space Station.

On October 11, 2000, the shuttle *Discovery* flew the one-hundredth space shuttle mission, carrying a large truss, the Pressurized Mating Adapter-3, four large gyroscopes, and two heat pipes to the International Space Station. Before the launching of the shuttle *Discovery* in March, 2001, on a mission to bring the second crew to the International Space Station, James Kelly, the pilot, noted that, twenty years after the inception of the space shuttle program, the shuttle had finally realized its initial goal of transporting people to and from a permanent workplace in low-Earth orbit. During its first twenty years of operation, NASA's space shuttle fleet carried more than 600 astronauts and placed more than 3 million pounds of cargo into orbit.

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See also: Accident investigation; Apollo Program; Crewed spaceflight; National Aeronautics and Space Administration; Spaceflight

Spaceflight

Also known as: Space exploration, space travel

Definition: Flight beyond Earth's atmosphere through the use of artificial satellites, space probes, or crewed spacecraft.

Significance: Spaceflight is considered the greatest scientific, technological, and human adventure of the twentieth century, allowing humans to explore what is considered by many to be the final frontier.

Background

Humans have long dreamed of leaving Earth to explore extraterrestrial worlds. Ancient writers told stories of trips beyond Earth, and natural philosophers speculated that heavenly bodies were made of an element completely different from terrestrial elements. In the sixteenth century, Polish astronomer Nicolaus Copernicus vastly expanded humanity's knowledge of the space containing these heavenly bodies by locating the Sun, instead of Earth, at the universe's center. As astronomical knowledge increased, storytellers imagined spaceflights of increasing sophistication.

In the nineteenth century, writers such as Jules Verne depicted space travel in elaborate technical detail. In the twentieth century, science-fiction writers described spaceflight with scientific accuracy, and their stories became more popular than they ever had been, as the practical means of going into space became a reality.

History

Just as Orville and Wilbur Wright had to solve several basic problems before achieving success in their first airplane, so, too, did spaceflight pioneers need to solve such problems as discovering a way to escape Earth's gravity. Rockets were first proposed for spacecraft propulsion in the twentieth century. The Russian engineer Konstantin Tsiolkovsky wrote extensively on the theory of spaceflight, including the need for multistage rockets, where two or more rockets are ignited in turn. The American physicist Robert H. Goddard designed, built, and launched the first liquid-fueled rockets. During World War II, the German rocket pioneer Wernher von Braun led a team of scientists who developed the first rocket-powered ballistic missile. Although the Germans designed this V-2 as a weapon, it became the model for all rockets—military, scientific, civilian, and commercial—that followed it.

Toward the end of World War II, the U.S. and Soviet military captured German scientists and engineers who had worked on the V-2 project. These scientists formed the core of postwar rocket-research programs. The United States launched more than fifty captured V-2 rockets and began using two-stage rockets for upper-atmosphere studies. Some of these vehicles achieved spaceflight, reaching the point where space begins, about 62 miles (100 kilometers) above Earth's surface. However, they did not have enough speed to go into orbit.

The Soviet Union was the first country to achieve orbital spaceflight when Sputnik 1 began to circle Earth on October 4, 1957. This first artificial satellite ushered in the age of spaceflight. A month later, the Russians launched Sputnik 2, which contained the dog Laika, the world's first space traveler.

These first Soviet spaceflights created a sensation around the world and especially in the United States, where it had long been assumed that Americans would be the first to achieve spaceflight. The Sputnik flights did much to change the nature of the Cold War from a political conflict between the United States and the Soviet Union to a comprehensive competition involving science, technology, and economics. Spaceflight became a symbol of the achievements of two different societies, capitalist and communist.

After civilian rockets failed to launch American satellites, President Dwight D. Eisenhower turned to the military for assistance. Five days after Sputnik 2 entered orbit, the U.S. Army used a Jupiter C rocket to orbit Explorer 1, whose instrumentation had been developed by University of Iowa physics professor James Van Allen. This Explorer mapped a doughnut-shaped region of high radiation surrounding the Earth that was later named the Van Allen radiation belts.

After the Soviet Union launched Sputnik 3 on May 15, 1958, U.S. leaders realized that the United States was falling behind in the space race. An acrimonious debate between Congress and the Eisenhower administration ensued, with the final resolution that the U.S. space program needed an effective legislative foundation. This legislation, the National Aeronautics and Space Act of 1958, created a civilian agency to explore space: the National Aeronautics and Space Administration (NASA). The act made no mention of crewed spaceflight, but its broad charter gave NASA the responsibility for the scientific, but not military, exploration of space.

During the first few years of the space age, uncrewed spaceflight characterized both U.S. and Soviet programs. These uncrewed spaceflights ranged from satellites in low-Earth orbit to probes aimed at interplanetary space. The first successful lunar probe was the Soviet Union's

Luna 1, which flew by the Moon in January, 1959. In March of that year, the United States Pioneer 4 glided by the Moon, and in September, the Soviet's Luna 2 became the first human artifact to land on the Moon. A month later, the Russians used their circumlunar probe Luna 3 to photograph the far side of the Moon.

Soon after these uncrewed satellites and probes were launched, both Soviet and American scientists began work on crewed space vehicles. Because of their lead in large rockets, the Soviet Union was able, on April 12, 1961, to launch the world's first crewed spacecraft, Vostok 1, a 3-ton sphere with a 2-ton service module. Soviet cosmonaut Yuri Gagarin thus became the first person to orbit Earth. After Gagarin's single orbit and safe return to Earth, the Soviet Union achieved several firsts and set several records. It launched several endurance record-setting crewed spaceflights and had a cosmonaut take the first space walk. Furthermore, Vostok 6 was piloted by Valentina Tereshkova, the first woman to make a spaceflight. The Soviets were also the first to orbit a spacecraft containing three cosmonauts.

The initial U.S. program for crewed spaceflight was called Mercury, and it became the responsibility of the newly formed NASA. A few months into John F. Kennedy's presidency and less than one month after Gagarin's flight, Alan Shepard became the first American astronaut launched into space, though his suborbital flight in a Mercury capsule lasted only about fifteen minutes. The first American orbital flight was made by astronaut John Glenn on February 20, 1962. Other Mercury flights stretched the spacecraft's orbital time to more than one day, and scientists and astronauts gained much valuable experience and information from the program, including the fact that humans should be active pilots rather than passive passengers during the missions.

While the United States and the Soviet Union developed their crewed spaceflight programs, both countries continued to develop uncrewed satellites and probes. For example, Americans launched the Television Infrared Observations Satellite (TIROS), the first weather satellite, in 1960, and it recorded more than 23,000 cloud images. Mariner 2, sent off by U.S. scientists in 1962, became the first spacecraft to explore another planet, Mars. From 1962 to 1965, the United States sent a series of Ranger probes to the Moon to take close-up photographs of its surface. The first successful soft landing on the Moon was that of the Soviet Union's Luna 9 on February 3, 1966. The United States achieved a successful soft landing on June 2, 1966, with its Surveyor 1. On April 3, 1966, the Soviet's Luna 10 became the first probe to successfully orbit the Moon. The first American lunar orbiter went around the Moon on August 14, 1966. With these and other lunar projects, it seemed obvious to many that the United States and the Soviet Union were engaged in a race to land humans on the Moon.

Crewed Lunar Spaceflights

The early Soviet successes in spaceflight placed intense political pressure on the U.S. president and lawmakers to find some accomplishment by which the United States could pull ahead of the Soviet Union. President Kennedy's advisors suggested a crewed landing on the Moon as such an achievement, and on May 25, 1961, Kennedy stood before Congress to ask the nation to "set the goal of landing a man on the Moon, before this decade is out, and safely returning him to Earth."

To attain this goal, NASA officials first had to decide how to get to the Moon. Eventually NASA scientists chose a lunar orbit rendezvous method, and consequently astronauts practiced rendezvous and docking techniques as part of the Gemini Program, a series of increasingly demanding missions with a two-person spacecraft. The Gemini missions had three phases. In the earliest missions, which began in 1965, astronauts tested the spaceworthiness of the Gemini spacecraft. They also performed the first American extravehicular activities (EVAs) and made the first-ever use of a personal propulsion unit. The middle Gemini missions, Gemini 4, Gemini 5, and Gemini 7, explored human endurance in space by progressively extending stays to two weeks, the maximum time that an Apollo lunar trip was expected to take. The final Gemini missions allowed astronauts to master the techniques of chasing a target vehicle and docking with it.

Apollo was the name of the mission to land men on the Moon. Tragically, before its first orbital trial, the Apollo Program came to an abrupt halt when, on January 27, 1967, a fire killed three astronauts, Roger Chaffee, Virgil "Gus" Grissom, and Edward White, in the Command Module (CM) during a countdown exercise. The spacecraft had a pure oxygen atmosphere and much flammable material, and a spark caused by an electrical short circuit ignited flames that rapidly engulfed the astronauts, who died of asphyxiation. Until the fire, the Apollo Program had proceeded without major difficulties, but these deaths delayed the first missions. NASA scientists redesigned the CM by minimizing flammable materials and changing the prelaunch cabin atmosphere to a mixture of 60 percent oxygen and 40 percent nitrogen.

The success of the Apollo missions depended on the gigantic Saturn V rocket that had been developed by

Wernher von Braun. The initial missions in the Apollo series were uncrewed tests of the Saturn and CM engines. For example, on April 4, 1968, the CM and the Lunar Module (LM) were tested on Apollo 8. The first crewed test, which began on October 11, 1968, was Apollo 7, the objective of which was to test the safety and reliability of all the spacecraft's systems. The first spaceflight involving humans leaving Earth orbit and traveling to the Moon was Apollo 8. This flight began on December 21, 1968, and the spacecraft went into lunar orbit on December 24, when the astronauts described the Moon's surface and read a passage from the first book of the Bible. The Apollo 9 mission in March, 1969, tested the Command and Service Module (CSM) and the LM in Earth orbit, and the Apollo 10 mission in May tested the CSM and LM in a lunar orbit.

Apollo 11, the lunar landing mission, took place between July 16 and July 24, 1969. On July 20, Neil Armstrong, after adeptly piloting the LM to its destination, became the first person to step onto the surface of the Moon, and he was later joined by Edwin "Buzz" Aldrin. Armstrong and Aldrin spent about two and one-half hours collecting rocks and setting up scientific experiments. Several hours later, their capsule, the *Eagle*, rocketed from the Moon to rendezvous with the CSM, the *Columbia*, which was piloted by Michael Collins. All three astronauts returned safely to Earth, where they received a jubilant reception.

From 1969 through 1972, six other Apollo missions traveled to the Moon, although Apollo 13 was unable to land on the lunar surface because of an explosion in one of its oxygen tanks. The Apollo 13 crew had to use the life-support systems of the LM *Aquarius* to help them survive the long trip back to Earth. NASA engineers consequently redesigned the oxygen tanks, and the final four Apollo lunar missions were able to explore the Moon safely and extensively. The hundreds of pounds of Moon rocks that were returned to Earth have given scientists a deep understanding of the origin and evolution both of the Moon and of the entire solar system.

Spaceflight After Apollo

Travel to the Moon was a risky and expensive enterprise, and neither the United States nor the Soviet Union made the trip in the 1980's and 1990 s. Critics of crewed spaceflight pointed out that science was much better and more inexpensively served by space satellites and probes. In the three decades after Apollo, robotic explorers such as Viking, Voyager, and Galileo proved to be highly efficient knowledge-gatherers. In 1976, two Viking spacecraft arrived at Mars: an orbiter that photographed the planet from above and a lander that analyzed rocks on the surface.

In 1977, two Voyagers were launched by NASA to start their twelve-year journey to the outer reaches of the solar system. The scientific instruments and cameras on the Voyagers sent back highly detailed information about the giant planets of Jupiter, Saturn, Uranus, and Neptune, along with the planets' fifty-seven moons. Voyager highlights included dramatic pictures of the turbulent storms of Jupiter's complex atmosphere, revelations of the complexities of Saturn's many rings, active volcanoes on Jupiter's moon Io, Neptune's Great Dark Spot, and nitrogen geysers on Neptune's moon Triton.

In 1997, Galileo became the first spacecraft to orbit an outer planet, and it has gathered much useful information about Jupiter's moons. The Soviets, too, used robotic probes in their scientific studies of the solar system. For example, in 1975, Venera 9 landed on the surface of Venus and returned the first pictures of its rocks and soil.

These uncrewed missions did not mean the end of crewed explorations of space. In 1971, Soviet scientists launched Salyut, the world's first space station. The Americans later launched their own space station, Skylab, which was visited by three-person crews in the 1970's, during which time astronauts made detailed studies of Earth's continents, oceans, and atmosphere. In 1975, the United States and the Soviet Union cooperated in the first international docking in space, when astronauts and cosmonauts performed an orbital rendezvous between an Apollo and a Soyuz capsule.

To make crewed spaceflight less expensive and more frequent, NASA developed the Space Transportation System (STS), commonly known as the space shuttle. Because landings at airfields are much less expensive than splashdowns at sea, and because it makes economic sense to reuse rockets, NASA engineers designed the space shuttle as a winged vehicle that was launched as a rocket, with two recoverable rocket boosters, and landed as an airplane.

In 1981, the space shuttle *Columbia* made its first flight. The other orbiting space shuttles of the 1980's and 1990's were *Challenger, Atlantis*, and *Discovery.* The missions of these shuttles included launching artificial satellites and retrieving them for servicing and repairs; performing scientific experiments in space; conducting secret military missions; and launching commercial communication satellites.

Despite NASA's aim for routine trips to space, the shuttle was plagued with problems, most notably the *Challenger* explosion on January 28, 1986. All seven crew members, including Sharon Christa McAuliffe, a New Hampshire schoolteacher, were killed. NASA stopped all shuttle missions while a special commission appointed by President Ronald Reagan studied the accident in order to determine the cause of the accident and the prevention of future such tragedies. The cause was a failure of a rubber ring that sealed the joint between two segments of one of the rocket boosters. To prevent any recurrence of this disaster, NASA engineers redesigned the booster joints and added a bailout system that improved chances for crew survival in a crisis. The space shuttle resumed flying on September 28, 1988, with the liftoff of a redesigned *Discovery.*

One of the successes of the revamped STS was the Hubble Space Telescope (HST), which was launched from an orbiting shuttle in 1990. The HST was an uncrewed observatory far above the atmosphere of the earth, whose haze, clouds, and turbulence hampered telescopes on the ground. Unfortunately, after the HST was in orbit, astronomers discovered a problem with its mirror that seriously hindered its effectiveness. A shuttle repair mission in 1993 helped the HST achieve its astronomical potential. The HST was then able to take dramatic photographs of star births in the Eagle nebula and of galaxies 10,000,000,000 light-years away. It also measured an unimaginably gigantic burst of gamma rays in a distant galaxy that is the most powerful explosion ever observed.

The 1980's and 1990's were also characterized by an increasing number of spaceflights from countries other than the United States. On February 20, 1986, the Soviets launched the large Mir Space Station, which remained in orbit until 2001, when it was manipulated to fall harmlessly into the Pacific Ocean. During Mir's fifteen-year existence, cosmonauts set endurance records and learned much about how humans can live for long periods in space. After the Soviet Union ceased to exist in 1991, Russia took over the operation of Mir. Space cooperation between America and Russia resumed in 1995, when the space shuttle began to dock with Mir, which was periodically occupied by astronauts from various countries, including the United States.

With the end of Mir, crewed spaceflight centered on the International Space Station (ISS). The idea behind ISS was to share among several nations the cost of the construction and operation of a large space station. However, the structure and timetable of the ISS was continually changed during the presidencies of Ronald Reagan and Bill Clinton. The United States, Canada, Japan, Russia, and the European Space Agency (ESA) agreed to cooperate in building the redesigned ISS, whose construction actually began in outer space in 1998. The completed space station, planned to be the size of a football field, is the focus of spaceflights in the twenty-first century.

The participation of several nations in ISS was but another indication of the increasing involvement in spaceflight of countries around the world. Although the United States and the Soviet Union monopolized the early history of spaceflight, France launched its first satellite in 1965, and Britain its first in 1971. Fourteen nations founded the ESA in 1975 to combine their economic and scientific resources to develop new spacecraft for various missions. One of ESA's achievements was the space probe Giotto, sent to study Halley's comet in 1986. Japan also sent a probe to Halley's comet, and the nation's Advanced Earth Observing Satellite, launched in 1995, has gathered important information on Earth's lands, seas, and atmosphere. Other nations that have become actively involved in spaceflight are China, India, Canada, Israel, Australia, Brazil, Sweden, and South Africa.

Another trend of the late twentieth and early twenty-first centuries has been the commercialization of spaceflight. Various communications satellites have proved to be successful moneymakers for several companies. Some companies and governments have begun research on commercial crewed spaceflight, but these efforts have encountered serious difficulties because of the high cost of spaceflight. Similar problems have hindered plans for interplanetary travel, such as a crewed voyage to Mars. Critics of crewed spaceflight argue that it redirects funds from useful uncrewed programs and from important social and medical programs. In contrast, enthusiasts of crewed spaceflight emphasize the dreams that have energized scientists and engineers throughout history and the ineradicable desire to explore other worlds.

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See also: Aerospace industry, U.S.; Apollo Program; Wernher von Braun; Crewed spaceflight; Gemini Program; Robert H. Goddard; Manufacturers; Mercury project; National Committee for Aeronautics; National Aeronautics and Space Administration; Orbiting; Reentry; Rockets; Satellites; Saturn rocket; Space shuttle; Sputnik; Konstantin Tsiolkovsky; Uncrewed spaceflight; Uninhabited aerial vehicles; Vanguard Program

Spanish Civil War

Date: From 1936 to 1939

Definition: A military conflict resulting from a Nationalist rebellion, led by General Francisco Franco, against Spain's Republican government.

Significance: The Spanish Civil War has been considered the precursor to World War II and the testing ground for air power, including the German military tactic of the Blitzkrieg.

Background

Air power proved to be a major factor in the Spanish Civil War, a fratricidal conflict between Spain's two major antagonists during the 1930's. The Spanish Civil War resulted in the deaths of more than 300,000 combatants, of another 100,000 killed in murders and executions, and perhaps of an additional 200,000 who died from starvation and disease. Moreover, because most of the major European powers had become involved to a greater or lesser extent before the conflict finally concluded in March, 1939, the Spanish Civil War has been characterized as the opening round of World War II.

The war began in July, 1936, when Spain's conservative faction, subsequently known as the Nationalists, rose up in an attempt to overthrow the country's legitimate government, the Republicans, or Loyalists. Backed by the country's wealthy elite and the Catholic Church, a group of army officers started an insurrection in Spanish Morocco, across the Mediterranean Sea in North Africa. Spain's Republican government, also known as the Popular Front, supported by a wide spectrum of leftist elements and most of the country's urban population, reacted immediately to the threat.

The Popular Front government quickly secured the support of the Soviet Union, and, to a lesser extent, the governments of France and Great Britain. The latter two countries, in backing Spain's legitimate government, sought to stress the doctrine of nonintervention in what they considered Spain's internal affairs. Despite their sympathy for the Republicans, the French and British offered little in the way of material assistance.

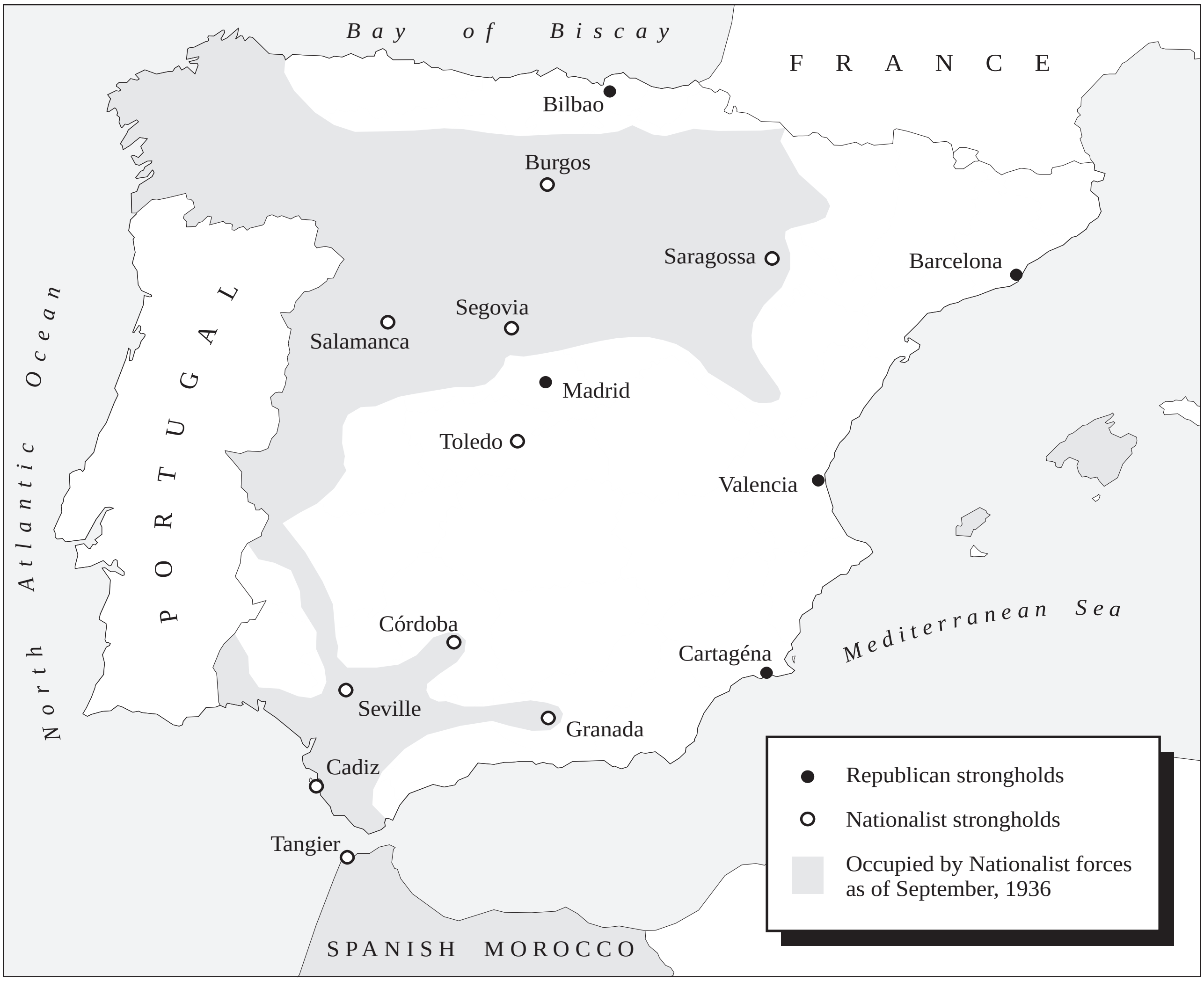
The army rebels, led by Francisco Franco, Spain's youngest general, secured the backing of German chancellor Adolf Hitler and Italian dictator Benito Mussolini. Germany and Italy quickly began to furnish aid to the Moroccan rebels, who needed to transport their forces to the Spanish mainland. Also siding with Franco, although more or less surreptitiously, was Portugal's dictator, Dr. António de Oliveira Salazar, who feared the spread of the leftist ideology espoused by the Spanish Republicans to his own country.

Republican Spain itself had little in the way of a military force by which to defend itself against the rebel threat. Most of the regular army had joined the Nationalists, leaving the government's defense in the hands of inadequately armed and trained workers' militias. The Republicans had to acquire materials from abroad to counterbalance the military strength of their adversaries.

Foreign Assistance

Mussolini had had strong contacts with the Spanish monarchist government that had preceded the Popular Front. After the civil war commenced, he immediately pledged Italian aid to Franco's Nationalists. Both parties announced themselves as strongly anticommunist and saw the Loyalists as ideological enemies.

In the month following the outbreak of the rebellion in Morocco, Mussolini dispatched a number of trimotor Savoia bombers to both Melolla, Morocco, and Seville, Spain. The aircraft served both to bomb Loyalist naval vessels and military installations and to transport members of Franco's Moroccan troops to the Spanish mainland. Mussolini sent more than seven hundred aircraft to the Nationalists in the course of the war. By 1939, some 192 Italian pilots were serving in the Nationalist air force.



Although Hitler sympathized with Mussolini's ideological quarrel with the Republicans, his own decision to come to Franco's aid had much more practical applications. First, he wanted an ally, or at least a neutral power, on France's southern flank that would allow German forces access to the western Mediterranean and the Atlantic Ocean in the event of future hostilities. German submarines later used Spanish harbors to refuel and repair their submarine fleet during World War II. Hitler also sought to secure from Spain foodstuffs, wool, copper, and iron and pyrite ores to feed his war machine. Significantly, participation in combat against the Loyalist forces gave the Germans the opportunity to develop tactics that would be employed in the ensuing world war.

Within a month of the commencement of hostilities, Germany had dispatched eighteen new German Junkers trimotor bombers and six pursuit planes as well as thirty German pilots. As had the Italians, the Germans also furnished a substantial number of transport planes to aid the transfer of Franco's troops, especially the hardened and tough Moroccans, to the mainland. These airlifts became the first major aerial troop transports in military history.

The German fighters ordered by Hitler to Spain adopted the name the Condor Legion. They represented the best military force and equipment available in Germany at the time. Some nineteen thousand Germans served in the Condor Legion, whose equipment included planes, tanks, antiaircraft guns, artillery, transports, and seaplanes.

By war's end, the Germans had tried out twenty-seven different types of aircraft in Spain. In the combat's final year, they had replaced the Heinkels He-51, an inferior airplane, with what proved to be the fastest fighter used in the war, the Messerschmitt Me-109E. The German ace Captain Werner Mölders shot down fourteen enemy planes. Over the course of the conflict, Germany produced a total of fifteen aces, fighter pilots with five or more kills.

Many leftists in the French government had initially expressed support for Spain's Loyalist administration, but France nevertheless refused to supply arms to the Madrid government. Many of France's conservative and religious factions sided with the rebels. The French chose to take the route of nonintervention, even though the Italians and the Germans had already begun to supply Franco's forces with massive amounts of military aid, especially in terms of air power.

At the civil war's commencement, the Spanish government bought a small, inadequate supply of armaments on France's open market. The French writer André Malraux personally rounded up a number of aircraft, hired pilots to fly them, and delivered them to Spain. The aircraft involved were not state of the art, consisting of about thirteen unarmed Dewoitine and six Potex fighters. Malraux organized the Escuadrilla España, also called the First International Air Squadron, composed of volunteers and mercenaries, which represented the main air support for the Loyalist forces in the early stages of the war. At its beginning, Republican Spain's air force had consisted of only about sixty planes, twenty-five of which were fit for combat.

As did the French government, the British government, with a labor majority, expressed sympathy for the Loyalist cause. The British joined the French in maintaining a hands-off attitude in the struggle. They believed that the war would spread throughout Europe if they and the French entered the war on the Republican side. As events unfolded, however, a war involving most of Europe did break out as the Spanish Civil War itself came to a close in 1939.

The Soviet Union proved to be the only ally of Republican Spain that contributed any substantial aid to that country. The Russians provided both pilots and approximately eight hundred aircraft, consisting mostly of Polikarper 1-15's, called "Chatas," and Moskas. They also furnished military experts, guns, and tanks.

However, the distance from Russia to Spain proved to be a major obstruction in the Soviet's aid program. Few Russian ships of the type needed to move this war matériel were available. Most of the equipment had to be moved by water. Any ships seeking to deliver goods to the Loyalists faced Italian and German fighter aircraft and bombers.

Despite this harassment, the Soviet Union managed to make some fifty shipments to Republican Spain during the course of the war. The Republicans responded by paying the Soviet Union more than 500 tons of gold, valued at $518 million, from the Spanish treasury. Much of the equipment and ammunition performed poorly once employed in battle, for the Soviets had shipped a great deal of miscellaneous armaments for which they no longer had any use. The tanks and planes, however, did prove to be critical to the Republican defensive effort and protected Madrid itself from capture for most of the conflict.

Although Soviet leader Joseph Stalin wanted to keep the nation's aid program under wraps, the Soviets did make another major contribution to the Loyalist effort. They began a worldwide campaign to induce leftists and leftist sympathizers to join the ranks of the Republican government in their resistance to the Nationalists and their German and Italian allies. The International Brigades' forces broke down into separate national units. The Eleventh Brigade consisted of anti-Nazi Germans; the Twelfth, of a combination of Germans, Italians and French; the Thirteenth, of Poles, Czechs, and other Eastern Europeans; the Fourteenth, of French and Belgians; and the Fifteenth, of British, and North and South American volunteers. Malraux's First International Air Squadron had volunteers and mercenaries from countries throughout the world.

The Progress of the War

Despite the heroic efforts of the Spanish workers and their foreign volunteers, the poorly armed and equipped Loyalists proved in the long run to be no match for Franco's regulars and his Italian and German allies. The Soviet Union, in its attempts to supply the Republican government, encountered increasing difficulties from both the aggressive German and Italian interference with shipping and the French refusal to allow supplies shipped into their seaports to cross the frontier into Spain.

The Nationalist air force, composed primarily of German and Italian aircraft, flew over Republican positions with impunity, subjecting the major cities held by the government to regular bombing attacks. The Nationalists had gained permanent air supremacy by as early as October, 1936. On April 26, 1937, forty bombers of the Condor Legion attacked the northern Basque city of Guernica. Although the city was not an important military target, it was virtually destroyed, with more than one thousand civilian casualties from among the city's seven thousand inhabitants. The Germans would subject enemy cities to similar degrees of intense destruction during World War II.

As the Loyalist cause continued to deteriorate, aid furnished by foreign allies began to falter. The Soviet pilots who had made up a large part of the barely surviving Republican air force left the combat area by late 1937. Reduced to perhaps seven thousand volunteers near the conclusion of the war, the International Brigades withdrew at the request of the Spanish Republican government itself in November of 1938, ostensibly in a vain attempt to appeal for the withdrawal from Spanish soil of all foreign troops on both sides. Over the course of the war, the poorly armed Brigade forces suffered almost twelve thousand casualties: French, German, Italian, American, and Eastern European fighters who gave their lives in the struggle against Fascism.

Aftermath

Undoubtedly, the nonintervention pact signed by Great Britain and France played a major role in the ultimate defeat of the Spanish Republican government. Both Germany and Italy had poured both personnel and equipment into the Nationalist campaign. By the war's end, the Germans and Italians made up the bulk of the Nationalist military effort. Soviet aid, in contrast, had to be moved far greater distances and under constant attack. Despite the support of the majority of Spain's population, the Republican government could not survive Franco's rebellion.

Carl Henry Marcoux

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See also: Antiaircraft fire; Bombers; Fighter pilots; Guernica, Spain, bombing; Luftwaffe; Messerschmitt aircraft; Military flight; World War II

Spirit of St. Louis

Also known as: Ryan NYP (New York-to-Paris)
Date: Built in 1927
Definition: The first airplane to fly solo across the Atlantic, from New York to Paris, piloted by Charles A. Lindbergh.
Significance: Lindbergh's New York-to-Paris flight in the *Spirit of St. Louis* further proved the feasibility of transatlantic flight, changing the face of civil and military aviation.

In 1927, there was no more famous aviator in the world than Charles A. Lindbergh, and no more famous aircraft than the *Spirit of St. Louis*, the California-built Ryan monoplane that he flew alone and nonstop from New York to Paris that year. The flight was made in an attempt to win the $25,000 Orteig Prize, to be awarded to the first person to make a nonstop flight between New York and Paris.

Raymond Orteig offered his prize of $25,000, for the first pilot to fly nonstop from New York to Paris, in 1919. Originally, the prize was open for a period of five years, but airplane technology was not yet advanced enough for anyone to even make the transatlantic attempt in the early 1920's. When the prize was still unclaimed in 1926, Orteig extended the prize's term to 1931. By this time, transatlantic flight had begun to seem technically possible, and Lindbergh, who was already making a name for himself as a barnstormer, mechanic, and airmail pilot, was one of several aviators who decided to try his luck.

In 1926, Lindbergh raised $15,000 in backing from a consortium of St. Louis businessmen and set out to find a plane. Most people believed that multiple engines were the key to long-distance flight, but Lindbergh believed that he would have a better chance of success with the lightest possible plane, thereby increasing his fuel efficiency. He initially tried to purchase a single-engine plane from Columbia Aircraft Corporation, a New York company, but negotiations failed when the president of Columbia Aircraft wanted too much control over the project.

The Aircraft

Lindbergh had previously contacted the Ryan Aeronautical Company, a San Diego aircraft manufacturer, and in

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February, 1927, Lindbergh finally contracted with the company for the aircraft. The plane, which cost $10,580, was custom-built for that one flight. Named for Lindbergh's financial backers, the *Spirit of St. Louis* was a high-wing monoplane constructed out of steel tubing, an aluminum cowling over the nose, spruce, and cotton cloth painted with aircraft dope covering the body of the plane. Much of the space in the aircraft was taken up by fuel tanks, according to Lindbergh's desire to fly solo so as to save weight and carry more gasoline. The pilot's position was behind the large fuel tank positioned just behind the engine, necessitating a small periscope for forward vision (the pilot could also look out of side windows); the plane carried a total of 451 gallons of fuel. The engine was a remarkably reliable 223-horsepower, nine-cylinder Wright Whirlwind air-cooled radial engine mounted in the nose of the aircraft. The plane was 27 feet, 8 inches from nose to tail and 46 feet from wingtip to wingtip. She weighed 2,150 pounds empty and 5,135 pounds fully loaded.

The Flight

Though U.S. Navy flying boats had made a crossing from Newfoundland to Portugal, with a stop in the Azores, in May, 1919, and British Royal Air Force officers John Alcock and Arthur Whitten Brown had flown nonstop from Newfoundland to Ireland the next month, Lindbergh's would be the first solo nonstop transatlantic flight, and his route was considerably longer. Lindbergh planned his flight carefully, and took off from Roosevelt Field in New York at 7:54 A.M. on May 20, 1927. At 10:24 P.M. on May 21, Lindbergh landed in Paris after a 33.5-hour flight, having fought exhaustion (he had not slept for twenty-four hours before his flight), hallucinations, and ice formation on the plane during the flight. Upon landing, the plane was mobbed by thousands of spectators and slightly damaged before it could be taken into a hangar. A week later, the plane repaired, Lindbergh flew the plane to Belgium, then to England, from where he and the crated airplane returned to the United States on an American cruiser.

The Aftermath

After a year of touring the United States and South America, the remarkable plane was donated on April 30, 1928, to the Smithsonian Institution, where it is now part of the permanent collection of its National Air and Space Museum in Washington, D.C. The flight catapulted Lindbergh (soon dubbed "Lucky Lindy") to a worldwide fame that would never leave him; he spent the rest of his life as an ambassador for the advancement of aviation and, later, for environmental causes. The accomplishment of the plane itself was also remarkable for many reasons. It showed that a small, single-engine aircraft could be rugged and reliable enough for the rigors of transatlantic flight; it further proved that nonstop crossings were feasible, and it showed that airplanes in general had reached a level of safety and reliability that meant they could be used for regular transportation.

Robert Whipple, Jr.

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See also: Airplanes; Charles A. Lindbergh; Monoplanes; Record flights; Transatlantic flight

Spitfire

Definition: The most important single-seat fighter used by the British Royal Air Force (RAF) during World War II.

Significance: The Spitfire served on the front lines of every theater of World War II and was produced in greater numbers than any other Allied fighter.

Evolution

Reginald J. Mitchell, the chief designer of the Supermarine company, designed the Supermarine Type 224 in response to a request for new RAF fighter aircraft to meet Air Ministry Specifications. The Type 224 flew for the first time in February, 1934. However, Mitchell was dissatisfied with the plane even before it flew and believed he could design a much better fighter aircraft by ignoring the specification. The Supermarine company undertook the work as a private venture, and the new design, the Spitfire, was accepted by the Air Ministry in January, 1935. Mitchell had previously designed a successful series of racing seaplanes for which the Rolls-Royce company had produced a powerful engine. Development of this engine produced the Rolls-Royce Merlin, which was chosen to power the Spitfire.

Description

The Spitfire was a low-wing, single-seater fighter aircraft of all-metal construction, featuring a retractable undercarriage and enclosed cockpit. Initially it was armed with eight 0.303-inch Browning machine guns, with which the Battle of Britain (1940) was fought. Later models carried gradually increasing armament, until the last, produced after the war, carried four 20-millimeter cannon. It could also carry bombs for use in the ground attack role. The most outstanding visual feature of the Spitfire, and the one by which it could always be recognized, was the elliptical wing shape featuring a smooth curve on the trailing edge to meet a lesser curve on the leading edge at the pointed wingtip.

In Service

The Spitfire went into service with RAF fighter squadrons in late 1938, and, by the start of the war in September, 1939, was being flown by nine squadrons. By the time of the Battle of Britain, it was being flown by nineteen squadrons. Although it was not the most numerically important British aircraft, as was the Hawker Hurricane, the Spitfire played a vital role. Equal in performance to the Luftwaffe's Messerschmitt Bf-109 fighter, it could take on the Bf-109 even though the British fighters were often outnumbered by the fighters that escorted the German bombers.

The Spitfire had been designed to intercept bombers attacking the British Isles, and, for this purpose, it did not need a great range. After the Battle of Britain had been won, the RAF gradually shifted, with increasing confidence, to a more offensive mode. The Spitfire was used to fight far from home, over enemy territory. In order to provide the necessary range, it was fitted with external fuel tanks to allow it to seek out the Luftwaffe in its home territory.

Development

The first Spitfires could reach speeds of 360 miles per hour and heights of 31,000 feet. By the end of the war, later models reached speeds of 460 miles per hour and heights of 44,000 feet. Later models received a newer, more powerful engine, the Rolls-Royce Griffon. The British Royal Navy also needed modern fighter aircraft, and the Spitfire was fitted with an arrester hook and catapult attachments to become the Seafire, in which guise it operated from aircraft carriers. The first Seafires were simply modified Spitfires. In order to render them fully suitable for naval use, they were redesigned to allow the wings to fold for storage purposes below decks.

Production

The advanced design of the Spitfire and its complicated elliptical wing initially caused production problems, because the hundreds of subcontractors necessary to ensure the required production rate were simply unused to the design. The bombing of the Supermarine works at Southampton during the Battle of Britain almost halted production, and it was quickly decided to disperse the factories, which added to production difficulties. However, new factories were built and additional men and women were trained, and, by the end of 1941, production of Spitfires was more or less satisfactory.

Fighting

The Spitfire was designed to fight other aircraft, and at this it was perhaps the best all-around fighter aircraft of World War II. Its real strength, however, lay in its superb maneuverability, which few aircraft could even approach. It could out-turn every German fighter, and although some models that were developed for a specific purpose did not have quite the same ability as others, generally speaking, the Spitfire was beloved by all who flew it.

The armament with which the Spitfire started the war soon became inadequate and was upgraded to include two 20-millimeter cannon in the Mark V and most subsequent models. However, some Spitfires were built with no armament at all. It had been found that the Spitfire, with modifications, could fly fast enough and high enough to avoid any attempts at interception and so, fitted with cameras, it became the backbone of RAF reconnaissance units.

Post-World War II Use

The end of World War II did not mean the end of the Spitfire, and the Seafire saw service with the British Royal Navy in Korea. In 1948, Israeli Spitfires flew alongside Israeli Bf-109's against Egyptian Spitfires in a confrontation in the Middle East. The RAF continued to use the Spitfire in a weather reconnaissance role until June, 1957.

Of more than 22,000 Spitfires and Seafires built, fewer than seventy are preserved, but approximately one-half of these remain airworthy and may be seen at flying displays all over the world.

Hugh Wheeler

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See also: Airplanes; Battle of Britain; Fighter pilots; Luftwaffe; Messerschmitt aircraft; Military flight; Monoplanes; Reconnaissance; Royal Air Force; World War II

Spruce Goose

Also known as: HK-1, HK-4 Hercules, Hughes H-4 Hercules, the Hughes Flying Boat, the "Flying Lumberyard"

Date: Design work began in 1942; a prototype was completed and one test flight was accomplished in 1947

Definition: In terms of wingspan, the largest aircraft ever built; because of its wooden construction, also one of the most controversial airplanes ever built.

Significance: The *Spruce Goose* flying boat was designed during World War II to transport cargo or troops over long distances; its sole flight, over a distance of one mile in 1947, is a landmark in aviation history; its massive size and distinctive wooden construction have made it a true American icon.

Development

With a wingspan of 320 feet—longer than a football field—the *Spruce Goose* has the distinction of being the largest aircraft ever built. Planned and designed during World War II, when materials such as aluminum were in short supply and were reserved for the most urgent military projects, the *Spruce Goose* earned its name from its nearly all-wood construction. Only the flaps, or control surfaces, were made from fabric; the remainder of the plane was fashioned from layers of plywood especially constructed at the Hughes Aircraft Company plant in Culver City, California. Despite its nickname, the "*Spruce Goose*," only about 5 to 10 percent of the craft is constructed of spruce; the remainder is birch plywood. The name stuck, however, because, in the words of one worker, "nobody could think of a word that rhymed with birch."

The idea for such a gigantic seaplane originated with F. H. Hoge, Jr., a member of the Planning Committee of the War Production Board. After German submarines sank some 300,000 tons of British and American shipping during May, 1942, Hoge proposed to solve the submarine problem by building flying boats to transport cargo and troops across the Atlantic Ocean. Unlike conventional aircraft, flying boats could land or take off on bays or harbors and did not need long, land-based runways.

The idea intrigued the industrialist and shipbuilder Henry Kaiser, famous for building the Liberty Ships during World War II. In July, 1942, he suggested that the United States build an "aerial freighter" of at least seventy tons, a "gigantic flying ship" beyond anything imagined by the nineteenth-century science fiction writer Jules Verne. Kaiser asked for help from the billionaire Howard Hughes, a crack designer and pilot who had broken several airspeed records during the 1930's.

The project was approved in October, 1942. A team from Hughes Aircraft Company would design the craft and build one prototype and two additional planes. Once tests were completed, Kaiser's companies would begin regular production. The project was initially designated the HK-1 (HK for Hughes/Kaiser). Once design work had begun, Hughes employees voted to name it the H-4 Hercules. Hughes himself disliked the popular name of "*Spruce Goose*" and preferred to call the aircraft "the Flying Boat."

The project fell well behind schedule very early, mainly due to a multitude of design and construction problems. Kaiser dropped out of the project, and Hughes was forced by various government bodies to defend the project. Only continued support from the War Production Board and the personal intervention of President Franklin D. Roosevelt kept the project going.

Events in *Spruce Goose* History

May, 1942: Federal government official F. H. Hoge, Jr., proposes that the German submarine threat be countered by the construction of massive "aerial freighters" to fly cargo and troops across the Atlantic Ocean.

July, 1942: Industrialist Henry Kaiser proposes that the United States build "aerial freighters" of from 70 to 500 tons.

August, 1942: Kaiser suggests that billionaire and aviator Howard Hughes meet with him concerning the "aerial freighter" project.

November, 1942: A new Kaiser-Hughes corporation signs a federal government contract to design and manufacture *Spruce Goose* aircraft.

June, 1946: Sections of the *Spruce Goose* are moved from the Culver City, California, plant of the Hughes Aircraft Company to a final assembly site near Long Beach, California.

August, 1947: Hughes begins testimony before a congressional committee investigating the *Spruce Goose* project.

November, 1947: Hughes flies the *Spruce Goose* for the distance of a mile in Long Beach Bay.

February, 1982: The *Spruce Goose* is moved to become a public exhibit alongside the ocean liner *Queen Mary* in Long Beach.

October, 1992: The *Spruce Goose* is shipped via ocean barge to Portland, Oregon, to become a public exhibit in McMinnville, Oregon.

Design

The problems involved in designing and building such an airplane were massive. Kaiser had suggested that the overall size of the first prototype be seventy tons, but Hughes made the work more challenging by changing the size to some two hundred tons. The goal was an aircraft that could carry 130,000 pounds of cargo or 750 troops (twice the passenger load of a modern Boeing 747).

Working at the Hughes Aircraft Company plant in Culver City, California, and at other sites, the Hughes team tested a variety of shapes for air and water efficiency. The final design model, based on decisions largely made by Hughes himself, recorded the lowest air drag of any seaplane ever tested at the National Advisory Committee for Aeronautics' Research Center at Langley Field, Virginia. Instead of a double-hulled plane, Hughes choose a single-hulled design which would require a wingspan 50 percent larger than the next largest plane of the time, the Martin JRM Mars. It was also decided that the aircraft would have a sizeable single vertical tail.

The final design divided the interior of the fuselage into two decks connected by a spiral staircase: a flight control deck for the operating crew and a cargo deck. Two railroad cars could fit in the interior cargo space, on a floor that was designed to carry 125 pounds per square foot. If planks were provided for its tracks, a 60-ton army tank could drive inside, under its own power, without the need to dismantle any part of the tank. The hull also contains eighteen watertight compartments, twelve of which might flood without sinking the craft.

In its final design, the *Spruce Goose* has an overall length of 218 feet. Its 320-foot wingspan exceeds even that of the U.S. Air Force's modern transport, the Lockheed C-5A Galaxy. The tail alone, at 113 feet, is more than eight stories high. The hull is 265 feet wide and the wings, at their thickest, are more than 11 feet thick. The craft has a gross weight of 400,000 pounds and a range of 3,500 miles. It cruises at 175 miles per hour and has a landing speed of 78 miles per hour.

Hughes chose to power the plane with Pratt & Whitney R-4360 engines. Eight of these twenty-eight-cylinder, 3,000-horsepower engines were mounted in the wings. The engines, radial in shape, sport four-blade Hamilton

Standard propellers more than 17 feet in diameter. There are a total of 448 spark plugs to service and maintain. Although the total engine horsepower of 24,000 is impressive, the engines' ability to lift a craft of more than 400,000 pounds is a real achievement for both their makers and the Hughes team's overall design efforts.

Flight controls that would respond reliably and quickly were a special problem for such a gigantic aircraft. The layout of the flight controls on the flight deck is conventional—a dual column and wheel to turn the elevator and ailerons, and pedals for the rudder. Less conventional is the way that the craft was designed to respond to these controls. Instead of a mechanical system, Hughes and his team chose a hydraulic system in which pressurized oil moves the control surfaces. Purely mechanical links between the flight deck and the rest of the plane would have required the strength of 150 to 200 men just to turn the controls. Mechanical links also are unreliable in such a massive aircraft. The *Spruce Goose* is so large that changes in temperature could cause metal parts to expand and contract, possibly jamming in the process.

In addition to wing fuel tanks, there is a central fuel system in the hull. Fuel lines in the wings, however, have slip joints to allow for wing deflections of as much as 13 feet during flight.

The *Spruce Goose* pioneered the use of a 120-volt DC electrical system in airplanes. This relatively high voltage leaves a safety margin in case of electrical leakage in any of the 32 miles of wire inside the *Spruce Goose*. It also allows manageable wire sizes to be used. (A 24-volt system, the engineers calculated, would have required solid aluminum rods 2 inches in diameter in order to carry the current.) Electrical relays are specially designed to work at high altitudes.

Image Not Available

Construction

A special building at Culver City, claimed to be the world's largest wooden building at the time, was used to build the subassemblies of the *Spruce Goose*. The most challenging construction problems involved the extensive use of wood. The Hughes team spent a great deal of time fashioning a wood construction process that would hold together in the stresses of flight. Although metal would be available in sufficient quantities during the last two years of World War II, that was not true when the *Spruce Goose* project began. At that time, aluminum and other key materials were reserved for higher priority war projects.

The structure of the aircraft was created from laminated layers of wood. The process chosen for laminating the wood, called Duramold, had first been used by Hughes in 1934 to construct parts of his record-breaking H-1 racer airplane. Birch was selected because it created a stronger plywood than spruce. To secure the most suitable birch wood, a team of specialists was sent to inspect and purchase trees in Wisconsin.

Layers of wood were bonded together with three different types of epoxy glues, and heat and steam were applied to "cure" the glues. The process required special jigs and construction techniques, some of which have remained secret. Workers had to wear gloves, since the oil from fingerprints might weaken a glue joint. For the wings, some 8,000 nails were used to hold the wood layers together until the glues had cured. All had to be removed later with special nail pullers.

Considerable sanding of the plywood exterior was necessary. A coat of wood filler was applied to all exterior surfaces, followed by a layer of sealer, a layer of rice paper, and two coats of spar varnish. The final step was a layer of aluminized spar varnish, which gave the *Spruce Goose* its silver color. These steps produced a smooth, glossy finish that was said to be more air efficient than aluminum skins, which require large numbers of rivets, which cause drag.

Assembly and Flight

In the summer of 1946, one year after World War II had ended, the subassemblies of the *Spruce Goose*, including the hull, tails, and wing sections, were transported to a dry dock and assembly site near Terminal Island, in the vicinity of the Long Beach naval base.

In 1947, the project came under attack from Republicans in the House of Representatives, who insisted that the *Spruce Goose* was a fitting symbol of the wastefulness of the Democratic administration of President Roosevelt. One congressman termed the flying boat "the flying lumberyard." Although Hughes defended the project passionately in congressional hearings, privately he told company workers to accelerate the project or "the next time you'll see me in jail." Hughes, who had spent much of his time during the war working on another aircraft, the XF-11, now worked at the assembly site for the *Spruce Goose* full time, although, characteristically, he did his work at night.

On November 2, 1947, a test of the plane was scheduled which involved taxiing the craft across Long Beach Bay. Some members of the press were invited to ride aboard the plane, and Hughes took the controls. After two successful trips across the bay, Hughes increased the plane's speed during the third attempt. He delighted a sizeable crowd of onlookers by lifting the plane off the water. After traveling for a mile at a height of about 70 feet, the craft landed smoothly. Although it was the only flight ever made in the *Spruce Goose*, it became a memorable moment in aviation history.

Although Hughes described the test flight as "just great," he never flew the craft again. There are varying opinions as to why he made no further attempts. Some argue that the plywood construction was not totally satisfactory (some workers claimed that Hughes attempted to address this by adding a corrugated aluminum skin and metal stiffeners into the gigantic wing). Others believe that Hughes saw congressional criticism as a challenge and lost interest after the successful flight.

Yet Hughes continued to spend money on the aircraft. Although the original plans had called for three *Spruce Gooses*, no other versions of the planes were ever produced. The prototype remained in Hughes's control for the remainder of his life, sitting in a hangar that was air-conditioned to provide the proper humidity to preserve the wood.

The craft was kept airworthy and the engines were fired up every month. The *Spruce Goose* was painted white. Hughes continued to make improvements, such as installing more powerful engines. When flooding damaged the *Spruce Goose*, Hughes built a larger hangar. While the United States government spent some $22 million on the project, Hughes spent an estimated $7 to $18 million dollars of his own money to complete and maintain the *Spruce Goose*.

The *Spruce Goose* as an Exhibit

Four years after Hughes' death in 1976, rumors circulated that the airplane was going to be disassembled so that pieces could be given to museums around the country. There were public protests, and the United States House of Representatives voted to declare the *Spruce Goose* a national treasure. Finally, the airplane was moved to another section of Long Beach, where it was put on display next to the ocean liner Queen Mary. Its new home was the world's largest geodesic dome, some 400 feet in diameter.

In 1988, the owner of the *Spruce Goose*, the Aero Club of Southern Californa/Aero Exhibits, sold the aircraft to the Evergreen Aviation Museum of the Evergreen Aviation Company in McMinnville, Oregon. A large section of the geodesic dome was removed to allow the *Spruce Goose* to be disassembled and placed on an ocean barge for its long journey.

Niles R. Holt

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See also: Airplanes; Howard Hughes; World War II

Sputnik

Date: Beginning October 4, 1957
Definition: The first man-made satellite to orbit Earth.
Significance: The launching of Sputnik 1 demonstrated that artificial satellites could be placed into orbit and transmit radio signals to Earth, opening the era of space exploration.

Early History of the Sputnik Program

The launching of the first man-made, Earth-orbiting satellite traces its history back to 1946, when Premier Joseph Stalin ordered the beginning of the Soviet Union's postwar rocket program. Soviet aeronautical engineer Sergei Korolev, later known as the father of the Soviet space program in the 1950's and 1960's, was appointed chief designer. Initially Korolev's group flew captured German V-2 rockets from Kapustin Yar, near Volgograd. Korolev, like many of his contemporaries, envisioned huge rockets that could be used for the exploration of space. However, political leaders could justify the large expense of a rocket development program only as part of a military system. The development of the atomic bomb required the construction of a long-range delivery system, either a long-range bomber or an intercontinental ballistic missile (ICBM). The first Soviet Earth-orbiting satellite came about as a result of both the interest of Korolev in exploring space and the interest of the Soviet premiers, Stalin and later Nikita Khrushchev, in having a rocket to deliver atomic bombs to the United States.

Sputnik's R-7 Rocket

Korolev's group developed the Soviet ICBM, a missile called the R-7. The design of the R-7 rocket remained secret until 1967, when the Soviet Union displayed the rocket at the Paris Air Show.

The R-7 is a one-and-one-half-stage ballistic rocket, measuring about 68 feet tall and about 34 feet across at its base. It consists of a central core surrounded by four strap-on booster rockets. The core of each of the strap-on booster rockets is a cluster of four rocket engines. At liftoff, the R-7 rocket employs twenty rocket engines, each generating 55,000 pounds of thrust, firing simultaneously. The liftoff thrust is more than 1 million pounds. When the four strap-on booster rockets exhaust their fuel, they drop off, leaving the four engines of the central core to provide the final thrust to deliver a warhead to its target or a satellite to orbit. The basic R-7 rocket can place about 3,000 pounds into a low orbit around the earth.

The R-7 rocket was successfully tested as an ICBM for the first time on August 27, 1957. It was used in unmodified form to launch the first three Sputnik satellites. As it became necessary to launch heavier satellites, a second stage was added to the R-7 to improve its performance.

The First Sputnik Satellite

Even before the R-7 rocket was test flown, Korolev suggested, in a secret memo to the Soviet government in 1954, the possibility of launching a satellite. Later, Korolev's group proposed to the Soviet National Academy of Sciences the possibility of launching an Earth-orbiting satellite using the new rocket. The International Geophysical Year, an eighteen-month period in 1957 and 1958 dedicated to the scientific study of the earth, provided the opportunity. Scientists recognized that many geophysical questions could be investigated only through the use of satellites. A satellite could be used to determine the density of the atmosphere high above the earth and could serve as a sensitive probe of the mass distribution in the earth, and satellite-borne instruments could monitor both radiation in space and the strength of the earth's magnetic field.

After Korolev was given the go-ahead to launch an Earth-orbiting satellite, a team to build the satellite was established. The satellite team set to work designing and building an ambitious, 3,000-pound satellite carrying an array of scientific instruments. This complex scientific satellite project fell behind schedule, and it appeared to Korolev that the R-7 rocket would be ready to loft the first satellite before there was a satellite ready to launch. Because the United States had announced its own plans to launch a satellite, it became imperative for the Soviets to launch their satellite as soon as possible.

Korolev's rocket design group decided to design and build a simple satellite in their own facility, in order to have something to launch when the R-7 was ready. In just two months, Korolev's group assembled what became the world's first artificial satellite, named "Sputnik," the Russian word for "traveler." This first Sputnik was simply an engineering test satellite that carried no scientific research instruments.

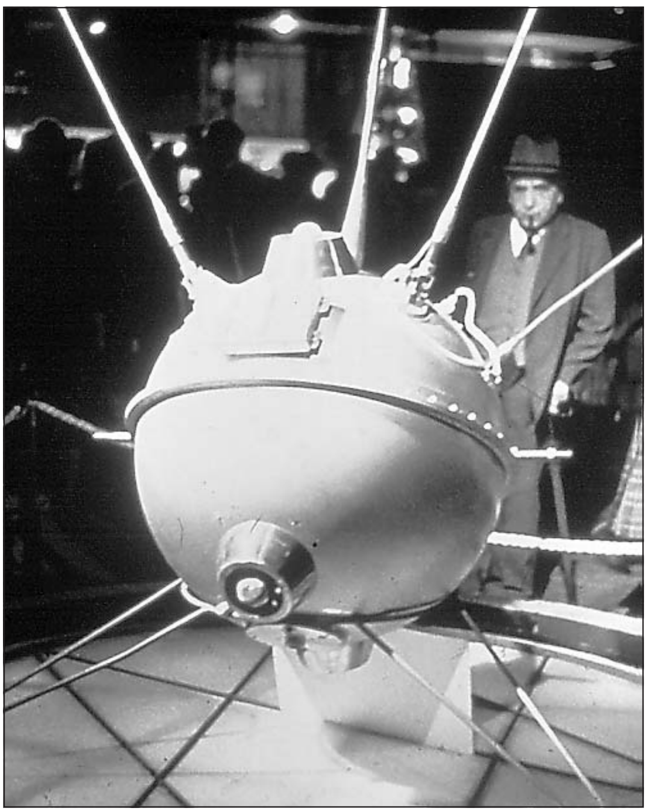
The R-7 rocket carrying Sputnik 1 lifted off from the Tyuratum Launch Facility on October 4, 1957. During the launch, Sputnik 1 was housed inside a protective nose cone on top of the R-7 rocket. After the core rocket had reached an altitude of 142 miles and a speed of 26,249 miles per hour, the rocket shut down, and Sputnik 1 was in orbit. The orbit was highly elliptical, with a low point of 142 miles and a high point of 588 miles above the earth's surface. Sputnik 1 circled the earth once every 96.2 minutes. Because its orbit was inclined about 65 degrees from the equator, Sputnik 1 traced out a path over the globe that took it over most of the populated regions of the world once every day.

Sputnik 1 was spherical in shape with a diameter of 22.8 inches and a weight of 184 pounds. The spherical shell was made of an aluminum alloy, and the interior was filled with nitrogen, a gas that would not condense even at the cold temperatures in space. At launch, four communications antennae, each about 9 feet in length, were folded to allow the satellite to fit into the nose cone of the R-7 launch vehicle. After Sputnik 1 was placed in orbit, the nose cone was jettisoned, the antenna were deployed, and the satellite separated from the core rocket. Sputnik 1 had two radio transmitters, working on frequencies of about 20 megahertz and 40 megahertz.

The temperature inside the aluminum shell of Sputnik 1 was monitored using sensors that produced small changes in the transmitter frequency with temperature. It was not known how much the temperature inside the satellite would vary as the Sputnik traveled from the sunlit to the dark side of the earth in a cycle that repeated every 96 minutes. These temperature measurements provided information on the design changes that might be needed on future satellites to maintain a uniform interior temperature.

The core rocket that carried Sputnik 1 remained in orbit for sixty days. The Sputnik 1 satellite remained in orbit for ninety-four days, although its batteries had drained and the transmitter had ceased to function after twenty-one days.

Although Sputnik 1 was designed only as an engineering test satellite, it did produce useful scientific results. The aerodynamics of spherical objects were well understood, so the rate at which the orbit of Sputnik 1 decayed as a result of air drag provided the first measurement of the air density at the orbital altitude. These measurements indicated that the air was ten times more dense than some scientists had previously modeled. In addition, the properties of the ionosphere, the upper region of the earth's atmosphere, were examined by monitoring how the 20- and 40-megahertz radio signals from the transmitters on Sputnik 1 were altered during passage through the upper atmosphere.



Sputnik, launched by the Soviet Union on October 4, 1957, was the first artificial satellite to orbit Earth. (NASA CORE/Lorain Valley JVS)

The First Scientific Sputniks

Sputnik 2, launched on November 3, 1957, was the first Earth-orbiting satellite to carry a full complement of scientific instruments. Sputnik 2, which weighed 1,118 pounds, was conical in shape, measuring about 12 feet long and about 6 feet in diameter, to maximize the use of the space available inside the R-7's conical nose cone. Sputnik 2 was placed into a highly elliptical orbit, coming within 140 miles of the earth's surface at closest approach and going out to 1,038 miles from the earth's surface, circling the earth once every 104 minutes.

The major purpose of Sputnik 2 was to study the effects of space travel, particularly weightlessness, on animals. The Soviet Union had previously launched animals, including dogs, on high-altitude rocket flights, providing extensive information on the response of animals to the liftoff acceleration. On previous rocket flights, however, weightlessness had lasted for only brief periods of time.

Sputnik 2 carried an 11-pound dog, named Laika, into orbit. The monitors on Sputnik 1 had already demonstrated that the interior temperature could be maintained in a range suitable for survival. However, the nitrogen atmosphere of Sputnik 1 was unsuitable to support life. To provide a suitable atmosphere, Soviet scientists used a system of reactive chemicals to give off oxygen for Laika to inhale and another chemical system to absorb the carbon dioxide that Laika exhaled. Information on Laika's physical condition was radioed to Earth, and Soviet scientists concluded that animals could withstand weightlessness during orbital flight. Because the technology did not exist in 1957 to return Sputnik 2 and its passenger, Laika, to Earth, the dog was put to death by an injection of poison after providing seven days of biomedical data. Sputnik 2 fell from orbit on April 14, 1958.

Sputnik 2 also contained instruments to monitor the amount of solar and cosmic radiation penetrating the spacecraft's walls. The intensity of this radiation in orbit had not been known before Sputnik 2. This flight demonstrated that sufficient shielding could be provided by spacecraft walls in order to allow the short-term survival of animals in space.

Sputnik 2 demonstrated that animals, and presumably humans, could survive weightlessness and the radiation of the space environment and demonstrated techniques to provide oxygen, to clear the air of carbon dioxide, and to maintain a livable temperature in an orbiting spacecraft. Instruments on Sputnik 2 showed that the radiation intensity increased as the spacecraft's altitude and latitude increased. Later spacecraft showed that this was due to Sputnik 2 entering the edge of the Van Allen radiation belts, bands of high-energy-charged particles circling the earth beginning at an altitude of about 600 miles.

Sputnik 3, launched on May 15, 1958, made use of the full 3,000-pound lofting capability of the R-7 rocket. The satellite weighed 3,018 pounds, carrying 2,130 pounds of scientific and communications equipment. Unlike the biological mission of Sputnik 2, Sputnik 3 was designed to conduct a geophysical study of the space environment. It carried instruments to measure the solar and cosmic radiation outside the spacecraft, the earth's magnetic field, the rate of impact of micrometeorites, and the properties of the ionosphere. Sputnik 3 was placed in a very similar orbit to that of Sputnik 2, coming within 141 miles of the earth's surface at closest approach and going out to 1,168 miles from the earth's surface. Sputnik 3 took 106 minutes to circle the earth. Its instruments continued to function for almost two years, until Sputnik 3 reentered the earth's atmosphere on April 6, 1960.

Sputnik 3 performed a series of geophysical measurements. It began to map the belts of radiation that surround the earth. Sputnik 3 detected a sharp increase in the drag on the satellite in the same regions where the intensity of high-energy electrons hitting the satellite increased. The magnetometer on Sputnik 3 produced the first map of the earth's magnetic field.

Impact of the Sputnik Launches

The news that the Soviet Union had launched the world's first artificial satellite shocked much of the world. Although many people in Europe and North America had regarded Soviet science and engineering as inferior to that of the West, Sputnik 1 demonstrated Soviet capability in space technology. Within hours of the launching of Sputnik 1, U.S. senator Lyndon B. Johnson initiated a complete investigation into the state of the United States satellite and missile programs. Boris Chertok, the deputy director of the Soviet ICBM project, was surprised by the effect of the news of the launching of Sputnik 1. "We thought the satellite was just a simple thing: What mattered to us was to test the rocket again to gather statistics on how its systems were functioning. And suddenly the whole world was abuzz. It was only later that we understood what we had done." In response to Sputnik 1, the United States undertook a massive reform of education, with a new emphasis on science and mathematics courses.

Historically, most nations have claimed sovereignty over the airspace above their territories and have regulated flights of aircraft in their airspace. The launching of Sputnik 1 resulted in the development of new principles of international law, because Sputnik 1 passed over many nations, including the United States. Because these other countries did not protest when Sputnik flew over their territories, the principle was established that any nation can orbit a satellite over the territory of another nation.

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See also: Crewed spaceflight; Orbiting; Russian space program; Satellites; Spaceflight; Uncrewed spaceflight

Stabilizers

Definition: Small wings that are placed at positions forward or aft of an aircraft's wings to provide balance in pitch and yaw during flight. On a missile, stabilizers may also be known as fins.

Significance: Without stabilizers, it would be very difficult or even impossible to control the orientation of an aircraft or missile in flight.

Early attempts to achieve gliding flight used only wings, occasionally adding the shifting of weights beneath the wing to keep the wing balanced in its motion. At any given angle of attack, there is some point on the wing where the forces are in balance, but this position, sometimes known as the "center of lift" or "center of pressure," moves forward or aft as the wing's angle to the flow changes. The location of this point and its distance from the center of mass or gravity of the wing or vehicle will determine its pitching moment, that is, the tendency of its nose to move up and down, rotating around the center of gravity. It is considered desirable to have the center of lift behind the center of gravity for positive stability, that is, to create a natural tendency for the vehicle to return to level flight after any disturbance. For example, in a stable aircraft, a gust-induced increase in lift will cause the airplane to rotate nose downward and automatically reduce its lift in correction. Because of this, a stable airplane will always have a tendency to rotate nose down in flight unless that rotation is counteracted by another force or moment. This correction is the purpose of the horizontal stabilizer.

Horizontal Stabilizers

The horizontal stabilizer is normally placed on the rear or tail of the fuselage, somewhat like the tail feathers of a bird. This placement requires the stabilizer to have a downward load or negative lift to counteract the nose-down moment of the wing. The common horizontal stabilizer is usually a small wing placed toward the rear of the fuselage and mounted at a negative angle of attack so that it will cause a downward force. The stabilizer is usually equipped with flaps known as elevators, which can be moved up and down to alter the force on the stabilizer, allowing the pilot to rotate the aircraft nose up or nose down in pitch. This allows control of the angle of attack of the wing and, hence, control of the lift produced by the wing. When larger control forces are needed, the whole stabilizer is designed to be moveable or to rotate about a pivot point, and it is then known as a stabilator or elevon.

Some airplane designers believe that the horizontal stabilizer should be in front of the wing, where it can correct the nose-down pitch of the stable wing with an upward force, thus increasing the lifting capability of the aircraft instead of decreasing it, as may happen with a tail-mounted stabilizer. The Wright brothers and other early aviators used this arrangement on their primitive designs but, like most others, eventually built airplanes with the horizontal stabilizers at the tail. When the horizontal stabilizer is in front of the wing, it is called a canard. There are special circumstances, such as transonic and supersonic flight, where canards may have advantages, but most analyses show that the best place for the horizontal stabilizer is near the tail of the aircraft.

Vertical Stabilizers

The vertical stabilizer is almost always mounted above the tail of the airplane. It is designed to limit the rotation of the aircraft in yaw, operating as a sort of weathervane, much like the feathers at the aft end of an arrow. Attached to the vertical stabilizer or fin is the rudder, which acts as a flap on the winglike stabilizer to move left or right and create forces which will yaw the airplane when desired.

The vertical stabilizer on most single-engine airplanes is mounted on the fuselage at a slight angle to counteract the torque of the engine, which tends to make the fuselage try to roll in a direction opposite to the turning of the propeller. Some aircraft have two vertical stabilizers where larger control surfaces are needed or where at very high angles of attack, part of the stabilizer may be in the wake of the fuselage.

Vertical and horizontal stabilizers are placed on an airplane in many different arrangements, depending on the control needs of the design. Sometimes the horizontal stabilizer is mounted on the vertical stabilizer, either at its top in a T-tail arrangement or part of the way up in a cruciform design. Often the vertical/horizontal tail arrangement is dictated by the need to control the airplane in stall and to make sure that, in that situation, the vertical stabilizer and rudder are not in the wake of the horizontal stabilizer, where their usefulness would be very limited.

Missile Stabilizers

The stabilizers on a missile are often simply referred to as fins. These small wings are mounted at the tail of the missile and are often fully moveable and do not have attached flaps. These moveable fins provide both balance or stability in flight and the control forces needed to maneuver.

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See also: Airplanes; Hypersonic aircraft; Missiles; Rockets; Supersonic aircraft; Tail designs; Wing designs

Stealth bomber

Also known as: B-2 bomber, Spirit bomber, Flying Wing

Date: First introduced in November, 1988; first flight on July 17, 1989

Definition: The first U.S. military bomber with stealth capability.

Significance: The B-2 stealth bomber was the first strategic bomber that could penetrate enemy air defenses, attack enemy sites, and return without the assistance of fighter jets by using stealth technology.

The Need for an Invisible Plane

During the Cold War, one of the difficulties facing the U.S. military was how to penetrate the Soviet Union's complex air defense systems in case of war. In the event of a military conflict with the Soviets, U.S. planes would have to fly extended distances, evade Soviet defenses, bomb their targets, and return to U.S. airspace. This would require fighter escort for protection and would result in losses from antiaircraft systems.

The B-2 or "stealth" bomber became the answer to this problem. Jack Northrop, founder of the aircraft company that bore his name, had developed the idea of a plane that would lack the usual wings and tail used to control and stabilize the aircraft as early as 1949. Northrop's design became known as the flying wing. Starting in the 1960's and continuing through the 1980's, the plane would be the most researched and most secret weapon developed by the U.S. military.

The stealth bomber was preceded by a prototype, the SR1-7, which was known for slanted surfaces that made it less visible to radar. Continued development of the stealth bomber continued into the 1970's outside of public view. Only President Jimmy Carter's slip of the tongue, that the military was developing a "stealth" bomber, brought the aircraft to the attention of the public.

By the 1980's, the U.S. military build-up included continued secret development of the stealth bomber. Its unveiling on November 22, 1988, gave the public its first view of the plane that was to change the way aircraft were built.

The "Stealthy" Plane

The B-2 bomber was different from its predecessors in its ability to evade radar and other air defenses. There are several features of the B-2 that define it as the first stealthy plane of its type.

The curved surfaces and relatively flat exterior of the stealth bomber, which stands only 17 feet high, serves to confuse radar, which tends to pass over and around it. The aircraft is coated with a special paint that scatters radar beams when they hit the plane. The graphite composition of the plane's exterior—the exteriors of most planes are made of aluminum—also absorbs radar signals. The design and composition of the B-2 baffles the main detection devices used by air defense systems and allows the bomber to penetrate them without being detected.

Spotting the stealth bomber with the naked eye is also difficult. Its slender shape and dark color can make it hard to see in daylight or dark. Even in the unlikely event it is seen, the stealth bomber has the capability to evade attack from the ground.

One of the worst dangers to bombers is a heat-seeking missile. These missiles are programmed to locate aircraft using the plane's heated exhaust as a guide. The B-2 is protected from such attacks. The plane's engines are located inside the plane, and the exhaust system, located at the top of the plane, cools the air from the engines before releasing it. This confuses the detection equipment on heat-seeking missiles and complicates efforts to shoot down the bomber from below or the air.

The B-2's design also makes the bomber fuel efficient, giving it a range of 6,000 miles. This allows it to fly a mission without being refueled, a process that makes bombers vulnerable to attack.

How the B-2 Flies

The plane's stealth capabilities caused difficulties for its designers in creating a plane that could fly and be controlled. Because the B-2 lacks the standard wings and tail section with flaps and rudders to control direction and ascent and descent, they had to create an entirely new design.

The lack of conventional wings, which control ascent and descent, forced designers to place all control items on the rear of the plane and to turn over many pilot decisions to onboard computers. At the outside rear of the plane there are two rudders, used to keep the plane from yawing off course. Minute adjustments to the direction of the plane are made by the B-2's computers. Also at the rear but nearer the center of the plane are three pairs of elevons, devices used to steer the plane and adjust it for descent and ascent. These act in the same way as the flaps on the wings of a standard plane. Once again, their use is controlled by onboard computers. Finally, at the center rear of the plane is the gust loud alleviation system (GLAS). The system takes the place of stabilizers, with computer adjustments to steady the plane when it hits air turbulence.

The Future of the B-2

The collapse of the Soviet Union and its elimination as a military threat to the United States called into question the need for a bomber invisible to a nonexistent radar system. The high cost of building the B-2 in times of limited defense budgets also threatened the system. The original plans for 132 planes that would carry out the bulk of U.S. air attacks during a war was reduced to 21 planes. This decision had the additional consequence of doubling the cost of each plane, to approximately $1.2 billion. This raised complaints that the B-2 was taking up funds needed for other military projects.

Although the B-2 will never see action against the type of air defenses it was built to penetrate, the development of stealth technology produced a dramatic shift in military aircraft design. Instead of the large jet designs developed after World War II, the sleek, curved design has become the model for a new generation of military aircraft.

Douglas Clouatre

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See also: Aerospace industry, U.S.; Antiaircraft fire; Bombers; Experimental aircraft; Flying Wing; Military flight; Missiles; Radar; Stealth fighter

Stealth fighter

Also known as: F-117A, Nighthawk, Black Jet

Dates: First prototype flown on December 1, 1977; first operational F-117 flown on June 18, 1981; first combat mission, flown on December 20, 1989

Definition: The first warplane to fully incorporate stealth technology.

Significance: The Lockheed F-117A Nighthawk launched a quantum escalation in air warfare technology with a radar-evading stealth design that negated the advantage attained by radar-equipped antiaircraft weapons during the 1960's and 1970's. With its precision bombing capability, the Nighthawk achieved spectacular success in the 1991 Gulf War and gave the United States intimidating leverage in other disputes.

Birth of the Stealth Plane Concept

With increasing effectiveness of radar during World War II (1939-1945), efforts intensified to reduce or obstruct the radar signature of aircraft. Germany planned an airplane whose surfaces absorbed or deflected radar beams. The Allies used foil strips, called chaff, to obscure radar returns. During the Cold War (1945-1991), radar-equipped fighters and guided surface-to-air missiles (SAMs) spurred construction of radar-jamming devices and antiradar missiles. Reacting to improved Soviet SAMs, the Lockheed Corporation's Advanced Development Projects Division, also known as the Skunk Works, also tried to reduce the radar size of its long-range spy planes.

The Israeli Air Force's misfortunes against the Arabs' Soviet-supplied air defenses in the Israeli-Arab October War (1973) especially shook U.S. military leaders, who feared that Soviet weapons might render American air power impotent. They held a design competition for a radar-evading plane. Lockheed, with its experience in spy-plane design, won with a blueprint that used both shape and radar absorbent material (RAM) to make the plane's radar size many times less than that of any plane ever made. The Nighthawk, with a 43-foot wingspan, 65-foot length, and 12-foot height, had a radar signature that was roughly equal to that of a small bird.

The Nighthawk's shape, more than its RAM, determined its stealthiness, and computer limitations in calculating radar deflection meant that the plane resembled a series of interconnected triangular facets. Further, its aerodynamic instability required computer-assisted flight controls. Still, Lockheed flew a two-engine prototype in 1977. Wanting to preempt foreign countermeasures during development, U.S. military leaders kept the project highly secret, and code-named it "HAVE BLUE."

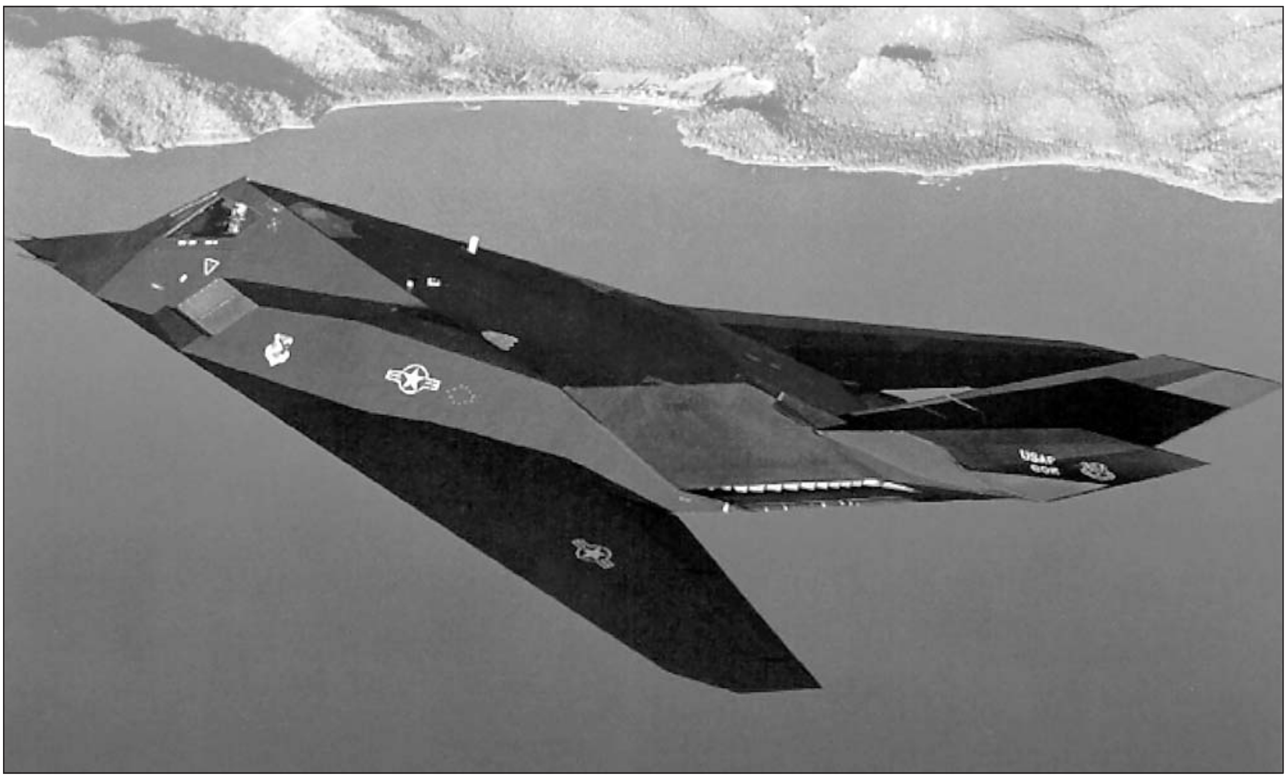
Development

Delivering the first fully developed F-117A to the U.S. Air Force challenged Lockheed designers, because they had to incorporate weapons delivery systems, avionics, bigger engines, air refueling capability, and other features, all while retaining the prototype's stealth characteristics. Further, given the lethality of then-current antiaircraft weapons, the Air Force wanted the plane as soon as possible. Lockheed delivered the first model in 1981, well ahead of modern jets' normal delivery schedule.

The resulting F-117A was a black subsonic warplane that carried one pilot, had two non-afterburning jet engines, and weighed approximately 50,000 pounds fully loaded. It carried a drag chute to reduce its high landing speed after touchdown. It had two bomb bays for weapons and relied upon weapons computers, an infrared night-vision device, a laser designator, and a sophisticated autopilot system for pinpoint delivery of laser-guided bombs. It could also drop unguided bombs. Nighthawks were not completely radar-invisible, but good mission planning and their design defeated radar target tracking.

Operational History

In 1982, the Air Force created a secret unit to fly the jet, now code-named "SENIOR TREND." In 1985, the unit had enough planes and operational experience to pass its first combat readiness inspection. Throughout the 1980's, the F-117A operated in extreme secrecy at the isolated Tonopah Test Range in Nevada. Because the F-117A was supposed to be unseen, it was flown only at night. Unit



The F-117A proved its worth in the Gulf War and other conflicts throughout the 1990's. (USAF) members could not divulge the plane's existence until 1988, and Nighthawks did not appear in public until 1990. Possessing about fifty-five planes divided into three squadrons, the unit became the Thirty-seventh Tactical Fighter Wing in 1989.

Nighthawks helped commence hostilities during the Operation Just Cause invasion of Panama (1989), but their greatest moment was during the Persian Gulf War (1991) with Iraq. Sustaining no losses or battle damage during their night missions, Nighthawks attacked heavily defended, high-value targets such as weapons bunkers, command centers, and SAM sites. They flew only 2 percent of wartime air missions, but accomplished 30 percent of all strategic raids. Small numbers of Nighthawks destroyed targets that defeated larger formations of other types of jets.

In 1992, as part of post-Cold War restructuring, the Air Force transferred its F-117's from Tonopah to the Forty-ninth Fighter Wing at Holloman Air Force Base in New Mexico. Further, the service relaxed many of the plane's secrecy restrictions. During the 1990's, improvements were made to the Nighthawk's wheel brakes and avionics. American leaders deployed Nighthawks in disputes involving North Korea, Iraq, and Serbia. Nighthawks flew one Iraqi combat strike in 1993.

In 1999, F-117's participated in the North Atlantic Treaty Organization's Allied Force air campaign against Serbia. Three days into the campaign, Serbian forces downed one F-117A. Although precise details remained classified after the war, the apparent reasons were errors in mission planning and coordination as well as Serbian SAM radar operators' brief, fortunate glimpse of their target. Another F-117 received battle damage during the 79-day war, but otherwise Nighthawks continued to hit strategic targets while remaining unscathed.

As the twenty-first century began, the Nighthawk's future was uncertain. Newer stealth planes were either operational or in development. Questions remained over whether the Serbians or others had exploited information derived from the downed Nighthawk's wreckage. High operating costs prompted questions about the craft's ultimate worth. However, the F-117A remained an undeniable triumph in air power.

Douglas Campbell

F-117A Nighthawk Characteristics

Primary Function: Fighter/attack
Builder: Lockheed Aeronautical Systems
Power Plant: Two General Electric F404 engines
Length: 65 feet, 11 inches
Height: 12 feet, 5 inches
Weight: 52,500 pounds
Wingspan: 43 feet, 4 inches
Speed: High subsonic
Range: Unlimited with air refueling
Armament: Internal weapons carriage
Unit Cost: $45 million
Crew: 1
Date Deployed: 1982
Inventory: Active force, 54; ANG, 0; Reserve, 0

Source: (www.af.mil/news/factsheets/F_117A-Nighthawk.html), June 6, 2001.

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See also: Aerospace industry, U.S.; Fighter pilots; Gulf War; Lockheed Martin; Military flight; Radar; Stealth bomber

Strategic Air Command

Also known as: SAC
Date: From 1946 to 1992
Definition: A part of the United States Air Force tasked with delivering nuclear and conventional weapons against strategic targets, primarily in the Soviet Union.
Significance: The Strategic Air Command (SAC) was a specified command of the United States Air Force. SAC's bombers, equipped with nuclear bombs, and missiles, equipped with nuclear warheads, provided

two-thirds of the deterrent force of the United States against the Soviet Union during the Cold War.

Early Years

Established on March 21, 1946, in preparation for an independent Air Force, SAC inherited most of the Army Air Force's personnel and equipment geared toward strategic bombing of enemy targets worldwide. Strategic bombing targets were those that would destroy the will and the means of an enemy to wage war, such as the industries and infrastructure that enable a nation to wage war, and population centers that a nation cannot bear to risk losing to a retaliatory strike. Although in 1946 SAC had no real nuclear capability, the vast bomber fleets left over from World War II were central to SAC's early power.

Lieutenant General (later General) Curtis E. LeMay held the position of commander in chief of SAC from October 19, 1948, through June 30, 1957, and left a strong impression on the command. Under his leadership, SAC changed from a peacetime force using airplanes remaining from World War II, with training taken only half-seriously, into a global force of jet bombers and support aircraft on permanent war alert. LeMay forced SAC to assume a constant wartime posture. Originally, SAC units rotated between bases within the United States for training and bases in Great Britain, Spain, Guam, Newfoundland, and Libya, which were closer to their targets in the Soviet Union. As longer-range aircraft entered service, SAC kept more of its assets inside the United States.

SAC's ICBM Force

The original mission of SAC was the delivery by heavy bombers of conventional and, by 1949, nuclear weapons to targets around the world, primarily in the Soviet Union. In the mid 1950's, SAC began the development of intercontinental ballistic missiles (ICBMs) to counter the Soviet threat in this area. With its bombers and missiles, SAC controlled two-thirds of the Triad, the combination of land-based bombers, land-based missiles, and the Navy's submarine-based missiles, all capable of delivering a catastrophic nuclear strike, which the United States maintained during the Cold War. SAC and the Air Force as a whole saw ICBMs and later, shorter-range missile systems as complementary to its crewed bombers, and never sought to replace the crewed bomber. This was because the crewed bomber gave the president more options during a crisis. A bomber could be called back from a mission, but a missile, once launched, would proceed to its target and could not be recalled.

SAC received the lion's share of the Air Force's budget, on the theory that its mission was the most vital. Throughout its existence, SAC remained tightly organized. SAC functioned as a specified command, meaning that it had a defined mission under the authority of the National Command Authority. Under President Dwight D. Eisenhower, the Department of Defense became more centralized and the secretary of defense, rather than the secretary of the Air Force, held direct operational control over SAC. This change reflected the major technological developments that had occurred since World War II. The threat of Soviet air attacks on the United States meant that SAC needed to respond to the orders of the president immediately. This required the most direct and short chain of command possible.

Other Missions

Although less known, SAC also held missions related to control of the seas, including reconnaissance, mining, and attacking of enemy ships. The Navy was never comfortable sharing its mission to control the seas with SAC. However, SAC's reconnaissance missions over land, using the U-2 aircraft for many years, provided invaluable intelligence throughout the Cold War. The U-2 that discovered Soviet intermediate- and short-range missiles in Cuba in 1962 flew as part of SAC.

Types of Aircraft

Originally, SAC operated with a mixture of propeller-driven B-29's and B-50's, which were an improved version of the B-29. Later years saw the adoption of a few wings of B-36's, which were originally equipped with six pusher-type propellers, and later retrofitted with four additional jet engines. SAC's first all-jet bomber was the B-47. The success of the B-47 led some in Congress to push to end development of its successor, but LeMay pushed to field the B-52, which first flew in 1952. The B-52, with eight jet engines and enormous payload, had intercontinental capability. The B-52 remained the backbone of the SAC throughout the existence of the command and beyond. In 1960, the B-52 fleet was augmented by the B-58, which was the first supersonic bomber. The B-58 proved to be a maintenance nightmare and changes in strategy led to its removal from the Air Force inventory in 1970. The FB-111 joined the SAC inventory in the 1970's and 1980's, while limited numbers of the B-1 entered service in the 1980's. Even fewer B-2 stealth bombers joined SAC shortly before the reorganization that ended the command. Through the end of SAC and for decades after, the B-52 remained the Air Force's primary strategic bomber.

In-flight Refueling

SAC leaders soon realized that if true intercontinental power was to be realized, it would need an effective method of in-flight refueling. After early experience with propeller-driven tankers proved difficult and dangerous, SAC pushed for the adoption of a jet tanker. This requirement was answered by the KC-135, first flown in 1954. With the KC-135 and the B-52, SAC no longer needed to maintain forward bases in order to attack the Soviet Union. The American bomber fleet, and hence the nuclear weapons it would carry, could be based in the United States or its territories. In the late 1980's, SAC augmented its KC-135 tanker fleet with the KC-10.

Détente

Throughout its existence, SAC focused on its ability to deliver a devastating counterstrike against the Soviet Union after the Soviet Union had attacked the United States. This formed part of the strategy known as mutual assured destruction (MAD), whereby the United States and the Soviet Union were discouraged from launching a first-strike nuclear attack against the other because of the ability of the other nation to inflict a major counterstrike that would cause an unacceptable level of damage to the nation that struck first. This ability to withstand a nuclear attack and maintain enough assets to strike back, thereby discouraging the Soviet Union from attempting a first strike, became known as deterrence. In order to provide a creditable deterrent, SAC physically and operationally adopted measures to allow it to function after receiving a Soviet attack. This included burying Titan and Minuteman missile silos, surrounding them with steel-reinforced hardened concrete, and keeping them on constant alert status. Beginning in 1955, SAC kept one-third of its bombers on alert, with crews trained and ready to take off within fifteen minutes of notification. In 1961, President John F. Kennedy raised this to 50 percent of SAC aircraft. During periods of increased tensions in the early 1960's, SAC kept part of its B-52 fleet airborne at all times, to allow a retaliatory strike against the Soviet Union in the event of a surprise attack on the United States. SAC also maintained the National Emergency Airborne Command Post (NEACP), also known as "Looking Glass," which consisted of several EC-135's, one of which was airborne at all times from 1961 through 1990. After 1990, it remained on quick reaction ground alert and was able to take off within a few minutes.

SAC in War

Although SAC was created and existed primarily to provide deterrence against the Soviet Union, the command also played a part in several armed conflicts. In theory, during a conventional war SAC filled the role that strategic air forces had played during World War II: destroying the industry and national infrastructure that allowed an enemy to wage war. However, during the Korean and Vietnam Wars, political considerations of limited warfare prevented SAC from fulfilling that mission.

The Korean War

When the Korean War broke out, SAC became involved in the war, although indirectly. SAC bombardment groups were attached to the Far East Air Force for strategic bombing missions against North Korea. Using a combination of B-26's and B-29's, the airmen flew missions from South Korea and Japan to wreak havoc on Communist convoys, trains, and industrial targets. However, they were forbidden to attack the sources of most of the Communist supplies inside China and the Soviet Union.

The Vietnam War

During the Vietnam War, SAC became involved with bombing Vietcong base camps in South Vietnam and providing close air support to U.S. and South Vietnamese forces operating in South Vietnam. Neither use can realistically be defined as a strategic use of air power. SAC bombers, primarily B-52's, flew from American bases in the Philippines and on Guam to perform these missions. At the same time, tactical U.S. Air Force elements and naval aviation were bombing strategic targets in North Vietnam as part of Operation Rolling Thunder, which ran from 1965 to 1968. In 1972, under the Nixon administration, SAC carried out the Linebacker I and II bombing campaigns against strategic targets in North Vietnam.

Operation Desert Storm

During Operation Desert Storm, the 1991 war against Iraq, seven SAC B-52 bombers flew missions from Barksdale Air Force Base, Louisiana. The B-52's flew fifteen hours to their launch points to release air-launched cruise missiles with conventional warheads against strategic targets inside Iraq. The B-52's then returned to Barksdale after a nonstop thirty-five-hour flight, with numerous in-flight refuelings.

The End of SAC

After the collapse of the Warsaw Pact and the Soviet Union in 1989 and 1990, the Air Force began to implement a major reorganization to reflect the changing world situation. Under the plan, most of SAC was incorporated with most of Tactical Air Command to create the Air Combat Command in 1992. A year later, the ICBM force was transferred to Space Command. SAC's crest, which consisted of a shield-shaped image of a mailed fist holding lightening bolts and olive branches set against a background of the sky, became the basis for the new U.S. Strategic Command. Strategic Command, a joint service command, controls most Air Force and Navy assets geared toward strategic missions.

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See also: Air Combat Command; Air Force bases; Air Force, U.S.; Air Force bases; Bombers; Missiles; Stratofortress; Superfortress; Tactical Air Command

Stratofortress

Also known as: B-52, BUFF (big ugly fat fellow)

Date: The YB-52 prototype first flew on April 15, 1952; the first operational B-52 (B model) was delivered to the U.S. Air Force at Castle Air Force Base, California, on June 29, 1955

Definition: The longest-serving and largest-weapons-capacity nuclear and conventional bomber in the United States inventory, featuring four under-wing engine pods with two engines each, midair refueling capability, and a crosswind landing gear system.

Significance: The B-52 was the third all-jet bomber to be mass produced in the United States, after the B-45 and B-47. The B-52 was originally designed to penetrate the former Soviet Union and deliver nuclear bombs while flying at high altitudes. Its primary mode of weapons delivery later became one of very-low-altitude penetration. The aircraft was the mainstay of U.S. nuclear bomber forces from the late 1950's into the early 1990's.

Development

B-52's were delivered to the U.S. Air Force from 1955 to 1962. During this production run of 744 airframes (excluding the two prototypes), eight models of the B-52 were built. Each model was an improvement on the previous version. Even decades after the last B-52 rolled off the factory floor, overhauls, modifications, and improvements have been made that maintain or improve the capability of this extremely versatile combat aircraft.

Two identical prototypes were fabricated and called the YB-52 and XB-52. They were the only models that had tandem pilot seating (one in front of the other). Three B-52A models were built and used for testing. Fifty B-52B models were produced. Twenty-seven of these were RB-52B's, which were used for reconnaissance. Greater fuel capacity was added to the design for the thirty-five B-52C models.

Next manufactured were 170 of the D models. The D model later became famous for the "big belly" modification, which was accomplished during the Vietnam War. The internal bomb bay of the D was modified to add fifty-seven more internal bombs. The E model had improved navigation and electronic jamming equipment. One hundred E models were made. A change in engines precipitated the F model. The F model had an improved version of the Pratt & Whitney J-57 engine, which produced 13,750 pounds of thrust. Eighty-nine F models were completed.

The G models were the most prolific version, with 193 being procured by the Air Force. The G had a shortened vertical stabilizer on the empennage and increased fuel capacity; the gunner position was moved from the tail to the front of the aircraft with the rest of the crew. A total of 102 B-52Hs were constructed. This final version had a 20-millimeter vulcan cannon (Gatling gun) in the tail instead of the previous four .50-caliber machine guns. The most significant change for the H model was the Pratt & Whitney TF-33-P-3 turbofan engine. These turbofan engines were much more powerful and fuel efficient than the previous turbojets.

Crew Positions and Duties

B-52's had six crew members: gunner, electronic warfare officer (EWO), navigator, radar navigator, copilot, and pilot (aircraft commander). The crew compartment was divided into two levels, each about 5 feet in height. The only place a crew member could stand completely erect was next to the ladder that connected the upper and lower decks. Gunners in the A through F models were completely separated from the rest of the crew and sat in the tail of the plane. Although the gunners in the tail did not have a normal ejection seat like the rest of the crew, they could blow the back of the fuselage away and bail out in case of an emergency. In the G and H models, the gunners sat in the front cabins facing aft on the top deck next to the EWOs, who sat on the right side of the aircraft.

The electronic warfare officers use radio receivers to detect enemy surface-to-air missiles (SAMs) and airborne interceptor (AI) attacks. The EWO can electronically jam enemy SAMs and AI radar to make it difficult to hit the B-52 with a radar-guided missile. The EWO can also dispense chaff, small strips of aluminum that reflect radar, or flares to misdirect radar-guided or heat-seeking missiles.

The navigator sits in the lower level and faces forward. This person is responsible for deciding when to turn and what airspeed to fly to make sure the weapons explode at the correct time. The navigator also launches the missiles. The radar navigator or "radar" (in World War II this position was called the bombardier) is responsible for making sure the weapons hit the intended target. During low-level portions of the flight, the radar helps keep the pilots from flying into mountains and also accomplishes final aiming of the bombs. The radar sits to the left of the navigator. Both navigators are equipped with downward ejection seats.

The pilot flies the airplane manually, except during high-altitude cruise when the autopilot is typically engaged. During midair refueling, the pilot can work up a sweat trying manually to stay close behind a KC-135 for forty-five minutes to get the needed fuel. Manually flying low-level at altitudes down to 400 feet above the terrain and at 350 to 425 miles per hour is also a physical and mental challenge. Typical training flights last from five to eight hours; combat missions in Vietnam sometimes took eighteen hours.

B-52 Stratofortress Characteristics

Primary Function: Heavy bomber
Builder: Boeing
Power Plant: 8 Pratt & Whitney engines, TF33-P-3/103 turbofans
Thrust: Up to 17,000 pounds per engine
Length: 159 feet, 4 inches
Height: 40 feet, 8 inches
Wingspan: 185 feet
Speed: 650 miles per hour
Approximate Empty Weight: 185,000 pounds
Maximum Takeoff Weight: 488,000 pounds
Range: 7,652 nautical miles
Armament: Approximately 70,000 pounds mixed ordnance of bombs, mines, and missiles
Crew: 5 (aircraft commander, pilot, radar navigator, electronic warfare officer)
Accommodations: 6 ejection seats
Unit Cost: $74 million
Date Deployed: February, 1955
Inventory: Active force, 85; ANG, 0; Reserve, 9

Source: Data taken from (www.af.mil/news/factsheets/B_52_Stratofortress.html), June 6, 2001.

Cold War and Vietnam

The Strategic Air Command (SAC) was formed on March 21, 1946. SAC was the Air Force organization that was given initial responsibility for nuclear weapons. In the beginning, aircraft were the only method of delivering nuclear weapons. Then came intercontinental ballistic missiles (ICBMs) and the U.S. Navy's submarine-launched ballistic missiles (SLBMs). Nuclear ground alert was started in the late 1950's and continued into 1991. This ground alert had aircraft, weapons, and flight crews ready to take off on fifteen minutes' notice or less. Airborne alert was employed for several years, including during the Cuban Missile Crisis of 1962. Two B-52's have crashed while on airborne alert. One crashed near Thule, Greenland. The second had a midair collision during air-refueling. The aircraft parts and nuclear weapons fell into the Mediterranean Sea and on Spain.

The most important reason for having bombers with people in them was that they could be sent on nuclear missions and then called back before destroying targets. Once launched, ICBMs and SLBMs cannot be recalled or destroyed. Crewed bombers can be moved or launched to show that the United States is serious about its intent to use nuclear weapons. This show of force can be made without actually having to set off a nuclear explosion.

In the middle of the Cold War, the B-52 was forever immortalized in the film *Dr. Strangelove* (1964). This motion picture was a macabre comedy that showed the seriousness of nuclear war and the theory of mutually assured destruction. This concept is based on the premise that neither side will start a nuclear war if both sides believe it will end up completely destroying the home country as well as the enemy.

B-52's were employed in Vietnam from 1964 to 1973. It was the first time B-52's were in combat. During this time, gunners shot down two enemy fighter planes (MiGs). The major offensive battles fought by the B-52 in Vietnam were ArcLight, Bullet Shot, and Linebacker II. The eleven days of intense bombing during Linebacker II in December, 1972, had a major effect on the peace talks and the end to this Southeast Asian conflict.

Weapons

The B-52 can carry weapons inside the fuselage bomb bay and also on two wing-mounted pylons, one under each wing next to the fuselage. During conventional (nonnuclear) combat, the B-52 has been primarily used for carpet bombing. This occurs when large numbers of explosions are desired over a large or spread-out target. Except for the "Big Belly" modified D model, which could carry more than one hundred 500-pound conventional bombs, normal loads were fifty-one 500-pound or fifty-one 750-pound high-explosive bombs. The B-52 can also carry several types of mines designed to be dropped into the ocean. In the 1980's, B-52G's were altered to launch Harpoon air-to-ship missiles for destroying ocean-going military ships. Runway destruction or antipersonnel land mines, chemical weapons, and even bombs that open to deploy leaflets over enemy territory can be delivered by the B-52.

Many different nuclear weapons can be carried by the B-52. Typical bombs are the B-28, B-53, and B-61. The Hound Dog was a 1960's supersonic winged missile that was so large that only one could be carried under each wing. The short-range attack missile (SRAM) has a two-stage solid rocket motor that propels the missile at over Mach 5. Capacity for carrying SRAMs and air-launched cruise missiles (ALCMs) is the same: six on each wing and eight on a rotary launcher in the bomb bay. ALCMs can be launched over a thousand miles away from the target and then fly at speeds just under the speed of sound at a few hundred feet above the ground. A typical nuclear weapons load in the 1980's may have consisted of four bombs and eight SRAMs in the bomb bay plus twelve ALCMS on wing pylons for a total of twenty-four nuclear warheads per aircraft.

Future of the B-52's

During the Persian Gulf War in 1991, complete air superiority was achieved over the skies of Iraq. The Air Force determined that B-52's would only be used in a conventional war when most enemy aircraft had been destroyed. This reduced the need for gunners and also brought on the phasing-out of gunners in 1992. By the mid-1990's, all but the remaining H model B-52's had been sent to Davis-Monthan Air Force Base in Tucson, Arizona, for storage. Of the B-52's in storage in the desert, all but the Gs have been destroyed and sold for scrap metal. That leaves ninety-four B-52H models still flying. The Air Force plan is to have these last remaining H models in operational service well past 2010. The B-52 holds the record for a combat aircraft in constant operational service, since June 29, 1955. Interestingly, the runner-up for claim to this record is the former Soviet Union's equivalent to the B-52, the Tupolev Tu-95 Bear bomber. The Tu-95 was accepted into operational service on December 20, 1955, just six months after the B-52.

Although the B-52 has been supplemented and will someday be completely superceded by the B-1B and B-2 bombers in the nuclear and conventional war fighting roles, there will never be another airplane that will bring to mind the tenuous years of the Cold War and the term "nuclear bomber" like the B-52.

John C. Johnson

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See also: Air Force, U.S.; Bombers; Jet engines; Military flight; Missiles; Stealth bomber; Vietnam War; World War II

Superfortress

Also known as: B-29, Superfort

Date: Designed between 1939 and 1943; began production in 1943; first combat in 1944

Definition: A very-long-range (VLR), four-engine U.S. bomber of the World War II era.

Significance: The long range of the Superfortress, used in the Pacific theater during World War II, enabled the U.S. Army Air Force to conduct a strategic bombing campaign against Japan in 1944 and 1945. B-29's carried out the most devastating bombing raid in history on March 9-10, 1945, when more than three hundred Superforts destroyed 16 square miles of Tokyo while killing 83,000 people; it was also the aircraft that dropped atomic bombs on Hiroshima and Nagasaki in August, 1945.

Development and Production

Measuring 99 feet in length and 142 feet in wingspan, weighing 120,000 pounds loaded, and costing $930,000 per aircraft, the B-29 was the largest and most expensive bomber from World War II. Size and cost, however, were only two of the attributes that set the Superfortress apart from other propeller bombers of the era. The B-29 flew higher (31,800 feet) and faster (365 miles per hour), carried a heavier bomb load (10 tons maximum), mounted greater armament (ten .50-caliber machine guns and one 20-millimeter cannon), and had a longer range (4,100 miles) than any other World War II bomber.

Additionally, its engines (four 2,200 horsepower Wright R-3350's), radar (APQ-13), pressurized cabins, remote-controlled armament, and use of a flight engineer marked the Superfortress as a new generation of bomber.

The Boeing Company, developer and manufacturer of the B-17 Flying Fortress, designed the B-29 in response to the desire of the U.S. Army Air Corps (renamed the U.S. Army Air Force in 1941) for a bomber superior in speed, bomb load, and range to those it already possessed, specifically the B-17 and B-24. After working up several models during 1939, Boeing engineers finally submitted a design in the spring of 1940, which was designated the XB-29. This design came close to meeting Air Corps' specifications, which included a top speed of 400 miles per hour, a bomb load of 1 ton, and a range of 5,333 miles. Awarded a contract to deliver three XB-29's, Boeing proceeded to create and test the plane that would become the Superfortress.

During testing, numerous problems cropped up, including a three-bladed propeller that proved deficient at high altitudes, hydraulic brakes that failed at landing, a multiwindowed cockpit that produced distorted visibility, gunners' sighting blisters whose windows frosted over, and a fire-control system that lacked accuracy. None of these problems, however, was as serious as the tendency of the Wright R-3350 engines to overheat and catch fire at high revolutions per minute. In fact, engine problems delayed the initial test flight, originally scheduled for July, 1942, until September of that year. They also led to the tragic death of Boeing's chief test pilot, Eddie Allen, who was killed along with his entire ten-man crew when the Superfort they were testing crashed in Seattle on February 18, 1943, and forced some two thousand changes by November, 1943.

Despite the plane's many bugs, some of which were never completely overcome, General Henry Harley "Hap" Arnold and other U.S. Army Air Force leaders remained committed to the B-29. Consequently, in 1943, they contracted with Boeing, Bell, and Martin to manufacture Superfortresses. Together, these three companies combined to produce 3,432 Superfortresses by war's end in August, 1945.

World War II

The B-29 became operational in June, 1944, when Superfortresses of Twentieth Bomber Command, U.S. Fourteenth Air Force began flying from Chinese bases, bombing targets in Thailand and in Japan's home islands. Five months later, in November, B-29's of Twenty-first Bomber Command, U.S. Twentieth Air Force, headquartered in the recently captured Mariana Islands, commenced bombing raids against the home islands. Because of the logistical difficulties involved in supplying the Superfortresses deployed in China and the great distance between the Chinese bases and their targets in Japan, the Marianas served as the main base of operations for the B-29 strategic air offensive from late 1944 until war's end.

During fourteen months of active service in World War II, B-29's dropped 170,000 tons of bombs, 146,000 on Japan itself, and laid 147,000 tons of aerial mines in Japanese and Korean waters. As a strategic bomber, the Superfortress proved most effective from early March to mid-August, 1945, when, thanks to General Curtis E. LeMay, commander of Twenty-first Bomber Command,

The B-29's long range gave it an advantage in the Pacific theater of World War II; the Enola Gay*, the plane that dropped the atomic bomb on Hiroshima, Japan, was a B-29.* (Library of Congress)

Twentieth Air Force abandoned high-altitude, daylight, precision raids using high explosive bombs in favor of low-altitude, nighttime, area raids using incendiary bombs. In this period, B-29 raids burned down 40 percent of urban Japan, inflicted an estimated 830,000 casualties (500,000 killed), destroyed 2.5 million buildings, reduced Japanese oil production by 80 percent, reduced its aircraft production by 75 percent, and reduced the number of its munitions factories in operation by 30 percent. The B-29 air offensive against Japan reached a destructive climax with its employment as the world's first nuclear bomber, when the *Enola Gay* dropped the uranium-based "Little Boy" atomic bomb on Hiroshima (August 6, 1945) and the *Bock's Car* dropped the plutonium-based "Fat Man" atomic bomb on Nagasaki (August 9, 1945).

Post-World War II Usage

After World War II, the development of jet-powered aircraft ultimately made the B-29 obsolete. However, the U.S. Army Air Force—and, from 1947, the U.S. Air Force—included Superfortresses in all bomber units until 1954. Superfortresses were employed as nuclear bombers until 1951 and saw action as conventional bombers in the Korean War (1950-1953), dropping an estimated 158,000 tons of bombs during that conflict. Great Britain briefly incorporated B-29's into the Royal Air Force in the early 1950's, while the Soviet Union, in the late 1940's, mass-produced a version of the Superfortress, designated the Tu-4, which the air force copied from U.S. Superfortresses that had made emergency landings in Siberia during World War II.

Although enjoying a relatively brief lifetime as a combat aircraft and plagued by numerous technological problems throughout, the B-29 Superfortress is generally acknowledged as the best bomber of World War II.

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See also: Air Force, U.S.; Boeing; Bombers; Korean War; Military flight; Royal Air Force; World War II

Supersonic aircraft

Also known as: SST

Definition: Aircraft that can fly faster than the speed of sound.

Significance: The speed of sound (Mach 1) is a milestone in the range of aircraft speeds, and aircraft that can fly faster than this speed are different in many ways from those that are not designed to exceed the speed of sound.

The first fifty years of aviation was characterized by ever-increasing aircraft speeds, as aerodynamic research found ways to reduce airplane drag and as engine and fuel improvements made possible continual improvements in thrust and power. By the 1940's, highly streamlined airplanes with modern wing designs and powerful piston engines were capable of approaching the speed of sound in a full-power dive. When this occurred, as it did scores of times in some fighter aircraft of World War II, unexpected things began to happen which made the aircraft difficult, if not impossible, for the pilot to control, and sometimes caused the airplane to fail structurally. These problems aroused investigations in aerodynamic theory and led to experiments that verified high-speed flight experience. All combined to reveal huge increases in drag as the speed of sound. or Mach 1, was approached, leading to the definition of this speed as the "sound barrier."

As a high-speed aircraft flies through the atmosphere, the surrounding air must accelerate as it moves around the plane. It is this acceleration that creates lift on the wing. The wing is shaped to cause more flow acceleration over its upper surface than its lower surface, and this results in lower pressures on top of the wing and, hence, lift. As aircraft speeds of 70 to 80 percent of the speed of sound are reached, portions of the flow over the wing will have accelerated to speeds greater than the speed of sound. Contrary to popular belief, it is not the existence of supersonic flow over the wing which causes the drag to rise. It is, rather, the normal inability of that supersonic flow to gradually slow back to subsonic speed that causes the problem.

When a supersonic flow over a wing tries to slow to subsonic speed it will usually do so in a very sudden speed drop, with an accompanying jump to a higher pressure. This sudden change in speed and pressure is known as a shock wave, and the pressure jump often causes the flow to separate or break away from the surface of the wing, resulting in a large, drag-producing wake. When this occurs, often at speeds between 70 and 80 percent of the speed of sound, the drag on the wing and, hence, the drag on the airplane begins to increase. The drag rises sharply as speed is increased beyond that point. At the same time, the new flow patterns over the wing change the way lift is produced on its surface and alter the way the aircraft tends to pitch nose up or down. Similar patterns of flow and separation over the stabilizer surfaces may result in an inability to use these to control the airplane, especially in view of the changed pitching moments. These changes, which can occur rather suddenly at the point of shock wave formation (the "critical" Mach number), can easily lead to loss of airplane control, along with increases in drag which quickly exceed the thrust of the engine. A plane not designed to handle these loading changes can suffer structural failure and even lose a wing or tail surface.

Breaking the Sound Barrier

The combination of drag increase and stability changes that occurred on a wing as the speed of sound was approached created a very real fear of the sound barrier among pilots of aircraft capable of reaching these speeds in high-speed dives. Fortunately for many of these pilots, the speed of sound is a function of air temperature and, hence, of altitude. As the diving plane descended to lower altitudes, the speed of sound increased, the plane's Mach number (its speed divided by the speed of sound) decreased, and the shock waves disappeared, if the aircraft could hold together that long.

Aerodynamicists and others who studied the flows around wings at speeds near that of sound learned to design wings and control surfaces that could handle the changes in this transonic speed range and, in the 1940's, they began to look at airplane designs which would allow flight beyond the sound barrier to supersonic speeds. The development of new jet and rocket engines also offered the hope of producing enough thrust to overcome the large increase in drag that occurred as Mach 1 was approached. One such design was the Bell X-1.

Despite the belief that drag became infinite at the speed of sound, a misinterpretation of aerodynamic theory, engineers at the National Advisory Committee for Aeronautics (NACA) knew that bullets and artillery shells flew at supersonic speeds. They realized that if an airplane could be supplied with enough thrust and if wings and stabilizers could be designed for transonic operation and control, it would be possible to break the so-called sound barrier. To help ensure their success, they modeled the shape of their new experimental airplane on an artillery shell.

The X-1 was equipped with a rocket engine and designed for air launch, in which it was dropped from beneath the wing of a B-29. Its rocket engine ignited for longer periods of time in subsequent flights, gradually pushing its speed toward Mach 1. Finally, on October 14, 1947, with Air Force Captain Charles E. "Chuck" Yeager at the controls, the X-1 reached and exceeded the speed of sound. At 700 miles per hour, Yeager had reached Mach 1.06 before cutting off the plane's rocket engine. This X-1, which Yeager nicknamed "Glamorous Glennis," after his wife, now hangs in the National Air and Space Museum in Washington, D.C.

The X-1 and other experimental planes explored ever-higher supersonic speeds and evaluated aerodynamic and control theories related to transonic and supersonic flight. The Bell X-5, a small aircraft with variable sweep wings, tested the theory that increasing the wing's sweep would reduce the transonic drag rise. The Douglas Skyrocket reached Mach 2 in November, 1953, with Scott Crossfield as pilot. The Bell X-2 reached Mach 3 on September 27, 1956, but then tumbled out of control, crashing and killing the Air Force pilot, Captain Milburn Apt.

Supersonic Design

The theory that sweeping the wings would decrease the drag rise that occurs as Mach 1 is approached was developed independently in Germany and the United States well before the flight of the X-1, but it was confirmed by the X-5. Sweeping the wing lowers the effective Mach number of the flow perpendicular to the wing, and it is this component of the flow that influences the increase in drag at transonic speeds. Tests confirmed that as the wing is swept aft, the transonic drag rise is both delayed and reduced. This allows an aircraft with a swept wing to fly faster before experiencing the transonic increase in drag and allows it to fly through the speed of sound with less thrust. Nothing is free, however, and the reduction in drag is accompanied by a reduction in the lifting capability of the wing and requires more wing area for a given amount of lift. One way to accomplish this is by the use of a triangular or delta-shaped wing, a wing shape used on many supersonic aircraft.

One of the first supersonic designs for a U.S. fighter aircraft using a delta wing was the Convair F-102. In early tests in 1953, however, it was determined that this aircraft could not reach the supersonic speeds for which it had been designed. This led to a redesign of the aircraft based on the area rule concept developed by NACA engineer Richard Whitcomb. Whitcomb realized that when the air moving around an aircraft had reached the speed of sound, it had been compressed or squeezed together as much as it could be compressed and that the only way the flow could move around the airplane was to push the surrounding air out of the way, creating more drag. His theory said that this drag could be decreased if the airplane body or fuselage could be squeezed in enough to make room for the flow that had to go around the wing. The resulting fuselage shape became known as the "Coke-bottle" or "wasp-waist" design and its use in the redesign of the F-102 proved his theory.

When Whitcomb's area rule is applied to modern high-speed aircraft, the dramatic necking-in of the fuselage is not as evident as on the F-102. Designers have learned to blend wing and fuselage to give the required ideal variation of cross-sectional area or volume in more subtle ways.

Richard Whitcomb went on to develop other improvements in transonic and supersonic aircraft design, such as his supercritical airfoil of the 1960's. The supercritical airfoil is shaped in such a way as to produce a weaker shock wave than older wing designs as it accelerates toward Mach 1 and places that shock closer to the airfoil's trailing edge, thus reducing the transonic drag rise. This development is used on almost all high-speed subsonic and supersonic aircraft designed since the 1970's and allows subsonic aircraft to fly closer to the speed of sound with less thrust and fuel consumption than was possible with older airfoil shapes.

The SST

Many supersonic aircraft have been designed and flown since the flight of the X-1, and supersonic flight is now commonplace. The Concorde, developed jointly by British Aerospace and Aerospatiale of France in the late 1960's, flew in prototype form in 1969 and went into passenger service in 1976, allowing anyone who can afford its premium-priced ticket to cross the Atlantic Ocean at Mach 2. The United States and the Soviet Union also had programs to develop supersonic transports, with Boeing selected as the firm to build the American SST. Boeing later canceled the project, believing that there was insufficient demand to allow either an airline or a manufacturer to make a profit on such a plane. The Tu-144 resulted from the Soviet SST project, but only a few were built and the aircraft was withdrawn from service after several crashes. The Concorde was also temporarily withdrawn from service after almost twenty-five years of continual service after a crash on a takeoff from Paris on July 25, 2000, which was caused by debris on the runway piercing its fuel tanks.

Supersonic airliner flight has been limited by international agreement to travel over the oceans, limiting their usefulness to transatlantic and Pacific routes, and the Concorde does not have the range required for nonstop flights across the Pacific. At supersonic speeds, the twin shock waves coming from the leading and trailing edge of an SST's wings can result in loud and destructive sonic booms at ground level due to the sudden pressure change across the shock. As a result, flight of SST's over land has been forbidden and military supersonic flight is restricted to defined training areas.

NASA and companies such as Boeing and Airbus have continued to explore designs for supersonic passenger planes of the future but, as of 2001, none is on the way to production. There have also been explorations by several companies of the possibility of building a commercially successful supersonic business jet, and such a plane could be built by 2010.

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See also: Aerodynamics; Air France; Airbus; Airline industry, U.S.; Boeing; British Airways; Concorde; High-speed flight; Mach number; Manufacturers; National Committee for Aeronautics; National Aeronautics and Space Administration; Safety issues; Sound barrier; Stabilizers; Andrei Nikolayevich Tupolev; Richard Whitcomb; Wing designs

Swissair

Also known as: Swiss Air Transport Company, Schweizerische Luftverkehr AG, SA Suisse Pour la Navigation Aerienne

Date: Founded on March 26, 1931, as the merger of Basler Luftverkehr and Ad Astra Aero

Definition: A major world airline and the national flag carrier of Switzerland.

Significance: Swissair has a reputation for customer service and safety and serves a comprehensive global network of routes that spans four continents.

Corporate Information

Swissair was formed on March 26, 1931, in the merger of Basler Luftverkehr (Balair, founded in 1925) and Ad Astra Aero (founded in 1919). Swissair serves a network of routes covering Europe, North and South America, Africa, the Middle East, South and Southeast Asia, and the Far East. Ownership is shared by Swiss national and cantonal governments and private investors. Its headquarters are in Zürich, Switzerland. In 1981, the holding company Swissair Participation S.A. was created to run its non-airline subsidiaries, including hotel, restaurant, airline catering, real estate, travel agency, and freight operations.

The holding company evolved into a genuine holding structure with a new corporate name, the SAirGroup. The new structure comprises a small holding company, Swissair Group, responsible for overall group concerns (finances, corporate development, personnel policy, and communications) and four corporate divisions: SAirLines (all purely airline activities, including Swissair and Crossair); SAirServices, with its subsidiaries Swissport (ground handling), SR Technics (engineering and maintenance), and Avireal (facility management); SAirLogistics, for all cargo and logistics interests, including Swisscargo (air cargo capacity marketing), Cargologic (cargo handling and distribution), and Jetlogistics (airline catering logistics support); and SAirRelations, formerly Swissair Associated Companies and home to Swissôtel (hotel management), Gate Gourmet (airline catering), Rail Gourmet (train catering), Restorama (institutional catering), and Nuance International (travel retail).

Route Structure

In 1931, Swissair inherited from its predecessors routes within Switzerland and from Switzerland to the German Rhineland cities and Lyon, France. In 1932, it adopted the Lockheed Orion monoplane, giving it the fastest express service between Zürich, Munich, and Vienna. Suspending scheduled services during World War II, the company resumed regular flights in 1946 and by 1949 had begun transatlantic service between Switzerland and New York City. In the 1950's, routes were extended to South America and the Far East, reaching Tokyo in 1961. Since 1961, Swissair has cultivated routes and frequencies in all continents except Australia and with its alliance partners offers one of the most comprehensive airline networks in Africa.

Alliances and Partnerships

Swissair has a long history of participation in international airline groups. Swissair and SAS, the Scandinavian airline, initiated the cooperation in an agreement signed in 1958 in which they shared aircraft procurement and maintenance. The Dutch airline KLM joined in 1969, followed by the French independent airline UTA in 1970. Together the four members were called the KSSU Consortium (for the initials of each airline's name). Swissair also aligned itself with Delta Air Lines from the United States and Singapore Airlines in 1989 to form a global alliance.

Swissair became a leading member of the Qualiflyer Group, an alliance of several European carriers founded in March, 1998. The Qualiflyer Group encompassed Sabena, TAP Air Portugal, Turkish Airlines, AOM, Crossair, Air Littoral, Air Europe, LOT Polish Airlines, Volare Airlines, and PGA Portugalia Airlines, serving more than 200 destinations in Europe and more than 330 worldwide. Under the Qualiflyer Group umbrella brand, the member airlines tried to expand their respective networks and jointly market innovative products and services while retaining and cultivating their individual identities and brands.

Swissair also developed a broad partnership with American Airlines that included numerous codeshare flights over the North Atlantic and made most of American's domestic U.S. network a part of the Swissair world. Swissair also participated through its subsidiary Crossair in the European Leisure Group, which was created in 1998. It consisted of LTU, Sobelair, Balair/CTA, Crossair, Air Europe, and Volare. The aim of this group of largely leisure-oriented European carriers was to exploit the considerable growth potential in the vacation travel field and assume a leading position in the European market.

Another corporate milestone for the airline was the founding of the Swissair Sabena Airline Management Partnership, or AMP, on January 1, 2000. With the aim of managing two brands and two hubs with a single team, Swissair and Sabena's commercial units (marketing and product, sales, information technology, network, finance, human resources) were merged and a new alliance was born. The AMP became a London-based legal partnership with branches in Zürich, Brussels, and in various outstations around the world. In 2000, the AMP had 4,000 employees: 800 in Brussels, 1,000 in Zürich and 2,200 located in the outstations. The main goal of this coalition was to realize revenue potential by capturing commercial synergies, as well as to improve market potential by increasing connectivity and market penetration. This new partnership model was intended to allow for future growth and additional partners, enabling each partner to choose its own degree of integration. The Swissair Sabena AMP network reached 170 different destinations

Events in Swissair History

1931: Two Swiss airlines, Balair and Ad Astra, merge to form Swissair.

1933: Swissair becomes part of the European night mail network, with flights between Basel, Switzerland, and Frankfurt, Germany.

1936: The airline purchases two Douglas DC-3 aircraft.

1939: Swissair suspends its operations with the outbreak of World War II; they are later resumed.

1947: As Swissair becomes the national flag carrier of Switzerland, the airline inaugurates service to New York, with regular scheduled flights beginning two years later.

1960: Swissair takes delivery of its first DC-8 jet aircraft.

1968: The airline renews a prior cooperation agreement with SAS and also includes KLM, to form the KSS Group. The French carrier UTA will join two years later, and the group will be renamed KSSU Consortium.

1971: Swissair takes delivery of its first Boeing 747 wide-body jet.

1975: Swissair adds service to Beijing, China; Shangai, China; Tokyo, Japan; Salzburg, Austria; Dhahran, Saudi Arabia; and Abu Dabi, United Arab Emirates.

1984: The airline adds business-class service to all flights.

1989: Swissair enters agreements with Delta Air Lines, SAS, and Singapore Airlines.

1996: The airline introduces a nonsmoking policy on all European flights.

1998: A Swissair flight en route from New York to Geneva crashes off the coast of Nova Scotia, killing all 229 on board.

1999: Swissair makes its first flight with an all-woman cockpit crew.

2001: The airline files for bankruptcy, and the Swiss government approves a multibillion-dollar bailout.

(without code-shares) and had more than 170 aircraft. The Swissair Group originally took a stake of 49.5 percent in Sabena Belgian Airlines and planned to increase it to as high as 85 percent.

Bankruptcy and Reorganization

On September 11, 2001, terrorists hijacked four airplanes in the United States, crashing three of them into prominent buildings and killing thousands. The airline industry was plunged into chaos worldwide. Swissair, which had been pursuing an expansion program, saw its financial health deteriorate dramatically as it incurred massive losses. The airline grounded its entire fleet for two days when it could not pay its fuel and landing bills. In early October, Swissair was forced to file for bankruptcy protection. A few weeks later, the Swiss government approved a rescue package to provide the company with $1.2 billion, while the private sector promised to invest another $1 billion.

Under the scheduled reorganization, the new company would be headed by former Swissair subsidiary Crossair; Switzerland's biggest banks, Credit Suisse and UBS, had provided $940 million to buy Swissair's 70 percent share of Crossair in early October. The Swiss government would hold 20 pecent in the restructured airline, with 18 percent held by Swiss local governments and the remaining 62 percent held by banks and industry. The Swissair group expected to cut between 9,000 and 27,000 jobs when Crossair took over in March, 2002. In November, 2001, the AMP partnership was threatened when Sabena declared bankruptcy.

Safety

Swissair historically has had a good safety record. Its only recent accident occurred on the night of September 2, 1998, when Swissair flight SR111, a McDonnell Douglas (Boeing) MD-11 was lost off the coast of Peggy's Cove, Nova Scotia. The aircraft was en route from New York to Geneva when it went down carrying 215 passengers and 14 crew members. There were no survivors. The cause of the accident was still under investigation by the Canadian authorities more than two years after it took place. The crew had reported an electrical fire in the cockpit before the aircraft was lost and apparently it was not able to divert in time to a suitable airport for an emergency landing.

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See also: Accident investigation; Air carriers

T

Tactical Air Command

Also known as: TAC
Date: From 1946 to 1992
Definition: A part of the United States Air Force tasked to organize, command, train, and equip Air Force units for establishing and maintaining air superiority over designated combat areas, and working with ground commanders in support of battlefield operations.
Significance: The Tactical Air Command (TAC), in existence from 1946 through 1992, was a major command of the United States Air Force. Throughout the existence of TAC, American military forces enjoyed air superiority and close air support over battlefields from Korea through Iraq.

Structure

Tactical Air Command (TAC) was a major command created on March 21, 1946, in preparation for an independent Air Force. TAC inherited most of the Army Air Force personnel and equipment geared toward battlefield operations. During World War II, the Army Ground Forces and the Army Air Force (AAF) waged a constant struggle over control of air assets over the battlefield and the amount of air resources to be diverted away from strategic operations for tactical operations. The AAF often neglected tactical missions in favor of strategic ones. The Air Force accepted the responsibility for tactical air missions mainly to prevent the Army from keeping tactical air elements after the creation of a separate Air Force. However, TAC constantly struggled against the Strategic Air Command (SAC), which received the bulk of the Air Force budget, to receive adequate funding for its missions.

Soon after its formation, the Air Force moved TAC to Langley Field, Virginia, which would be its home base for most of its existence. Unlike its complement (and sometime rival), SAC, TAC remained relatively decentralized throughout its existence. This reflected the nature of its mission. Whereas SAC planes were expected to fight as members of SAC, TAC's aircraft would be attached to theater commands during war and not fight as part of TAC.

Of primary importance for tactical operations was gaining air superiority. Air supremacy is achieved mostly through air-to-air combat between fighter airplanes. When one nation's air force controls the airspace over a battlefield, its air power can be used for reconnaissance, disrupting convoys, providing close air support, and generally supporting ground operations.

During its existence, TAC progressed through several generations of aircraft. After beginning with leftover World War II propeller-driven planes, TAC began receiving jets, such at the F-86, during the Korean War. It later received the F-4 during the Vietnam War. In the post-Vietnam era, TAC received the F-15, the F-16, and the A-10, which was specially designed for TAC's ground support mission. In the late 1980's, TAC received the F-117 stealth fighter, the most advanced aircraft of its time.

Deployments

TAC was merged into the Continental Air Command in 1949, but was reestablished as an independent command at the start of the Korean War. TAC's primary mission was to develop units for tactical operations. Such units honed their skills training at bases in the United States. During wartime, these units were detached from TAC and attached to unified, specified, and joint commands for operations. In the 1950's, TAC developed the Composite Air Strike Force (CASF), highly mobile composite units of several types of aircraft organized for deployment for contingencies around the world. Although CASF was successfully employed in July, 1958, during the Lebanon crisis, and again that August in the Quemoy-Matso crisis with China, the CASF concept did not last long and TAC returned to attaching its units to other commands, such as the Far East Air Force, for combat.

In 1961, General Walter C. Sweeney, Jr., took command of TAC and began to change the culture of the command. Previously, TAC took pride in the contrasts between itself and the stricter, more centralized SAC. However, the world of aviation was becoming more complex, and the introduction of nuclear weapons in tactical aircraft required a more rigorous environment. Still, TAC retained much of its fighter pilot culture and never became as rigid as SAC.

TAC was not organized to fight as a command, but TAC units fought in all U.S. air wars between World War II and 1992. When the Korean War began in 1950, TAC-organized units quickly came to dominate the skies over North Korea, allowing United Nations ground forces to operate without hindrance from the air while daytime troop and supply movements became almost impossible for the North Koreans. During the Vietnam War, TAC fighters, ironically, became involved with the bombing of strategic targets in North Vietnam, while SAC bombers performed traditional tactical missions in South Vietnam. Still, TAC-organized and -trained fighter units provided the bulk of U.S. air power during the war.

The End of TAC

After the breakup of the Warsaw Pact in 1989 and the collapse of the Soviet Union in 1990, the Air Force began to implement a major reorganization to reflect the changing world situation. Under the plan, TAC was to be combined with SAC to create a new command. In practice, TAC absorbed most of the assets and personnel of SAC. This new command was designated as the Air Combat Command in 1992. TAC's crest, which consisted of a shield-shaped image of an upright sword with wings became the basis for the new Air Combat Command.

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See also: Air Combat Command; Air Force, U.S.; Air Force bases; Fighter pilots; Gulf War; Korean War; Military flight; Strategic Air Command; Vietnam War

Tail designs

Definition: Various arrangements of horizontal and vertical stabilizing surfaces at the rear part of an airplane.

Significance: An airplane's tail design is important because it stabilizes and controls the airplane in both up-and-down movements of pitch and side-to-side movements of yaw.

The Parts of an Airplane's Tail

The tail of an airplane is called by various names, such as "empennage" and "stabilizer." The preferred term is "stabilizer," because it is at least partially descriptive of the component's function. However, the stabilizer provides not only stability but also some of the airplane's control.

The tail of an airplane is designed to provide both stability and control of the airplane in pitch and yaw. There are many different forms an aircraft tail can take in meeting these dual requirements of stability and control. Most tail designs have a horizontal winglike structure and one or more vertical or near-vertical structures. Whenever practical, these structures are identified as the horizontal and vertical stabilizers, although some designs do not conveniently fit such a description.

The many types of airplane tail design include, but are by no means limited to, the conventional, T-tail, cruciform-tail, dual-tail, triple-tail, V-tail, inverted V-tail, inverted Y-tail, twin-tail, boom-tail, high boom-tail, and multiple-plane tail designs.

Conventional Tail Design

The conventional tail design is the most common form. It has one vertical stabilizer placed at the tapered tail section of the fuselage and one horizontal stabilizer divided into two parts, one on each side of the vertical stablilzer. For many airplanes, the conventional arrangement provides adequate stability and control with the lowest structural weight. About three-quarters of the airplanes in operation today, including the Airbus A300, the Boeing 777 and 747, and the Beech Bonanza A-36, use this arrangement.

The T-Tail Design

In the T-tail design, a common variation of the conventional tail, the horizontal stabilizer is positioned at the top of the vertical stabilizer. The horizontal stabilizer is then above the propeller flow, or prop wash, and the wing wake. Because the horizontal stabilizer is more efficient, it can therefore be made both smaller and lighter. The placement of the horizontal stabilizer on top of the vertical stabilizer can also make the vertical stabilizer more aerodynamically efficient. By making the vertical stabilizer more effective, its size may be reduced. However, the horizontal stabilizer in the T-tail layout imposes a bending and twisting load on the vertical stabilizer, requiring a stronger, and therefore, a heavier, structure. These loads are avoided in the conventional design. There is also the possibility that at the high pitch angle usually associated with landing the airplane, the horizontal stabilizer of the T tail will be immersed in the slower and more turbulent flow of the wing wake. In some cases, it is possible to compromise severely the control function of the horizontal tail. Nevertheless, the T tail is the second-most common tail design after the conventional.

Both major American transport plane builders, Boeing and McDonnell-Douglas, use the T-tail design. The Boeing 727, with its three fuselage-mounted engines, has a T-tail design, as do the variants of the McDonnell Douglas MD-90, formerly the Douglas DC-9. Other aircraft that employ the T-tail design are the Lockheed C-5A, the Gates Learjets 23 and 35A, the Cessna Citation CJ1, the Piper Lance II, and the Beech Skipper 77.

Cruciform-Tail Design

The cruciform tail is an obvious compromise between the conventional and T-tail designs. In the cruciform design, the horizontal stabilizer is moved part of the way up the vertical stabilizer. In this position, the horizontal stabilizer is moved up and away from the jet exhaust and wing wake. The lifting of the horizontal stabilizer also exposes the lower part of the vertical stabilizer, as well as the rudder, to undisturbed airflow. Undisturbed airflow on the rudder is important, particularly in the recovery from spins. A military example of the cruciform tail is the North American Rockwell B-1B supersonic bomber. Other aircraft that use the cruciform-tail design are the Dessault Falcon 100 and the Commander.

Dual-Tail Design

The dual-tail design, in which the two vertical stabilizers are placed at the ends of the horizontal stabilizers, was at one time fairly common on large flying boats and twin-engine propeller-driven bombers such as the North American B-25. In some cases, this arrangement is attractive, because it places the vertical stabilizers in the prop wash of wing-mounted propellers. The result is the maintenance of good directional control during low-speed operations. The positioning of the two vertical stabilizers at the ends of the horizontal stabilizers allows for a smaller, lighter, and more aerodynamically efficient horizontal stabilizer. However, the overall weight of a plane with a dual-tail design is greater than that of a plane with the single conventional-tail design.

The dual tail is part of the design of the Republic Fairchild A-10 ground-attack airplane, in which the plane’s two jet engines are mounted to the rear of the fuselage. When this airplane is viewed from the rear and slightly to either side, the engine exhausts, blocked by the vertical stabilizer, are not easily visible. If a heat-seeking missile is launched at a departing or escaping A-10, the main heat source, the engine exhausts, are at least partially blocked by the vertical stabilizer.

The Ercoupe, a private light airplane developed in the late 1940’s and still seen at small airports, uses a dual tail to keep the vertical stabilizer out of the wake from the fuselage and the wing-fuselage junction. The Ercoupe is unique in that it is the only commercial light airplane ever produced with the dual-tail design. Other craft that use the dual-tail design include the Consolidated B-24, the Short Skyvan, and the Martin PBM Mariner flying boat.

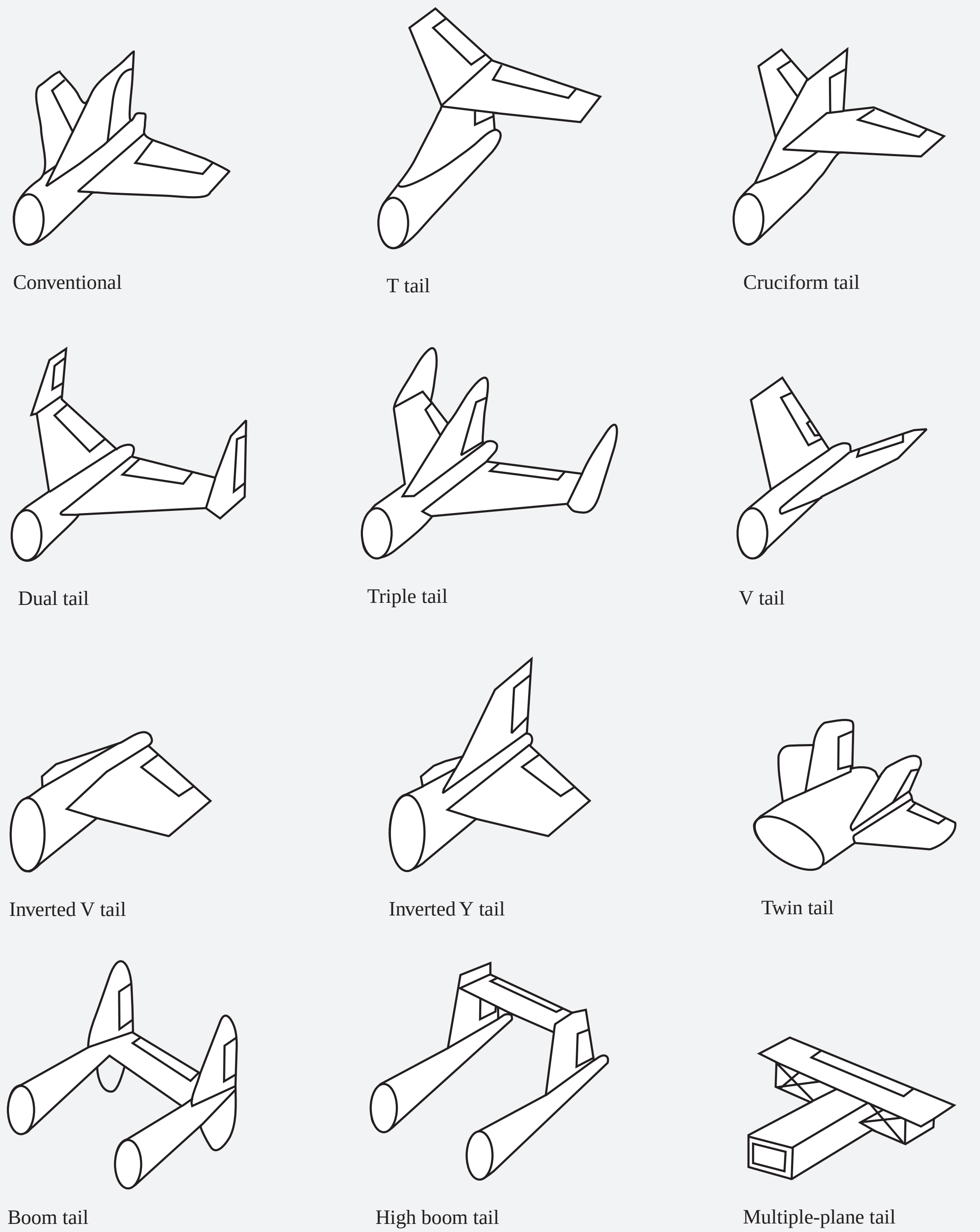
Triple-Tail Design

The triple-tail design, with two vertical stabilizers placed at the ends of the horizontal stabilizers and one mounted on the fuselage, is attractive when the height of the vertical stabilizer must meet certain restrictions, such as hangar-door height. Certainly this was the important consideration in the design of the Lockheed Constellation, one of the most significant passenger airplanes of the late 1940’s. Another well-known example of the triple-tail design is the Grumman E-2 Hawkeye.

V-Tail Design

The V-Tail, sometimes called the “butterfly” tail, has had limited application in airplane design, the most significant of which has been by the Beech Company in the Beechcraft Bonanza V-35. Clearly, the usual definition of horizontal and vertical stabilizers has no application to the V tail. The intended advantage of the V-tail design is that two surfaces might serve the same function as the three required in the conventional tail and its variants. Removal of one surface then would reduce the drag of the tail surfaces as well as the weight of the tail region. However, wind tunnel studies by the National Advisory Committee on Aeronautics (NACA) have shown that for the V tail to achieve the same degree of stability as a conventional tail, the area of the V tail would have to be about the same size as that of the conventional tail.

Airplane Tail Designs



Another disadvantage of the V tail has to do with turning the airplane. To turn left, for example, the pilot would press the left rudder pedal and bank the airplane with the left wing down. In V-tail aircraft, the right side of the V (as viewed from the rear) deflects upward, and the left surface deflects downward. This arrangement drives the nose to the left but also causes the airplane to roll away from the turn. Although this tendency to roll is overcome by the wing control provided by the ailerons, it is clear that one control of the airplane produces a secondary effect that opposes the primary effect of another control. This secondary effect of opposing the primary purpose of another control is called adverse coupling. Adverse coupling is one reason that the most recent Bonanza design, the A-36, uses the conventional tail.

The undesirable rolling motion caused by the V tail might be avoided by inverting the butterfly tail. However, except for a few small homemade glider-sail planes, this design has been avoided because of ground clearance problems.

Inverted Y-Tail Design

The inverted Y tail is actually a conventional tail with a noticeable droop to the horizontal stabilizers. In other words, the outer ends of the horizontal stabilizers are lower than the ends attached to the fuselage. The F-4 Phantom, originally a mainstay of the McDonnell Company, used the inverted Y tail to keep the horizontal surfaces out of the wing wake at high angles of attack. It is interesting to note that the tips of the horizontal stabilizers on the first McDonnell Navy fighter, the F-2H Banshee, were bent decidedly upward.

Twin-Tail Design

The twin tail is a feature of various air superiority fighters used by both the U.S. Navy (the F-14 Tomcat) and the U.S. Marine Corps (the F/A-18 Hornet). Although both the F-14 and F/A-18 designs have a superficial resemblance, they also have important differences. The tilt angle of the vertical stabilizer of the F-14 is more pronounced than that of the F-18, so much so that it approaches that of the V tail on the Beech model V-35 Bonanza. With two vertical stabilizers, the twin tail is more effective than the conventional single tail of the same height.

Boom-Tail Design

Boom tails are used when an aircraft's fuselage does not extend entirely back to the horizontal stabilizer. In both the Lockheed P-38 Lightning fighter of World War II and the Fairchild C-119 cargo plane, engines were mounted on the booms. In the case of the C-119, the twin boom allowed easy access to the rear of the fuselage for loading and removing cargo. The twin boom has also been used for an airplane with engines mounted in the fuselage, with one engine, known as the tractor, in the nose of the airplane and one engine, known as the pusher, in the rear of the airplane. Because the thrust of both engines is along the centerline of the airplane, it is much easier in this arrangement to compensate for the loss of one engine than it is in the wing-mounted engine installation. Both the Cessna Skymaster and the new Adam 309 have fuselage-mounted engines. In the case of the Adam 309 the horizontal stabilizer is raised to avoid propeller wake from the pusher, or rear-mounted, engine.

Multiple-Plane Tail Design

Finally, the obsolete multiple-plane tail design has two or more horizontal stabilizers. This layout was used extensively in bombing airplanes of World War I and even in a few early British passenger and freight-carrying airplanes. It may be seen again on the recently constructed replica of the Vickers Vimy airplane.

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See also: Airplanes; Guidance systems; Manufacturers; Roll and pitch; Stabilizers; Wing designs

Takeoff procedures

Definition: The process of launching an aircraft from the surface into the air for the purpose of controlled flight.

Significance: Takeoffs are necessary because all aircraft must become airborne safely. Their challenge lies in how quickly takeoffs occur under widely varied conditions.

Early History

Every flight begins with a takeoff. Takeoffs come in a variety of styles, and to the untrained, they seem simpler than they truly are. The takeoff presented the greatest challenge to early aviators in their design of controllable airplanes. Unsuccessful takeoffs held little evidence of their causes, because any one of numerous details, from poor planning to faulty design, could ruin a takeoff. Aviators had not amassed a database of accident reports from which they could glean knowledge, and they did not have the experience or insight to pinpoint the problem or sequence of problems causing each failed takeoff. Successful takeoffs require the right combination of aircraft design, favorable conditions, and skillful piloting. Takeoffs also require power. Early aviators such as Otto Lilienthal and Orville and Wilbur Wright first built hand- or foot-launched gliders that required only sufficient wind and downward-sloping terrain. Later, when the Wrights made a gasoline engine for their *Flyer*, they faced the same challenges that had kept Samuel Pierpont Langley from success. Because early engines were underpowered, takeoffs demanded much room and planning.

The Wright brothers, for example, launched their *Flyer* not from a field or a runway, but from a monorail track laid in a slight depression. They depended entirely on the engine to provide power for takeoff. The Wrights later supplemented their engine's meager takeoff power with a weighted catapult that required several men to raise and set. Within a decade, engine power began to grow, and by 1910, the Wrights had abandoned their monorail-takeoff system, allowing wheels to reduce the drag and absorb the stresses of railless launches. The Wrights also sought greater engine power to accelerate the *Flyer*'s mass and drag to the point that aerodynamic lift overcame gravity.

Takeoff Techniques

Although engine power for takeoff has increased dramatically since the time of the Wright brothers, takeoffs still need planning. The fixed wings of airplanes use airflow to produce lift, and power builds forward momentum to achieve flying speed. After the plane reaches flying speed, the pilot uses training and skill to leave the runway and enter the sky at the correct speeds, pitch attitudes, and recommended power settings. Simple airplanes have simple procedures: The pilot must point the nose skyward and maintain full power. More complex airplanes have different considerations. Complex airplanes require a specific time or height above the surface to make the first power change. Some engines have limits on the amount of time full power may be maintained, as pressures within the engine become very high. In the United States, the Federal Aviation Administration (FAA) certifies airplane engines with slight tolerance to overboost. Necessary for takeoff, overboost allows pilots to run the engine at very high power settings for a specified amount of time, after which the pilot must reduce the power to the recommended setting, usually called maximum except takeoff (METO), and maintain a prudent airspeed. Pilots may choose between three basic takeoff techniques, normal, short-field, and soft-field takeoffs. Their use depends on both the circumstances and the pilot's decision.

Takeoffs and Noise Pollution

In response to complaints by those who live near airports about the noise that takeoffs can generate, many airports in the late twentieth century adopted noise-abatement procedures to reduce noise pollution. Most airport noise is a by-product of takeoffs, and noise pollution remains one of the public's strongest objections to airports. Since the 1980's, this issue has been an expensive one for airports, as airports across the United States have been forced to buy nearby homes or to pay for expensive soundproofing to minimize the intrusion of noisy airplanes taking off.

After a taxiing plane has reached flight speed, the pilot must judge speed, pitch attitude, and power settings for a successful takeoff. (NASA)

Normal Takeoffs

Pilots use a normal takeoff when there is no need to employ either of the other two types of takeoff. For a normal takeoff, the runway length must pose no challenge, its surface must be firm and dry, and no appreciable obstructions should interfere with the airplane's climb path. Although normal takeoffs may seem routine to the observer, they require much skill on the part of the pilot. All takeoffs must be carefully planned. Normal takeoffs call for pilots to make certain there is no conflicting airplane traffic, to taxi onto the runway with the wing flaps properly set, and to apply takeoff power. At the right airspeed, the pilot raises the nose and allows the airplane to fly smoothly off the runway while making small adjustments to the pitch attitude to maintain the best rate-of-climb airspeed.

Short-Field Takeoffs

When pilots have a less-than-normal amount of runway available, they use a short-field takeoff technique. Details vary with airplane type, but pilots have basic techniques upon which they rely. The first involves using the aircraft's short-field takeoff charts to determine the minimum runway distance required by current conditions. These include wind direction and speed, air temperature, the airplane's weight, and the condition of the runway surface. Some takeoff tables or graphs include mention of the runway's slope or of the presence of tall grass, if the runway is not paved. In any case, aircraft manuals assume that the airplane is properly maintained, that its engine is producing full power as it did when new, and that its exterior is clean and free of drag-producing dents. The charts also assume that the pilot performs the takeoff procedure smoothly and skillfully, exactly as outlined by the manufacturer.

A pilot must use the runway's full length by taxiing to the very edge of the runway's end and then carefully aligning the airplane's nose with the runway's centerline. As with all takeoffs, the pilot must quickly ensure that engine oil pressure and oil temperature are proper. Holding the airplane stationary by applying and holding the brakes, the pilot adds power until reaching the manufacturer-specified power setting. When the engine sustains that power, the pilot releases the brakes so the airplane accelerates to the airspeed that the pilot determined when planning the takeoff. At that airspeed, the pilot notes how far down the runway the airplane has traveled, analyzes the airplane's acceleration, how much runway remains, and the airplane's ability to fly. Once airborne, the pilot raises the nose to a climb angle that results in the exact airspeed that the aircraft manual demands. The pilot maintains that climb angle and airspeed until no obstacles, such as trees, powerlines, or buildings, threaten the airplane's climb path. When safely above any obstacles, the pilot then lowers the airplane's nose, increasing the airspeed to one that provides a more efficient climb. This efficiency considers engine cooling, flight visibility, and other safety considerations.

Soft-Field Takeoffs

A third takeoff technique, the soft-field takeoff, involves runways that are poorly maintained, strewn with small debris, or are covered with snow or grass, muddy, or otherwise not hard, clean, and dry. Pilots use soft-field takeoffs to reduce the chance of damage to the nosewheel and to allow the airplane to leave the surface at an airspeed lower than that of either normal or short-field takeoffs. Soft-field takeoffs require a well-developed judgment, because soft fields often pose several challenges, some severe, usually at the same time. Unimproved airstrips are common in rural and remote areas, as are livestock and wildlife. Numerous accidents occur yearly in North America when airplanes collide with deer, coyotes, and even cattle, to name just a few wildlife hazards. Information as basic as the runway's dimensions are easily found for hard-surfaced runways, but these are often mere guesswork for grass and dirt strips. Compared to concrete runways, which are reasonably consistent in firmness along their entire length, soft fields can vary tremendously in a short distance. Grass causes drag, and long grass at unkempt, idle airstrips can retard an airplane enough to prevent takeoff. Grass that is wet from dew or rain is even more of a hindrance. Pilots sometimes cannot define the runway edges at soft fields, because there are no painted markings, nor any contrast between the runway and its surroundings, as there is on concrete or asphalt runways. Even those airstrips that have well-maintained grass and defined edges and are free of wildlife may still have drainage problems that are invisible to pilots. Some or all of an airstrip may have a very porous soil, which quickly drains away water. Another part of the strip might consist of soil that retains water below the surface, into which an airplane's wheels may sink. The nosewheel-equipped airplane has no advantage over tailwheel-type aircraft in this environment.

A pilot making a soft-field takeoff must handle the flight controls smoothly, because at the low speed and high nose angle demanded by a soft-field takeoff, roughly handled flight controls could force the airplane back onto the runway. Accidents involving the mishandling of the flight controls in such situations have resulted in damage to property and injury to persons. In the United States, applicants for pilot certificates must not only demonstrate as much skill as is practicable during the flight test, but also demonstrate knowledge relating to the various elements of soft-field takeoffs under various conditions. Safe and efficient takeoffs demand good planning and skill.

Takeoff Testing Standards

Because events during takeoffs happen so quickly as to seem automatic, flight instructors must carefully ensure that their students consider takeoffs an extreme low-altitude maneuver requiring good planning. Accident statistics consistently show mishaps occurring during takeoffs and landings. The aviation industry has worked to improve takeoff planning in different ways. In the United States, the Federal Aviation Administration (FAA) took steps in the mid-1990's to help flight instructors in their teaching by changing their Practical Test Standards requirements for all takeoffs. Applicants for U.S. pilot certificates must, before takeoff, verbally review the available runway assigned for takeoff, stating its length, the distance required for the takeoff, the airspeeds required for the technique to be used, and the departure procedure.

Seaplane Takeoffs

Seaplane takeoffs have their own considerations. Although seaplane operations are statistically less common than landplane operations, they are a vital part of aviation and require specialized knowledge. A landplane's pitch attitude, or the relationship of the nose to the horizon, is governed by the landing gear and remains constant until the moment a pilot rotates for takeoff. On the water, a seaplane or amphibian will change its pitch attitude with the rising and falling of the water, or of the taxiing speed, or with a shift in airplane loading. Aileron control is more critical in a flying-boat takeoff, because the craft's fuselage is a single-keel hull, and it rolls left and right just as in flight. Landplanes' wheels, as do twin floats on some seaplanes, prevent such rolling. Seaplane takeoffs promise excitement as water pounds the hull while the pilot gives full attention to getting the airplane "on the step." This means that the bottom of the hull or the floats are mostly out of the water as the wings increase their lift, and water pressure on the V-shaped hull or float bottoms releases its suction and allows the seaplane to fly.

Seaplane pilots must watch for boats, buoys, and such, but give extra care to partially or near-fully submerged logs or other obstacles. Even the water itself may become an obstacle, as seaplanes may strike a large wave that sends the craft airborne too soon for it to fly. As the craft settles onto the water again, a second wave may strike the aircraft in such a manner as to engulf the craft's nose. Over the decades, pilots have shared their experience to amass a pool of knowledge from which pilots may draw.

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See also: Aerodynamics; Air traffic control; Airplanes; Airports; Flight plans; Forces of flight; Landing procedures; Pilots and copilots; Runway collisions; Runways; Safety issues; Wright *Flyer*

Taxiing procedures

Definition: Steps to assist in the process of self-propelled aircraft movement on land.

Significance: Taxiing procedures are essential in moving aircraft to and from runways. Despite its apparent ease, taxiing demands pilot vigilance, as many mishaps occur during taxi.

History and Techniques

Before airplanes may take off for flight, they must travel from the parking ramp to the runway. Although most accomplish this by taxiing, that was not always so. The first flying machines, such as Otto Lilienthal's foot-launched gliders, Samuel Langley's houseboat-launched *Aerodrome*, and Wilbur and Orville Wrights' rail-launched *Flyer*, were not designed with taxiing in mind.

Soon, however, aircraft designers abandoned landing skids and foot-launches for humanity's oldest convenience, wheels. Even so, early wheeled airplanes could not taxi. Aircraft such as Louis Blériot's famous monoplane required handlers to trundle the airplane into the takeoff position or roll it to its parking spot after landing. Blériot and other early designers included main wheels to trundle their flying machines into takeoff position, and to the parking area after landing, but placed skids at the tail to retard movement on landing. Taxiing moves an airplane under its own power, using the airplane's control systems to steer.

By 1918, airplanes had grown large, and engines had attained enough power to make the labor-intensive trundling method inefficient. Eventually, the tail skid was replaced with wheels all around, one of which was steerable. It was extremely difficult to use the trundle method of ground movement to move the huge bombers built by manufacturers in Germany and England. Certainly, after World War I, taxi techniques had become well established.

A 1930's development was the tricycle landing gear. Tricycle landing gear places the third wheel under the nose, bearing the weight of the engine while the aircraft is parked or taxiing. That extra weight provided traction during taxi and reduced nose-over accidents when pilots applied brakes too enthusiastically. Tricycle landing gear lowered the nose permanently for taxiing, so pilots could look over engine cowlings to enjoy approximately the same view automobile drivers would see over their hoods. By the 1950's, the term "conventional landing gear" denoted the tailwheel type, because the word "tricycle" had become standard for the increasingly popular nosewheel system. By the end of the twentieth century, few manufacturers built tailwheel airplanes, although the tailwheel remained popular with amateur builders.

Designers learned quickly that flying machines, though at rest on the ground, remain subject to the wind. Because winds can be unpredictable, pilots taxi airplanes slowly, so that moving the throttle to idle allows a prompt stop. When taxiing into the wind, wings produce lift, which reduces brake and steering effectiveness. Because strong winds have overturned taxiing airplanes, pilot training since the 1940's has included positioning the flight controls so as to keep the wind flowing over the top of the airplane structure. For new pilots, automotive driving habits slow their learning to taxi. Taxiing pilots steer by using foot controls, or rudder pedals, and most brakes are activated by pressing the top of these pedals. This takes some acclimation.

Landing gear design also affects pilot taxi technique. Tricycle airplanes are easy to taxi. Tailwheel airplanes require greater attention. Wide landing gear makes taxiing more easy than does narrow gear. The wide-landing-gear design saw an extreme expression in the 1980's, when one amateur-built airplane appeared with wheels at each wingtip. The popular airplane was stable but could not negotiate very narrow taxiways.

Taxiing surfaces also affect taxiing procedures. Not all taxiing surfaces are clean and strong. They range from well-maintained concrete at major airports to narrow dirt strips at ranches and even to riverbanks and sandbars. Taxiing techniques must accommodate each of these. Generally, tailwheel-type airplanes are more suitable to rugged taxiing surfaces than are nosewheel-type aircraft.

Modern pilots learn to control their airplanes from first movement. Taxiing demands alertness, and pilots must keep track of the movement of everything else along the taxi path. Right-of-way issues and individual pilot habits make taxiing on busy airports an effort in safety. To observe the entire area, pilots must look around in a complete circle, which few airplane structures allow. Airport space is extremely valuable, so parking areas place airplanes closely together. Pilots must avoid people, other aircraft, and obstructions when taxiing. During the 1990's, pilot training in the United States began to require that pilots verbally announce "clear right" or "clear left" when taxiing past taxiways, runways, and parked aircraft or other obstructions.

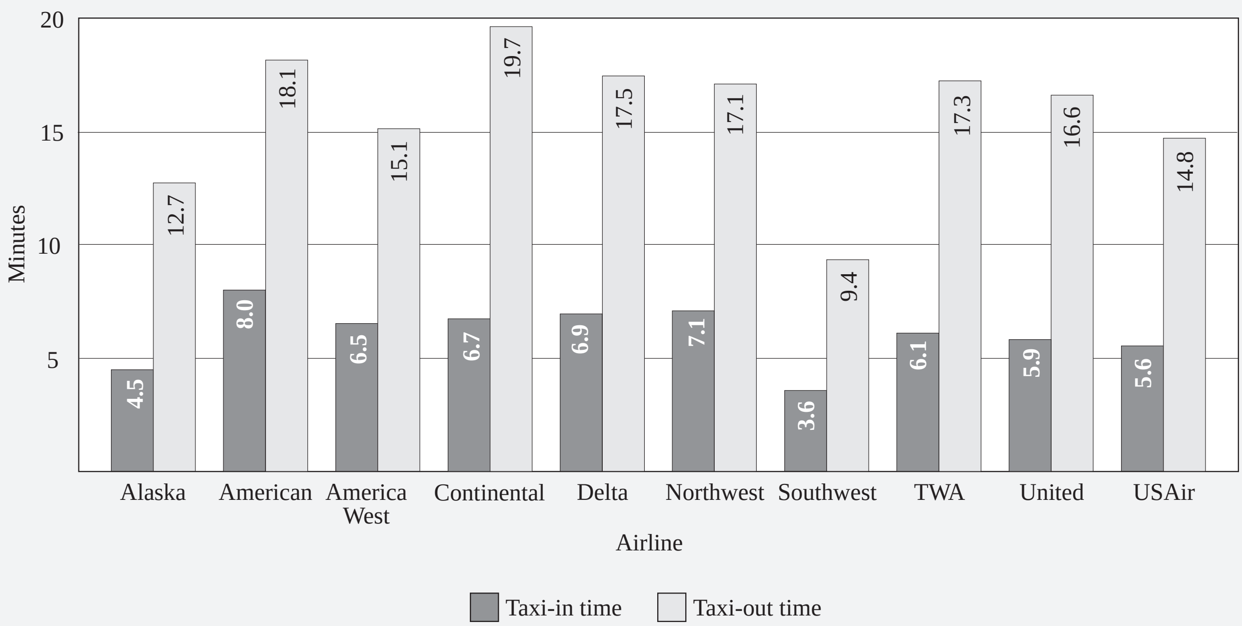
Water Taxiing

Seaplanes also taxi, and taxiing on water demands nautical, as well as aviation, skills. Water operations allow pilots to taxi with about two-thirds power, in a technique called step taxiing. Seaplane pilots use a step taxi when the takeoff or landing area is distant from where the seaplane will moor, or anchor. When not step taxiing, seaplane pilots taxi slowly when they are near the shore or at any time when speed would be hazardous. Because water is fluid, seaplane pilots must give even more attention than landplane pilots to the wind while taxiing.

Taxiing Accidents

Accidents do occur during taxiing. The two most common reasons for taxi accidents are pilot distraction or inattention and taxiing too fast for conditions. It is difficult to set rules for safe taxiing speed, because circumstances and conditions continually change. What is prudent one day

Average Taxiing Times of Major U.S. Airlines, 1999



Source: Data taken from Bureau of Transportation Statistics, U.S. Department of Transportation.

may be rash or reckless the next. Traditionally, pilots have used the phrase "a brisk walk" to describe a prudent speed. However, if a pilot needs to stop immediately, even that speed may be too fast. A third cause for taxi accidents or incidents is a pilot's holding the flight controls improperly for the wind conditions. Taxi accidents tend not to be newsworthy events, but are dangerous nonetheless. In all, taxiing, like flying, can be safe and enjoyable when responsible pilots follow procedures.

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See also: Air traffic control; Airplanes; Airports; Flight plans; Landing gear; Landing procedures; Samuel Pierpont Langley; Pilots and copilots; Runway collisions; Runways; Safety issues; Takeoff procedures; Wright brothers; Wright *Flyer*

Valentina Tereshkova

Date: Born on March 6, 1937, in Masslenikovo, Yaroslavl region, Russia, Soviet Union

Definition: The first woman to travel in space, who made forty-eight revolutions around the earth in a seventy-hour, fifty-minute spaceflight from June 16 to June 19, 1963.

Significance: In addition to being the first woman in space, Tereshkova was also the first space traveler with no prior experience as a test pilot. It was not until 1982 that Svetlana Savitskaya became the second Russian woman in space.

Valentina Tereshkova's father was a tractor driver who was killed in action during World War II. Her mother was a textile worker. In 1953, she left secondary school to work, but continued her education by correspondence course. In 1961, she earned a degree in cotton-spinning technology. In 1969, six years after her space flight, she graduated with distinction from the Zhukovsky Military Air Academy.

Tereshkova was an avid parachute jumper and made her first jump under the auspices of the Yaroslavl Aviation Club in 1959. In 1961, she became secretary of the local Komsomol (Young Communist League). The following year, she was one of five women selected for cosmonaut training, which included training in weightless flights, parachute jumps, and isolation and centrifuge tests. She excelled in physical training; however, she found rocket theory and spacecraft engineering more difficult.

In 1963, Soviet premier Nikita Khrushchev selected Tereshkova for the first pioneering mission that would include a woman. Tereshkova became the first woman in space on board Vostok 6, launched on June 16, 1963. She completed three days in space, more than the total flight time of all the American astronauts at the time, orbiting the earth forty-eight times. She landed about 380 miles (612 kilometers) northeast of Qaraghandy, Kazakhstan, in central Asia, on June 19, 1963.

On November 3, 1963, Tereshkova married fellow cosmonaut Andrian Nikolayev. On June 8, 1964, her daughter, Elena Andrianovna, was born. Elena had the distinction of being the first child born to parents who had both been exposed to space.

The women in space program slowed down considerably after Tereshkova's historic flight. An all-female flight aboard a Voskhod spacecraft in 1965 was canceled after the nearly disastrous flight of Voskhod 2. In 1982, Svetlana Savitskaya became the second Russian woman in space and later flew again in 1984. A planned all-female Soyuz T-15 flight commemorating International Women's Day in 1985 was also canceled due to problems with the Salyut 7 space station.

Tereshkova became a member of the World Peace Council in 1966. She was elected to the presidium of the Supreme Soviet in 1974 and was the Soviet representative to the United Nations Conference for the International Women's Year in Mexico City in 1975. Later, she served as vice president of the International Women's Democratic Federation and as president of the Soviet-Algerian Friendship Society. She was honored as a Hero of the Soviet Union and received the Order of Lenin and the United Nations Gold Medal for Peace.

Monish R. Chatterjee

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See also: Astronauts and cosmonauts; Orbiting; Russian space program; Spaceflight; Test pilots; Women and flight

Terrorism

Definition: The use of force or violence to achieve political goals through coercion and fear.

Significance: Although many threatening or violent events occur that resemble acts of terrorism, that term is more properly reserved for cases in which the perpetrators seek some political gain.

Terrorism and Commercial Aviation

Since the 1960's, commercial aircraft have been a favorite target of terrorists, for several reasons. One explanation emphasizes the political nature of terrorism, because airliners serve as symbols of their countries of origin. For example, in the mind of a terrorist, an attack on an American Airlines aircraft, anywhere in the world, is an attack on the United States. Airliners are usually filled with influential citizens of the country that sponsors the airline.

Additionally, in cases of aircraft hijacking, sometimes called skyjacking, any passengers on board the airplane who are not natives to the airline's country of origin provide a bonus in that their home nations will doubtless bring pressure upon the target country to satisfy the terrorist's demands.

Another reason for the popularity of airliners as terrorist targets is a tactical one. As bombing targets, commercial aircraft, incredibly complex machines operating at blinding speeds and altitudes, are distressingly vulnerable to even small explosive charges. In hijacking situations, airliners amount to self-contained, highly mobile vehicles capable of transporting hostages anywhere in the world, including to nations that may be sympathetic to the hijackers. The planes themselves can also be used as weapons.

Lastly, airliners make attractive terrorist targets because of the ultimate purpose of terrorism itself: to introduce widespread fear and insecurity. Terrorists are always weaker in numbers and arms than the entity against which they struggle. Their deficiencies do not allow them simply to declare war and settle their differences on the battlefield. Terrorism provides this weaker group with the means to magnify their power through hit-and-run attacks against a defenseless population, protected only by a government the terrorists hope will be exhausted in its futile effort and, eventually, give in to the terrorists' demands. Because many people harbor a fear of flying under the most ideal conditions, the specter of terrorist hijackings and bombings only exaggerates their concerns, further magnifying the terrorists' advantage.

Nonterrorist Commercial Hijackings

Since the early 1950's, commercial air carriers have been routinely commandeered by passengers. At that time, the hijacking of airplanes was a novel and daring means by which individuals or small bands of people fled Eastern European Soviet Bloc nations. To escape these communist countries, hijackers would produce weapons and seize control of an airplane flying a domestic route, divert it to a free country in the West, and deplane to seek political asylum, leaving the aircraft free to return.

During the early 1960's, another round of hijackings was initiated in the United States by Cuban expatriates who had fled their homeland during the Cuban Revolution. Homesick, unhappy with life in their adopted country, and hoping to ingratiate themselves with the communist regime by foiling the United States, they would hijack domestic U.S. air flights and divert them to Havana. Similar hijackings began to occur after the Mariel boat lift of 1980, when disgruntled Cuban expatriates employed them to return to Cuba.

In all these cases, the hijackers made no demands other than transportation to a place otherwise inaccessible to them. Because they would seize any aircraft capable of making the trip regardless of national origin, none of these hijackings can truly be regarded as terrorism.

One further category of nonterrorist hijackings began to occur during the early 1970's. A man calling himself Dan Cooper, erroneously reported by the press as D. B. Cooper, boarded a Northwest Airlines 727 flight from Portland, Oregon, to Seattle, Washington. In the air, he passed a note to a flight attendant that claimed he had a bomb in his briefcase. He demanded $200,000 and four parachutes, apparently wishing to suggest that he might force crew members to jump with him and thus ensure that the parachutes would be serviceable.

The airline quickly capitulated, and the flight crew landed the aircraft in Seattle. After receiving the money and parachutes, Cooper allowed the passengers to leave while retaining the flight crew. He then instructed the pilot to fly a course to Reno, Nevada. While over the wilds of Washington, he opened a rear door of the plane and leaped into the teeth of a below-zero storm. He was never seen again, although several thousand dollars of the ransom washed ashore in a Columbia River tributary nine years later. Cooper's hijacking and the twenty-seven copycat attempts that soon followed all amounted to spectacular robberies more than to acts of terrorism. The perpetrators made no demands other than for money.

Terrorist Commercial Hijackings

On July 22, 1968, an event occurred that would revolutionize both terrorism and commercial air travel. Three members of the Popular Front for the Liberation of Palestine, (PFLP), a splinter group of the Palestine Liberation Organization (PLO), seized control of a Boeing 707 flying a route from Rome, Italy, to Tel Aviv, Israel. The airplane was operated by El Al, the national airline of Israel.

The hijackers ordered the flight to Algiers, where Algerian troops guarded the Israeli hostages after releasing the non-Israelis. They held the victims captive for more than one month, until Israel released sixteen Arab prisoners in satisfaction of the hijackers' demand.

For the first time in history, terrorists had carefully targeted a particular country's national air carrier, and the passengers on board, for political effect. By placing so many people into mortal jeopardy, they had forced an antagonistic state to bargain with them, despite Israel's prior disdain, and they internationalized their struggle by turning it into a major media event.

With the creation of the state of Israel by the United Nations in 1948 and the series of wars between Arabs and Israelis that followed, more than one million Palestinians were dispossessed from their former homes. Mostly living in squalid refugee camps in neighboring Arab countries, the Palestinians desperately sought support for a return to what they considered their rightful homes. However, few people, particularly those in the West, paid much attention to their struggle. After twenty years of frustration and despair, some of these Palestinians began to execute raids across the border into Israel. Still, few people outside of the area took notice, and fewer offered support.

The 1968 El Al hijacking put the PFLP's cause on the front page of virtually every newspaper. Dr. Georges Habash, leader of the PFLP, remarked that "When we hijack a plane it has more effect than if we killed a hundred Israelis in battle. For decades world opinion has been neither for nor against the Palestinians. It simply ignored us. At least the world is talking about us now." The Palestinians surely realized that they would be roundly condemned for this act and for others over the next few years, but they believed it imperative first to capture the world's attention and later to rehabilitate their image.

Terrorists read the newspapers, and they are intelligent people. Almost immediately, groups everywhere began to imitate this victorious stunt, a phenomenon sometimes called the copycat effect. The Israelis learned a lesson, too, and instituted what are probably the most thorough airline security measures in the world.

Although political hijackings flourished worldwide over the next two years, no group seized planes more regularly or to greater effect than the PFLP. In 1970, the PFLP orchestrated probably the most ambitious terrorist hijacking operation of that period. On September 6, 1970, teams of PFLP terrorists simultaneously hijacked three aircraft, with a further attempt at a fourth.

The one failed attempt involved another El Al flight out of Tel Aviv, Israel. Two PFLP agents, one of them a woman, pulled handguns and hand grenades in midflight but were overcome by Israeli sky marshals with the help of passengers. The three other attempts proved stunningly successful. A Pan Am 747 flying out of Zagreb, Yugoslavia, was diverted to Cairo, Egypt, where the terrorists released the passengers and crew before they exploded the plane.

Parallel to this incident, other PFLP teams hijacked a Trans World Airlines (TWA) flight out of Frankfurt, Germany, and a Swissair flight out of Zurich, Switzerland, diverting both to an abandoned World War II-era British landing field in Zerka, Jordan. Hostages on board the airplane came from many countries, creating a negotiating nightmare for the victims' representatives but giving the terrorists tremendous leverage in bargaining for the release of imprisoned comrades. After weeks of discussion, the parties struck a deal freeing the hostages, with PFLP explosives experts punctuating the end of the ordeal by exploding the airplanes while news cameras rolled.

Although the PFLP's impetuous plan was a stunning coup that garnered invaluable publicity for the Palestinian movement, the PLO paid a price, because it had not cleared this operation with King Hussein of Jordan. The widespread condemnation resulting from the mass hijackings caused Hussein to reassess the wisdom of hosting what was turning into a highly armed, uncontrollable state-within-a-state. He ordered his army forcibly to expel the Palestinians. After fierce fighting, resulting in far more casualties than the Israelis had managed to inflict in twenty years of combat, the Jordanians swept the PLO out of their country. Familiar with relocation, the PLO settled in Lebanon.

The consequences of the PLO's expulsion were not long in coming. A new terrorist group surfaced, probably the most ruthless of all the groups under the PLO umbrella. This new group defiantly called itself Black September, after the month in which the PLO was evicted from Jordan. The Black September group is best known for two terrorist operations that occurred at airports rather than in flight.

The first, on May 30, 1972, involved three Japanese Red Army terrorists on contract to Black September who infiltrated the Lod Airport terminal in Israel. Because the strict Israeli security measures adopted after the 1968 hijacking would surely have prevented them from carrying weapons on board a flight, they simply fired their submachine guns and threw grenades into a crowd of deplaning passengers. Twenty-eight people were killed and another seventy-six were injured before Israeli airport security police killed two of the terrorists and captured the other.

Commercial aviation also played a peripheral role in what is one of the most compelling, publicity-grabbing terrorist operations of all time. The stage for this drama was the 1972 Olympic Games held in Munich, West Germany, which was eager to establish itself as a modernized country and to atone for the damage of World War II, particularly with respect to the Jewish victimization of the Holocaust. On September 5, eight Black Septembrists invaded the Israeli barracks at the Olympic village, killing two athletes and taking hostage the surviving nine Israeli team members.

The terrorists demanded the release of several members of Germany's Baader-Meinhof gang from prison, along with 236 Arab terrorists held in Israeli prisons. Israel was determined to take a hard-line approach to discourage future terrorist acts. After days of fruitless negotiations, the Germans laid an ambush. The terrorists and their hostages were helicoptered to a local military airport, where German police snipers opened fire. The terrorists, however, managed to kill all nine hostages with grenades and submachine-gun fire before they were captured or killed. Because of the great attention already attendant to the Olympic Games, people worldwide were riveted to this drama through its tragic conclusion.

The fact that both of the Black September terrorist operations involved airports rather than flights in progress is no coincidence. While commercial aviation remained as attractive to hijackers as ever, airline security staff was working feverishly to defeat the hijackers' tactics. Shortly after the Cooper hijacking, U.S. airports began searching carry-on luggage and boarding passengers through metal detectors. From a high of more than 150 terrorist and criminal hijackings worldwide in the two years from 1968 to 1970, the number of attempts dropped to about one-third that number in the years from 1971 to 1973 and by nearly another one-third in the years from 1974 to 1976. Purely terrorist hijackings dropped by nearly one-half during that time, a smaller reduction that probably reflects the intense motivation and greater resources of terrorists compared to other hijackers.

Terrorist Bombings

Although the act of hijacking airliners is popular with terrorists, the act of taking hostages carries serious disadvantages. Terrorists risk imprisonment if they surrender and death at the hands of counterterrorist forces if they do not. Because only the most committed terrorists would embark upon such risky missions, the use of bombs increased. Although a successful midair bombing denies terrorists the bargaining advantage of an airplane full of hostages, the dramatic impact and the specter of fear that such an act engenders within the traveling public are significant motivators.

Assuming that the bomber can manage to plant the weapon aboard the aircraft or dupe some innocent passenger into carrying it aboard, the risk to the terrorist is minimal. Another advantage is that, if the bomb can be timed to detonate over deep ocean waters, any incriminating evidence is virtually guaranteed to be unrecoverable.

The most prominent example of a terrorist bombing of a commercial airliner involved the crash of Pan Am Flight 103 over Lockerbie, Scotland, on December 21, 1988. The aircraft was a Boeing 747 en route to New York from Frankfurt, Germany, with a stop in London, England. All 259 people aboard the plane died as well as eleven more on the ground. A painstaking investigation concluded that

Image Not Available

Semtex plastic explosive concealed inside a radio stowed with checked luggage provided the blast that ruptured the baggage compartment, bringing about a catastrophic breakup of the aircraft. In 2001, two Libyan men were brought to trial in Scotland for the murders. The court acquitted one of the defendants and convicted the other, sentencing him to a twenty-five-year prison term.

Of particular concern is the new bombing technology, using sophisticated explosives and triggering mechanisms, in the hands of increasingly fanatical terrorists. For example, in 1996, a federal jury convicted three Middle Eastern men, including the mastermind of the 1993 World Trade Center bombing, for conspiring to blow up a dozen U.S. airliners, with an estimated four thousand victims, in a two-day spree of terrorism designed to punish the United States for its support of Israel. A chance fire in a Manila, Philippines, apartment rented to one of the men alerted police to suspicious materials and exposed the plot before the terrorists could complete their preparations.

The terrorists' plan was to smuggle powerful bombs using liquid nitroglycerin stabilized with cotton into contact-lens solution bottles hooked to timers built from rewired digital watches and 9-volt batteries. They intended to board flights with multiple legs and deplane at the first stop while leaving behind their carry-on luggage containing the bombs set to go off after the planes had again taken off.

Although new types of bombs are difficult to detect with existing airport security measures, new defenses are being developed. Because most bombs smuggled aboard aircraft are relatively low-powered, engineering efforts are being put forth to harden the luggage compartments against explosions. Efforts are underway to perfect and deploy explosive-detection systems using computed tomography technology to screen checked baggage; trace detectors to screen electronics, such as laptop computers and cell phones; and canine teams to screen luggage and vehicles visiting airports. Even with these efforts underway, however, most experts regard bombing as the most serious continued terrorist threat to commercial aviation.

Aircraft as Terrorist Weapons

Terrorists can also use aircraft as tools to commit terrorist acts. Although lacking the political goal needed to qualify as a true terrorist mission, one incident came close to succeeding on September 11, 1994, when a thirty-eight-year-old man named Frank Corder, after drinking alcohol and smoking crack cocaine, stole a Cessna 150 from a small airport in Maryland. He was not a licensed pilot but had received sufficient instruction for solo flight. Corder took off and flew southwest to Washington, D.C., where an accident reconstruction shows he deliberately dove the plane at the White House, crashing on the lawn just south of the building and sliding into its corner. Fortunately, the First Family was staying elsewhere at the time because the residence was undergoing renovation work. Corder had earlier told friends that he wished to commit a dramatic suicide by flying a plane into either the White House or the Capitol Building. Although his motive suggests drunken dementia more than terrorism, genuine terrorists can concoct a similar plan as an act of political defiance.

On the morning of September 11, 2001, in what was immediately termed the worst act of terrorism in history, four commercial jetliners were hijacked and three of them were crashed into significant American buildings. Two airplanes hit New York City's World Trade Center, collapsing both of the center's Twin Towers. Another crashed into the Pentagon, in Washington, D.C., collapsing part of that building. A fourth airplane crashed outside of Pittsburgh, Pennsylvania, when the passengers learned of the other hijackings by phone and confronted the terrorists. Many believed that the White House or the Capitol Building was the intended target.

Although no terrorist group immediately claimed responsibility for the crashes, it soon became clear that the terrorists were Islamic fundamentalists from the al-Qaeda network run by Saudi billionaire Osama bin Laden out of Afghanistan. It was the same group that had bombed the World Trade Center in 1993. In the weeks that followed, bin Laden threatened further terrorist acts against Americans and made such demands as the withdrawal of all Western troops from the Middle East and justice for Palestinians.

The hijackings exposed serious lapses in security. There were four teams of terrorists, nineteen men in all—two of whom were on a Federal Bureau of Investigation (FBI) watchlist. The hijackers smuggled box cutters and other knifelike instruments onto the planes. They gained relatively easy access to the cockpits, either killed or incapacitated the flight crews, switched off the transponders, and took over the controls. These acts also revealed the escalation of air terrorism. Because the hijackers were on a suicide mission, they did not need to worry about planting bombs, negotiating demands, or releasing hostages. Conventional wisdom about complying with the hijackers was useless.

Furthermore, especially in comparison to most hijackings, the plan was complex. Several of the hijackers had received sufficient training at aviation schools in Florida to control the jets in flight. (Such training solved a problem experienced in a similar attack by the al-Qaeda network in 1994, which failed in its objective of crashing into the Eiffel Tower because the pilot of the hijacked Air France jet did not cooperate and the terrorists could not fly the plane.) All four flights were scheduled to depart at roughly the same time. The hijackers chose Tuesday, a slow day of the week, to minimize the number of people on board and the odds of resistance. They claimed to carry explosives in order to control the passengers. (Ironically, one team failed because the hijackers apparently saw no harm in passengers calling people on the outside.)

The terrorists boarded flights at three different airports—Boston's Logan Airport, Washington's Dulles International Airport, and Newark International Airport in New Jersey—that were known to be lax in their screening procedures. They chose large jets, 767's and 757's, en route to California and thus carrying large amounts of highly flammable jet fuel to create mass destruction. They selected planes from the top air carriers in the United States, two from American Airlines and two from United Air Lines. They chose targets symbolic of the country's military and economic power. In the course of a few hours, they caused the deaths of more than three thousand people on the planes and on the ground. Most of all, the terrorists succeeded in striking fear in the hearts of Americans, many of whom had believed their country to be safe from such acts.

Not much imagination is needed to construct other scenarios using aircraft to carry out spectacular terrorist operations. Yet surprisingly, few of these incidents have been recorded. Some have been planned but, for various reasons, did not come to fruition. An explanation for this lack of initiative, perhaps, is that most terrorists do not have access to tools as sophisticated as high-performance aircraft or the training to operate them. Terrorists are still more likely to deliver bombs by hand than by airplane.

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See also: Accident investigation; Airline industry, U.S.; Airport security; American Airlines; El Al; Emergency procedures; Hijacking; National Transportation Safety Board; Pan Am World Airways; Safety issues; Trans World Airlines; United Air Lines

Test pilots

Definition: Pilots of new, certificated airplanes (production test pilots) or of newly designed, incompletely tested airplanes (experimental test pilots).

Significance: Test pilots ensure that new aircraft operate as they were designed to do, and that the aircraft is safe. Not only do they make sure that the aircraft fulfills its minimum requirements, they also test the outer limits of the craft's performance.

Before its first flight, every new airplane is at least partly an unknown quantity. Performance test pilots must have the skills needed to verify the handling and performance of an airplane just off the production line. Experimental test pilots must have the education and the skills required for the first flight and for the gradual extension of the flight envelope of an experimental aircraft, while being alert and prepared for unknown and unexpected engine problems and departures from controlled flight.

Performance Test Pilots

On a plane's first flight, a performance test pilot verifies the proper performance of the engine and all flight controls and cockpit instrumentation. However, extensive tests of flap or spoiler operation are commonly left for later flights; retractable gear may or may not be retracted for the first flight. Typically, the airplane is not quite trimmed for hands-off straight and level flight and some adjustments will have to be made when the airplane is back on the ground. The stall warning device will probably have to be adjusted to provide the proper advance notice. The engine will also be new and probably running hotter than when well broken-in.

Then the production test pilot must verify that all aspects of an aircraft's various systems are working properly and that it satisfies certification requirements in takeoff, climb, and cruise performance, as well as safe low-speed and stall behavior. This requires an intimate engineering knowledge of the aircraft as well as an ability to hold a given airspeed extremely accurately, with acute observational and communication skills.

Because of the popularity of homebuilt aircraft in the United States, many pilots become production test pilots in the early phases of the required test period. Although they are not required to pass any special tests or attend test pilot schools, they should thoroughly prepare themselves for the task and be even more alert to possible difficulties with instrumentation and the power plant. Possible performance ranges for homebuilt aircraft range from tens of knots in ultralights to hundreds of knots in turbine-powered designs. If the builder has designed the aircraft or made significant deviations from a proven design, the test pilot is really an experimental test pilot.

Experimental Test Pilots

The testing of experimental planes can be much more interesting, more glamorous, and more dangerous than performance testing. These test pilots have been responsible for testing and verifying all the major advances in aircraft performance in every decade of powered flight, from craft capable of speeds tens of miles per hour to thousands of miles per hour, from open-cockpit to blind flying, from propeller-powered to jet- and rocket-powered, and from kite-based biplanes to the space shuttle. Although ground simulators can do a good job of preparing the experimental test pilot for the handling and performance characteristics of an experimental aircraft, a great deal of knowledge, skill, courage, and levelheadedness is still required in advancing the frontiers of flight.

America's first flight test sites appeared near the end of World War I: the Army Air Force's McCook Field in Dayton, Ohio, and, in 1918, the Naval Air Test Center at Patuxent, Maryland. In recognition of the increasing speeds and complexity of aircraft, specialized, formal test pilot schools appeared in 1943 in Great Britain (the Empire Test Pilots' School) and in 1945 in the United States (the Naval Test Pilot School at Patuxent and the most famous, the United States Air Force Test Pilot School at Edwards Air Force Base on the dry lake bed near Palmdale, California).

Famous Test Pilots

Eddie Allen trained at England's famed center of advanced flight research and flight testing at Farnborough, Hampshire, in 1917, going on to become a test pilot for more than a dozen civilian and military groups and the acknowledged dean of American test pilots. He died in 1943 while trying to save a burning prototype of the Boeing B-29 bomber.

Jimmy Collins was a freelance test pilot during the difficult Depression years when work, especially good-paying work, was very hard to find. He specialized in zero-lift terminal velocity (precisely vertical) dives, which the Navy required for its planes at that time. Also a gifted writer, his description of the physical sensations in pushing over into straight-down flight makes for chilling reading even today. Collins perished in the pull-out from his last such dive, in Grumman's last biplane fighter, the XF3F-1.

Charles A. Lindbergh, barnstormer, top-of-his-class Army fighter pilot, and an experienced airmail pilot, participated in the design of his Ryan monoplane, the *Spirit of St. Louis,* in 1927, made carefully planned local and transcontinental test flights, and then flew it from New York to Paris to win the Orteig Prize. He thereby became America's best-known aviator, stimulating the growth of aviation in America as never before and never since. As a civilian test pilot during World War II, he tested fighter aircraft and developed methods for increasing their combat range.

Jimmy Doolittle presaged today's engineer/test pilot, earning a masters degree (1924) and then a doctorate in aeronautics (1925) from the prestigious Massachusetts Institute of Technology. Beginning as an Army Air Force test pilot, he became famous for a string of achievements. He was a race pilot in the 1920's and a test and demonstration pilot for the prewar Curtiss Hawk fighter. He participated in the development and test flying of the first gyroscope-based flight instruments and radio navigation aids that permitted totally blind flying from takeoff to landing, and developed and led a very early raid (1942) against Japan following the attack on Pearl Harbor in 1941; the squadron flew Army Air Force B-26 bombers from a carrier deck. He was elected an Honorary Fellow of the newly formed Society of Experimental Test Pilots (SETP) in 1957.

Charles E. "Chuck" Yeager, a World War II fighter pilot and an "intuitive engineer," completed a flight test pilot training program after the war and was chosen for the attempt to break the fabled sound barrier in the experimental research Bell X-1 rocket plane. In October, 1947, he did just that, producing the first sonic booms for the expectant, worried flight test personnel on the ground, becoming a legend in his own time, much as had Lindbergh and Doolittle.

Scott Crossfield, one of the founding members of SETP, was the first pilot to exceed Mach 2 (twice the speed of sound) in the rocket-powered Douglas D-558-2 in 1953, and made the first flights of the rocket-powered, hypersonic (Mach 6) North American X-15 in 1955.

Testing Procedures

Initially, test pilots used a knee pad to record their observations and then filled out a more detailed flight report after landing. By the late 1940's, especially for the X planes, research aircraft carried full on-board data acquisition instrumentation, which was eagerly read out upon landing. Contemporary automated telemetry systems relay acquired flight parameters to the ground as they are changing, allowing test flight engineers to immediately tell the test pilot where to take the next test point, and when to quit. Variable-stability aircraft such as the Bell X-22A (as modified by Calspan Corporation) can accurately reproduce the handling and performance of many other aircraft.

Test pilots have led the way to the solution of many deadly aeronautical traps. Perhaps the first to be encountered and at least partially solved was the tail spin: easily recovered from in some trainers if the center of gravity is not too far to the rear, but potentially deadly in heavy and fast aircraft. The next problem was flutter, which is an aeroelastic phenomenon in which aerodynamic forces generate an excitation at a natural frequency of the structure, such as a flapping flag in a strong wind; this is most likely for the ailerons and other control surfaces, but the usual result is a lost airplane. By the 1940's, the mysteries of "compressibility" were costing many lives as research and fighter aircraft went into unrecoverable dives. Up to perhaps Mach 0.3, the air can simply speed up and change its direction in response to the pressure differences around an airplane, but around Mach 0.6, 0.7, or 0.8, some air will reach the speed of sound because an increase in speed of the air over the wing is the way lift is generated. The point at which this occurs is called the critical Mach number and, soon after it is exceeded, shock waves perpendicular to the surface are generated where the air is abruptly slowed back down to subsonic speed. These superthin shock waves cause the air to separate, much like a low-speed stall, and render control surfaces ineffective; they also tend to oscillate in the fore-aft direction, producing control surface "buzz." Inertia or roll coupling was the next big problem, once the problems of supersonic flight had been overcome. Everyday hypersonic flight is the next frontier, and experimental test pilots will be expected to lead the way.

Test pilot flying has not been entirely a man's job. America's Jacqueline Cochran, Germany's Hanna Reitsch, and Great Britain's Joan Hughes have all been elected Honorary Fellows in SETP.

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See also: Aerospace industry, U.S.; Airline industry, U.S.; Jacqueline Cochran; Jimmy Doolittle; Experimental aircraft; High-altitude flight; High-speed flight; Charles A. Lindbergh; Manufacturers; Military flight; Navy pilots, U.S.; Pilots and copilots; Hanna Reitsch; Alan Shepard; Spaceflight; Valentina Tereshkova; X planes; Chuck Yeager

Testing

Definition: The process by which an experimental aircraft is proved to be safe, functional, and economically viable to produce.

Significance: Testing allows airplane engineers and designers to ensure that their design visions are practical and safe before an aircraft is put into commercial production. The procedure involves both real and computer-simulated tests of all elements of the craft, both individually and systematically.

Testing aircraft is often thought of as only encompassing test flights, more often than not conjuring a picture of a brave pilot climbing into the latest supersonic or hypersonic craft and driving it to the edge of space or beyond. This image has some validity, but aircraft testing also includes less glamorous processes involving computer simulations, laboratory tests, and other types of trials intended to assess how the aircraft will perform when it finally runs a test flight. However, such flights are of the utmost importance to any aircraft research program, which is the basis for the future of aviation.

Military flight tests are usually run at locations such as Edwards Air Force Base, California; the China Lake Naval Weapons Test Center, California; or the Patuxent River Naval Air Warfare Center, Maryland. Commercial tests are performed at sites such as Yuma, Arizona, and Moses Lake, Washington. These test flights are the extension of laboratory tests and computer simulations. Advances in technology must be tested in order to be put to use, and yesterday's cutting edge soon becomes run-of-the mill. For instance, after World War II, Douglas Aircraft tested its bright red experimental Skystreak model D-558, which reached speeds of Mach .80 to Mach .90. In 2001, approximately one billion airline passengers sat comfortably on airliners traveling at roughly the same speed.

Testing Oversight

There is much more to flight testing than trying out new concepts. Commercial and military aircraft are delivered daily to their ultimate users by Boeing, Lockheed, Airbus, and other manufacturers. When a B-777, an A340, or an F-16 comes off the production line, it is first turned over to production test personnel, whose function is to test the components of the new aircraft to ensure that it is ready for the ultimate customer. The customer, American Airlines or the U.S. Air Force, for example, then conducts a production acceptance flight to determine whether the aircraft meets specifications and is ready for delivery and payment. The military has its own personnel that perform these acceptance tests, and the Civil Aeronautics Authority (CAA)—the forerunner of the Federal Aviation Administration (FAA)—did likewise.

During the 1950's and 1960's, FAA inspectors were on the scene, personally checking the output of the manufacturer's engineers and technicians. Beginning in the 1970's, however, the FAA became increasingly dependent upon manufacturers to perform both standard testing and FAA inspections themselves, as "designated representatives of the FAA." With the increasing use of computer simulation in place of hard testing, the FAA has neither the personnel nor the training to oversee the manufacturer. The Boeing B-777 is a prime example in which the manufacturer performed all the testing oversight and approval on the extensively computer-designed aircraft.

There is also an ever-widening gap between the requirements of commercial and military aircraft performance envelopes. The modern subsonic commercial airline transport is designed to cruise at about Mach .85 at altitudes of 28,000 to 40,000 feet. The passengers are afforded living-room comfort, complete with pressurization holding the cabin at a comfortable maximum altitude of 8,000 feet, in-flight entertainment, meals on longer flight legs, cool drinks of their own choice, and an atmosphere of relaxation and safety. Although some modern commercial transport aircraft have found their way into military service as aerial refueling/cargo transports, medical evacuation airplanes, and VIP carriers, the requirements of the modern military have diverged into very specialized equipment. The military is interested in high speed, maneuverability, rugged survivability, deadly weapon delivery systems, and the ability to escape enemy radar detection. Although the armed forces are interested in economy of operations, cost is a secondary consideration compared to military performance. As a result, advances in engine performance have historically taken place in military development; in fact, the core of every engine model currently used on commercial aircraft had its beginning as a military engine. The testing requirements for new engines can run into billions of dollars, and if the military requirements diverge too far from commercial interests, there will be a significant demand for the establishment of a government-sponsored commercial jet development center.

The FAA, which is part of the Department of Transportation, is responsible for licensing all general aviation, business aviation, and commercial airline aircraft, a task that consumes a significant part of its $11 billion yearly budget. Aside from the few homebuilt experimental aircraft that fly in fairly quiet traffic areas, the FAA's mission is to certify that any new airplane will safely carry passengers and is airworthy. A new model is taken to the edge of its performance envelope by testing it under the most unusual and exacting conditions, conditions that might not occur in real life during many hundreds of thousands of flight hours.

Materials Testing

Flight testing, which is the ultimate appraisal of the finished vehicle, differs from the many preliminary tests, computer simulations, and other explorations that contribute to the success of the complete airplane. Laboratory testing of the airframe starts off with material science, and engineers must make decisions considering questions of the material's strength, cost, weight, and ease of manufacture, maintenance, and repair. The first aircraft frames, constructed prior to World War I, were composed of fine-grain spruce or similar wood covered with fabric stitched over the skeleton. Steel was used for the engine mounts, some fuselage structures, guy wires and braces, landing gear or skids, and various attachment fittings. Aluminum was still in short supply, very expensive, and had some serious fabrication drawbacks. Aircraft through World War I and up to the mid-1920's continued to utilize these materials, and they allowed new aircraft models to be constructed very rapidly. Fabric skins slowly became replaced by plywood, and aluminum crept into use in castings and other high-strength-to-weight parts. The wide use of aluminum in the 1930's allowed the rapid expansion of the airline industry with the Douglas DC family of aircraft. World War II combat requirements saw the development of new high-strength aluminum, then called 75S, and this material was immediately applied to the commercial airline business after the war in aircraft such as the Douglas DC-6 and the Lockheed Constellation. By 1950, titanium was becoming available, but the cost of $25 per pound was about the same cost as sterling silver. The continued search for new and better materials opened the door to nonmetallic materials such as fiberglass, carbon fiber/epoxy, and other synthetics such as Nylon, Dacron, Kevlar, Mylar, Spectra, and Technora. Aircraft material science both creates designs that demand the invention of new fabrics and utilizes new technology to create new designs.

Once it is possible and desirable to start the fabrication of parts, these components are tested either through computer simulation or on actual test fixtures. Testing is done to determine ultimate strength, fatigue resistance, crack propagation, notch sensitivity, and wear resistance. Once the individual parts are assembled into minor or major subassemblies they are again run through tests or simulations in a structural test laboratory to prove their suitability for incorporation into the finished airframe. Computer-controlled hydraulic jacks and fixtures, or sometimes just sand bags such as the Wrights used, torture the structures until they turn to scrap material.

In other laboratories, the major systems of the finished aircraft are also "wrung out." As an example, the DC-8, Douglas Aircraft's first jetliner, developed in the late 1950's, had the complete pneumatic, pressurization, and air-conditioning systems laid out in a ground test laboratory. Giant compressors and heaters simulated the "bleed air" from the aircraft's four jet engines, which was ducted through the simulated wings and fuselage to test the anti- and deicing system, and to run the cabin pressurization superchargers and the refrigeration compressors. The pressurized and air-conditioned air was then fed to a huge steel tank simulating the cabin volume. This pneumatic test program proved that a water separator was needed on the DC-8 air-conditioning system. On an early production DC-8 that lacked such a separator, a jet of cold water came out of the air-conditioning system, hitting Donald W. Douglas, Sr., the chairman, on the head. This same early jetliner had an "iron horse" fixture to test the control system layout for the flaps, ailerons, rudders, and elevators; an engine test stand to develop noise suppressors and thrust reverses; a fuselage panel test rig to test explosive decompression resistance of the DC-8's rip-stopper fuselage skin; a landing gear drop fixture to test impact resistance; a hydraulic laboratory to test the Skydrol-based system; a heavy, concrete bomb shelter and noise generator to design cabin noise insulation; a power generation laboratory to check out the aircraft's alternators; a complete layout of the radio rack and flight deck instrumentation; a microwave test facility to test the aircraft antennas; a full-scale mockup of the interior so that interior designers could simulate the look and feel of the passenger cabin (this facility was also used to examine the toilet and galley layout); and finally, a toilet test rig.

Many of these test programs can now be simulated with computers in three-dimensional models, which prevent the interesting arrangements found on the DC-8, where hydraulic, pneumatic, and electrical lines were planned to occupy the same space at the same time. The use of fiber optics and fly-by-wire (completely computerized flight control) will not only save weight, but also free space that in the past was taken up with heavy cables and giant wire harnesses. Testing will be different, but it will be testing nonetheless.

Frame Testing

Once the major systems and components are tested, there is the final "proving-up" of the aircraft. Sometimes a sacrificial aircraft structure is constructed, a complete structural aircraft without electronics, hydraulics, pneumatics, and other such items. This aircraft is placed in a giant fixture surrounded by a steel framework and computer-controlled hydraulic jacks that bend and twist the airframe to simulate flight loads up to what is called limit load. Limit load is the load that the designers expect the airframe never to exceed in even the most violent maneuvers. Once the airframe has passed the limit load test, it is repaired, if necessary, and then undergoes a fatigue life test program. The airframe is cycled. One airliner cycle includes pushback from the gate at maximum takeoff weight; taxi along a bumpy taxiway to takeoff position; the takeoff run itself; the pressure cycle, in which the fuselage is pressurized to 8 pounds per square inch; flight loads due to turbulence and normal flying; the depressurization of the fuselage on descent; the landing load, sometimes known as an organized "crash" on the runway; and the taxi back to the gate. Military aircraft have similar cycles, especially in the Navy where the plane is catapulted from the deck and arrested by a wire upon landing. Experience tells the designers how many cycles per day, week, or year the aircraft can expect to undergo. Fatigue testing simulates these cycles by taking the airframe through the equivalent of twenty-five to thirty years on a commercial jetliner. Military aircraft life is usually shorter since the planes do not fly every day except in combat. However, both military and civilian jets are being used over longer periods, far beyond their original design specifications. As a result, service life extension programs (SLEPs) have been initiated on numerous aircraft models. These aircraft are twisted, bent, and tortured in the test rigs until something breaks. The broken parts are either replaced or repaired and the torture continues, until airframes designed for twenty thousand to thirty thousand hours are SLEPed to sixty thousand to eighty thousand hours. Finally, when the engineers have tortured the airframe to its most extended life, it is taken to destruction by loading up the hydraulic jacks until catastrophic failure of a major component, such as the wing spars, occurs. The designers now know how much safety they have in their calculations—110 percent, 120 percent, and so on. The percent over 100 is how much load it took over maximum design load to create a catastrophic failure, and this is the margin of safety.

Flight Testing

The finished aircraft is now on the flight ramp ready for its first flight. The major components have been tested, the systems have been tested, and the airframe has been tested, but there are a few things yet to be done. During the construction of the first example of a new craft, extensive instrumentation is routed throughout the aircraft to measure parameters from every conceivable point of view. Stress and strain on the structure, pressures, temperatures, voltages, and frequencies are to be measured and recorded both on the craft and remotely. Safety equipment and systems have been installed, for as the old saw goes, "I told the Wrights, and I'm telling you, it'll never get off the ground." Preliminary tests are run before the plane takes off for the first time: low-speed taxi tests, braking tests, and high-speed taxi tests, in which the nose wheel is lifted off the ground. Finally, the first flight is undertaken, often with much media fanfare.

Once the first flight is accomplished, testers slowly expand the envelope by flying ever higher and faster, thereby testing all the systems of the aircraft. Back on the ground, or rather very near it, rejected takeoff tests are performed, in which testers accelerate the aircraft to flight speed, chop the power, and slam on the brakes to see if it can stop in the required field length. Burning tires usually accompany this test, since on the rejected takeoff test the engine thrust reversers cannot be used. Another exciting ground test on commercial aircraft is the evacuation test. The number of passengers that will be allowed on a commercial aircraft is determined by the FAA requirement that all passengers must be evacuated within ninety seconds with 50 percent of the doors or escape windows blocked. Furthermore the test passengers, usually manufacturer's employees and relatives, must be a cross section of the traveling public, so there must be children as well as senior citizens in the mix. They are seated in the aircraft's seats with seat belts fastened and an alarm is sounded. They have not been told which exits will not work, and all must go down the typical airline exit slide. The only unrealistic aspect of this test is that all test passengers know the test is coming, all know their jobs are dependent upon good test results, and they have not been frightened out of their wits by an actual emergency on the aircraft and know that the threat of real fire is not present. The final elements to prepare for commercial flight include training the airline crews, both in the cockpit and in the cabin, readying the ground handling equipment and ground crew, positioning spares, training the maintenance workers, and actually flying the routes the aircraft will fly when full of passengers.

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See also: Aerospace industry, U.S.; Airline industry, U.S.; Airplanes; Commercial flight; Experimental aircraft; Manufacturers; Military flight; Pilots and copilots; Test pilots; Wind tunnels

Ticketing

Definition: The purchase and assignment of a reservation for a seat on a scheduled or chartered airline service, to a particular destination at a particular time and date.

Significance: Airline ticketing is the first in a series of processes that allow a passenger to board a commercial aircraft for travel. The term "ticketing" is often used to describe the act of checking in with the airlines upon arriving at the airport to board a flight.

History

The airline ticketing process commenced with the earliest days of commercial aviation. The process, adapted from that of the commercial railroad services of the late nineteenth century in the United States, consisted of a passenger receiving a ticket of receipt upon purchase for air service. This ticket was then collected upon boarding of the scheduled aircraft. The ticket not only served as a receipt for the passenger but also allowed early airlines to keep paper records of those passengers who had purchased reservations on particular flights. In the earliest days of airline travel, tickets were most often purchased directly from airline representatives, at local offices, or at airport ticket booths.

During the growth years of the airline industry, this traditional method of ticketing was sufficient to handle the relatively moderate volumes of air passengers. A regulated civil aviation industry limited the number of flights an airline could operate from any given airport. Because the number of flights was limited, and because the flights involved relatively small numbers of passengers per flight, relatively few passengers arrived for ticketing at airport ticket booths, later known as airport ticket counters.

Interestingly, the airline infrastructure in those early days left much of the responsibility of passenger ticketing in the hands of the passenger. Passengers were responsible for having in their possession a paper ticket documenting their flight itinerary. Passengers who were required to change airlines to complete their trips would in fact be required to be ticketed twice along the way, because each airline performed ticketing for its own operations.

As the airline industry became an increasingly heavily used mode of transportation, complaints voiced by airline passengers began to increase and focused in particular on the inconvenience of the traditional ticketing process. Complaints of long lines at ticket counters were among the most common passenger complaints.

Computerized Ticketing

The development of computer reservation systems (CRS) beginning in the mid-1960's and the implementation of global distribution systems (GDS) through the late 1990's have represented the first major steps in the advance of airline ticketing technology. These systems have assisted travel agents in ticketing even the most complicated flight itineraries. Although passengers' tickets remained on paper, CRS systems lifted much of the burden from airline reservations agents and independent ticket agents. As a result, the ticketing process became a much more efficient procedure.

Electronic and Internet-Based Ticketing

In the early 1990's, the idea of a ticketing process that did not involve actual paper tickets was tested. Morris Airlines introduced "ticketless travel" in 1993, followed shortly thereafter by United Air Lines. Following the strategies of hotel and automobile-rental agencies, United Air Lines began offering passengers the option of receiving a confirmation number rather than a paper ticket upon purchasing a reservation. With a confirmation number rather than a paper ticket, passengers no longer had another piece of paper potentially to lose, have stolen, or forget on the way to their flight. The airline, in turn, saved the cost of producing and shipping a paper ticket to the customer. Ticketless travel was first introduced in the United Air Lines Shuttle market serving major cities in California. The strategy was met with sufficient acceptance to be deemed successful and set the standard for other airlines to follow. By the mid-1990's, it was estimated that more than 35 percent of all tickets issued on the airlines that offered such service were booked on electronic tickets, known as e-tickets, saving hours of time for passengers and millions of dollars for airlines.

Most recently, the use of the Internet has served as an option to complete the airline ticketing process. Internet-based airline ticketing has provided passengers with real-time information on seat and fare availability for any given flight and the ability to make flight reservations and purchase tickets. There may be no need for the passenger to interact directly with an airline representative or independent travel agent. Through this technology, passengers benefit from the conveniences of Internet-based commerce. Airlines benefit by transferring to passengers most of the work associated with purchasing a ticket, saving the airline labor costs. Labor costs have been reduced to the point where airlines are motivated to offer tickets at a discounted rate to passengers ticketing flights through the Internet.

Through both airline-sponsored and independent travel-related Internet sites, passengers can perform most of the traditional tasks associated with purchasing an airline ticket. Passengers can research schedules and fares, purchase tickets, reserve seat assignments, and, in some cases, make special requests, such as selecting particular meals or shipping special cargo.

Future of Ticketing and Self-Check-in

Although a passenger may have already purchased a ticket, a visit to the ticket counter is often mandatory for other processing tasks, such as presenting personal identification to an airline representative, checking in oversize baggage, obtaining a seat assignment on the aircraft, and receiving a separate boarding pass to be redeemed at the gate immediately prior to boarding the aircraft. As such, the advent of electronic and Internet ticketing did surprisingly little to reduce long lines and delays at airport ticket counters.

To address this issue, airlines have begun to implement self-service check-in units at airports. These machines can verify itineraries, provide standard FAA security briefings, and issue boarding passes. These machines are resulting in significant improvements in check-in efficiency and, for those that use the system, reducing the time required by passengers to complete the check-in process. As more passengers begin to use these new systems, it is expected that there will be fewer passengers waiting in lines as part of the traditional airline ticketing process. As such, the very definition of airline ticketing is a dynamic one, destined to change as the airline industry and associated technology matures and develops during the future of commercial aviation.

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See also: Air carriers; Airline industry, U.S.; Airports; Boarding procedures; Overbooking; United Air Lines

Tomcat

Also known as: F-14; F-14A (original TF30 engines); F-14A-plus, later known as F-14B (upgraded F110 engines, retrofitted after 1982); F-14D (newly built or retrofitted with F110 engines and ICS/IRST camera/infrared scanner nose fairings)

Date: Design begun prior to 1968; first operational use September, 1974 (Pacific fleet, USS *Enterprise*)

Definition: Long-range fighter interceptor developed by the Grumman Corporation for the United States Navy carrier-based operations.

Significance: The most advanced Western long-range fighter-interceptor aircraft in service during the post-Vietnam, post-Cold War eras.

Development

The F-14 entered development following the failure of the ill-conceived General Dynamics F-111, which had been built at the urging of former Defense Secretary Robert McNamara as a compromise weapon to fit the needs of

F-14 Tomcat Characteristics

Primary Function: Carrier-based multirole strike fighter
Builder: Grumman Aerospace Corporation
Propulsion: F-14A: Two Pratt & Whitney TF-30P-414A turbofan engines with afterburners; F-14B and D: Two General Electric F110-GE-400 turbofan engines with afterburners
Thrust per engine: TF-30P-414A: 20,900 pounds static thrust; F110-GE-400: 27,000 static thrust
Length: 61 feet, 9 inches
Height: 16 feet
Maximum Takeoff Weight: 72,900 pounds
Wingspan: 64 feet unswept, 38 feet swept
Ceiling: Above 50,000 feet
Speed: Mach 2+
Armament: Up to 13,000 pounds, to include AIM-54 Phoenix, AIM-7 Sparrow, and AIM-9 Sidewinder missiles; air-to-ground precision strike ordnance; one M61A1/A2 Vulcan 20-millimeter cannon
Crew: 2 (pilot and radar intercept navigator)
Date Deployed: December, 1970 (first flight)

Source: Data taken from (www.chinfo.navy.mil/navpalib/factfile/aircraft/air-f14.html), June 6, 2001.

both the U.S. Air Force and the U.S. Navy. The Deputy Chief of Naval Operations for Air, Admiral Tom Connolly, was instrumental in the development of the F-14 aircraft, and it was after him that the Tomcat ("Tom's Cat") was named.

The F-14 Tomcat fighter entered operational use in September, 1974, and quickly distinguished itself as a formidable carrier-based long-range interceptor capable of extraordinary maneuverability at both subsonic and supersonic speeds. The aircraft is equipped with a variable-geometry wing that scissor-folds into a triangular delta shape to optimize handling and performance at supersonic speeds, then expands to maximal surface area at slower airspeeds to maintain the aircraft's extraordinary level of performance and control. The operation of the wings is controlled automatically by an onboard computer that senses true airspeed and hydraulically adjusts the wings' angle through as much as 40 degrees. Interestingly enough, the idea of a variable-geometry wing had been suggested near the end of World War II by German engineers and, later, by British designer Sir Barnes Wallis, but the idea remained an obscure possibility of aerodynamic engineering until a working model could be made feasible through the use of modern computerized control systems.

Design

The F-14 carries two crew members in tandem seating. Behind the pilot sits a specialist weapons systems officer (WSO), electronic warfare officer (EWO), or a radar intercept officer (RIO). This distribution of labor between the pilot and his electronic systems specialist, coupled with the F-14's advanced avionics and its capability of launching BVR (beyond visual range) radar-guided weapons, makes the Tomcat a formidable opponent.

The size of the F-14 is likewise impressive. With a fuselage length of almost 63 feet and a maximal ground wingspan of just over 64 feet, the Tomcat is nearly the size of a small World War II Lancaster bomber. When fully loaded with fuel, crewmembers, and weapons, the aircraft's takeoff weight can exceed 74,000 pounds. In fact, the original F-14A design variant, incorporating twin Pratt & Whitney TF30 engines designed for the defunct F-111, was soon found to be underpowered. Other reliability problems with the TF30 engines manifested themselves, most notably turbofan-blade failures, earning F-14A pilots the unenviable nickname of "turkey drivers" from their aviator colleagues. These problems, however, were resolved by the retrofitting of the A-variant aircraft with more powerful F110-GE 400 turbofan afterburning engines in the model F-14A-plus (later called the F-14B) and in the later new breed F-14D. The top speed of the F-14D, with afterburners engaged, exceeds Mach 2.

Armament

The Tomcat's role can be succinctly summarized as that of protecting its carrier against hostile aircraft. To achieve this objective, the F-14 has been outfitted with the Hughes AWG-9 computerized radar control system, capable of attacking six targets simultaneously while tracking eighteen more out to a distance of 115 miles. Tomcat armament configurations include various combinations of AIM-7F Sparrow, AIM-54A Phoenix, and AIM-120A AMRAAM long-range radar-guided missiles for BVR interceptions and AIM-9 (standard) or AIM-9L (all-aspect) Sidewinder heat-seeking missiles for visual and medium-range targets. The F-14 is also equipped with a single 20-millimeter Vulcan M61 Gatling cannon capable of firing one thousand 20-millimeter rounds per minute. When fired, the M61 produces a ripping sound, like thick canvas being torn.

Combat Tactics

Tomcat combat tactics generally seek to optimize the probability of a long-range radar-guided interception at maximal distance using air-to-air Sparrow or Phoenix missiles, designated as a “fox one” kill. When a target has closed to visual range, the Tomcat can also be equipped for a close-range interception, or “fox two,” using infrared heat-seeking Sidewinder missiles whose “L-” or “Lima” variant (AIM-9L) has the ability to sense the heat signature of an enemy aircraft from all aspect angles, obviating the need for a Tomcat pilot to maneuver his aircraft into his opponent’s hot “6-o’clock,” or tail, position. The Vulcan M61 cannon wields more than three times the lethal destructive potential of the .50 caliber guns of World War II aircraft, yet the M61 is seldom fired due to the inherent difficulties involved in hitting an evasive target from a moving platform. The M61 cannon is best employed when the target is too close for missile interception. The term “fox four” (used tongue-in-cheek) indicates a deliberate midair collision with an enemy aircraft.

During combat in Libya (1981 and 1989) and in the Gulf War (1991) the F-14 proved itself to be an effective air-to-air weapons platform despite some notable disadvantages: the heat from the afterburners when operating at or near supersonic speeds, in combination with a large radar return caused by the shape and radar reflectivity of its nonstealth fuselage, presents a conspicuous target for heat-seeking and radar-guided missiles. The development of increasingly specialized aircraft during the late 1970’s and 1980’s, most notably attack fighters, such as the McDonald Douglas carrier-based F/A-18 Hornet, and the subsonic Lockheed F-117 Nighthawk stealth attack fighter, have enlarged upon some of the operational roles formerly exercised by the Tomcats. Despite this, the F-14’s have retained the “top gun” title among long-range interceptors and are expected to remain in active military service through the early decades of the twenty-first century.

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See also: Aircraft carriers; Fighter pilots; Gulf War; Hornet; Navy pilots, U.S.; Stealth fighter; Wing designs

Training and education

Definition: All flight and ground-based training and education for personnel who wish to be involved with the operation of aircraft.

Significance: Due to the complex nature of modern aircraft and their operation, the training and education of aviation personnel is essential.

Introduction

The U.S. aviation training industry is both highly structured and multifaceted, involving the training of pilots, mechanics, avionics technicians, air traffic controllers, and airline dispatchers, along with a variety of other engineers and technicians who make it possible for people and materials to be transported worldwide by air for military, commercial, or other civil service purposes.

History of Aviation Training

Aviation training originated in the United States, beginning in the nineteenth century with the U.S. Army's training of men to operate hot-air balloons used in aerial observation. Training for flight in heavier-than-air vehicles began in the summer of 1908. On August 1, 1907, the U.S. Army Signal Corps had established the Aeronautical Division under the direct command of Captain Charles deForest Chandler. Having been awarded a bid to provide one aircraft and two trained pilots for the Army, Orville Wright, who with his brother, Wilbur, had pioneered flight in a heavier-than-air craft, began flight instructing at Fort Myer, Virginia, that same year. Although neither would solo, the first two students were Lieutenant Thomas E. Selfridge and Second Lieutenant Benjamin D. Foulois. On September 17, 1908, Selfridge was tragically killed in an accident in which Orville Wright was severely injured. Foulois was transferred to Europe, and training was halted until the following year. Two subsequent students, Lieutenant Frank Lahm and Second Lieutenant Frederic Humphreys, were selected, and both soloed their first aircraft under Orville Wright's supervision at College Park, Maryland, on October 26, 1908.

Civilian Flight Training

Most aviation training in the United States is civilian flight training, in which ordinary citizens are trained to be pilots. Pilots may learn to fly a variety of different aircraft for recreation or airline transportation, or for more specialized purposes, such as aerial crop dusting, pipeline patrol, law enforcement, or sight-seeing operations. Those wishing to fly for purely personal transportation may choose to pursue either a Recreational Pilot Certificate or a Private Pilot Certificate. Either of these certificates requires that the pilot be at least seventeen years of age (although in order to fly solo in training, a pilot need be only sixteen years of age), have a mastery of the English language, and pass a basic physical examination.

A Recreational Pilot Certificate allows the holder to fly aircraft of up to 180 horsepower and to carry no more than one passenger into and out of smaller airports within fifty miles of the pilot's home airport during daylight hours only. The recreational pilot may fly into larger airports or venture farther than fifty miles from home only with the permission of a certified flight instructor (CFI). Training for the Recreational Pilot Certificate involves a minimum of thirty hours of flight training, including dual instruction and supervised solo operations.

A Private Pilot Certificate enables the holder to avoid the restrictions of the recreational certificate and involves a minimum of forty hours of flight instruction and supervised solo flights.

Those seeking careers in flying in which they will be paid for their services as pilots must possess either a Commercial Pilot Certificate or an Airline Transport Pilot (ATP) Certificate. In order to qualify for a Commercial Pilot Certificate, the pilot must have acquired at least 250 hours of flight time and be trained to fly in aircraft that are slightly larger and more complex than those aircraft required for private or recreational pilot training. A pilot wishing to be an airline transport pilot must have accumulated at least 1,500 hours of flight time and be at least twenty-three years of age.

Holders of Private Pilot Certificates and higher-level certificates may choose to add an Instrument Rating to their certificates, which enables them to operate an aircraft without visual reference to the ground in what is called "instrument meteorological conditions." This additional rating involves an additional forty hours of instruction in instrument flying procedures. Holders of Airline Transport Pilot Certificates are required to have an Instrument Rating. In addition, those pilots wishing to fly aircraft with more than one engine must add a Multiengine Rating to their certificate. These certificates allow pilots to operate aircraft with piston or turboprop engines weighing up to 12,500 pounds. For jet-powered aircraft or aircraft weighing more than 12,500 pounds, an additional certificate is required in the specific aircraft to be flown. Pilots certified in the previous categories may choose to be certified to fly airplanes, helicopters, gliders, gyroplanes, or seaplanes, or any combination thereof. Each certificate and rating requires the applicant to pass both a knowledge exam, administered in a computer-based testing format, and a practical flight exam given by authorized representatives of the Federal Aviation Administration (FAA).

Training Regulations

Civilian flight training is regulated under Title 14 of the Code of Federal Regulations (CFR), either Part 61 or Part 141. The basic difference between the two parts is that Federal Aviation Regulations (FAR) Part 141 training requires that the training be conducted under a greater degree of structure than that of Part 61. Under Part 141 of training, the lessons are structured under a standardized curriculum in which pilots must pass through various stages of training, each requiring an evaluation by a chief or assistant CFI separate from the student's primary flight instructor. This arrangement is intended to note and correct any of a student's problem areas prior to taking the final practical flight test that determines whether the individual will be awarded the pilot certificate sought. This test is accomplished at the end of a pilot's training for a particular certificate and is, again, given by a representative of the FAA. Provided that the student passes the check ride, the student is then awarded the certificate and is entitled to all of the privileges associated therewith. If the student's check ride is not satisfactory, the student must return for additional training before again taking the practical flight test.

Under FAR Part 61, the required training time is reduced slightly, with a Private Pilot Certificate requiring a minimum of 35 hours and a Commercial Pilot Certificate requiring 190 total flight hours. There is no difference for the ATP Certificate. Although there is less required structure under FAR Part 61 training, the required subject matter is the same.

Training conducted under FAR Part 61 ranges from individual flight instructors and students engaging in instruction in privately owned aircraft to many larger and more complex organizations that offer flight training. It is important to note that many flight training organizations and individuals operating under Part 61 have as much or more structure built into their curriculum as do Part 141 organizations, although some have less. When choosing where to undergo flight training, a prospective student would do well to make a site visit to observe and compare several organizations and individuals before making a final decision. For those wishing to obtain a degree in aviation, there are many two- and four-year institutions around the country offering degrees in aviation flight, aircraft maintenance, air traffic control, aviation electronics, or aviation management. For those wishing to pursue careers as airport administrators or airline pilots, a four-year degree is almost a necessity.

Military Flight Training

Individuals who wish to fly in the armed services must first qualify for selection as a pilot candidate. This involves a series of interviews by a pilot selection board, psychological and physiological aptitude evaluations, and fitness examinations. In addition, applicants must meet the criteria to serve as a military officer or warrant officer, which most often involves, among other criteria, a four-year academic degree, preferably in a technical field. Exceptions to this requirement are made in certain branches depending upon need and job requirements. In addition, serving as a pilot in the military obligates the individual to several years of military service, the length of which depends upon the military's current and projected needs for flight officers.

Upon selection, pilots are sent through a pilot screening program, which involves several hours of flight in a light aircraft in order to assess an individual's suitability for pilot training. After candidates pass this phase, they are sent on to primary flight training for several months of intensive ground school and flight training. When primary flight training is complete, the pilots are then routed to aircraft-specific training geared toward specific craft, such as fighters, transport, or bombers, based on their preferences, their primary flight training performance, and the needs of the military. During their aircraft-specific training, pilots undergo additional training in the aircraft in which they will serve prior to being assigned to a specific wing or squadron, where they will be fully qualified to fly their specific type of aircraft for specific types of missions.

Aircraft Maintenance Training

An individual wishing to pursue a career in the maintenance of aircraft as a civilian must choose from one of two options. The first option is to become employed as an aircraft repairperson. An Aircraft Repairman Certificate is earned through on-the-job training for a predetermined amount of time with an employer engaged in aircraft maintenance and repair. This certificate is given for a specific type of work performed, and the privileges of the certificate are forfeited upon termination of employment.

The second option is to pursue an Aircraft Mechanic Certificate. The individual may choose to pursue an Airframe Mechanic Certificate, a Powerplant Mechanic Certificate, or, more commonly, the combined Airframe and Powerplant Mechanic (A&P) Certificate. The mechanic certificate allows the holder to engage in the maintenance and repair of certified aircraft—all aircraft, other than ultralight aircraft weighing less than 254 pounds, for which no certification is needed—whether independently or as part of a larger organization. This certificate is awarded to the individual regardless of employment. In order to be awarded the airframe, the powerplant, or the A&P Certificate, an applicant must either complete an FAA-approved FAR Part 147 course of study at an aviation training institution, undergo thirty-six months of on-the-job training for both the airframe and powerplant certificates with an organization engaged in the maintenance and repair of certified aircraft, or study under the supervision of a previously certified mechanic.

The training for the A&P Certificate involves 1,900 hours of classroom and hands-on laboratory training consisting of such topics as engine overhaul, airframe inspection, hydraulics, welding, and sheet metal, as well as basic math, physics, and electricity. After the required training has been completed, individuals are required to pass a series of knowledge examinations, including a practical exam that demonstrates their competency to exercise the privileges of the certificate. An authorized FAA representative conducts this test. As with the pilot certificate test, individuals who fail the examination may be allowed to retake the exam, provided they undergo additional training or complete additional study. If mechanics so choose, they may pursue an inspection authorization certificate after they have been actively engaged in aircraft repair for three years. This certificate allows for additional inspection privileges beyond those allowed by the mechanic certificate. An additional knowledge test is required for the inspection authorization. Aviation mechanics may also pursue specializations requiring advanced training and certifications from outside agencies and organizations.

Mechanics may decide to pursue training in nondestructive testing or in avionics, such as aircraft radios and other flight electronics, in which case the applicant must pass a Federal Communications Commission (FCC) knowledge exam. Upon successful completion of this exam, applicants are awarded FCC certification allowing them to function as avionics repair technicians. Several institutions of higher learning in the United States have degree programs giving the student much broader and more in-depth training in avionics repair.

Military Aircraft Maintenance Training

For those wishing to serve as aircraft mechanics in the military, the process first involves enlistment and aptitude assessment along with routine physical and other suitability exams. After trainees complete basic training and boot camp, they then move on to job-specific training, which can take from a few weeks to many months of additional training, depending upon the specialty. Individuals who leave the military and wish to work as civilian aircraft mechanics must first be assessed by the FAA to determine whether they meet the requirements to begin a series of tests leading to the airframe mechanics' license, the powerplant license, or both.

Air Traffic Control Training

Although aircraft pilot and mechanic training comprise the majority of aviation training, there are many other professions within aviation that require a high degree of specialized training. Air traffic controllers, for instance, spend years becoming qualified and learning various nuances of their profession. In order to become air traffic controllers, individuals must have a mastery of the English language, be at least twenty-one years of age but no older than thirty years of age prior to beginning training, and possess certain cognitive abilities consistent with the air traffic control profession. In addition, they must successfully complete the Control Tower Operator's Exam leading to the issuance of the Control Tower Operator's Certificate, a basic air traffic control (ATC) certification. Successful certification also involves a series of practical examinations.

There are three basic avenues individuals can take in order to become air traffic controllers. The first involves enlisting in the armed services, primarily the Air Force and Navy, and choosing air traffic control as a specialization area if aptitude testing proves this is a viable option. The ability to perform many tasks at once in a highly dynamic and often hectic environment while maintaining a three-dimensional geometric orientation is a skill that will serve the aspiring air traffic specialist well. After leaving the service, military controllers are given preferential hiring treatment by the FAA to work as civilian air traffic controllers.

The second option is to attend one of the colleges and universities associated with the FAA's Collegiate Training Initiative (CTI) program. Students in these programs take specialized coursework in air traffic control and are then given preferential hiring treatment by the FAA as air traffic controllers.

The third option is to apply directly to the FAA as an individual and proceed through the official application process. This will involve a series of interviews and examinations in order to determine suitability for the job of controller. If a person is selected, the FAA will train that individual in accordance with the individual's strengths and the FAA's needs. Depending upon the type of specialization chosen, it may take several years before a person becomes fully qualified to perform normal job duties. Typically, a controller whose job involves handling a relatively low volume of traffic in the control tower of a less busy airport might be qualified in a few months, whereas a controller specializing as a radar controller might take several years to be fully qualified.

An individual who chooses the military follows a slightly different training route. After completing basic training or boot camp, a trainee is then routed along a training track consistent with the needs of the military and the aptitude of the trainee. The trainee might specialize as a tower operator dealing primarily with takeoff, departure, and landing clearances for a specific location or may specialize in radar control, dealing with and directing aircraft flying between airports or airbases. Depending upon the type of specialization, a trainee may need to be trained for up to two years or more before becoming fully qualified to perform normal job duties as a controller

Aircraft Dispatcher Training

Aircraft dispatching is another technical aviation job that requires a regimented training routine. Aircraft dispatchers are employed by U.S. and foreign passenger and cargo airlines to assist flight crews with the details of flight planning and management. Dispatchers are jointly responsible, with the flight captain, for the safe outcome of a given flight. Dispatchers assist the pilots in obtaining timely weather information, performing fuel calculations, and ensuring that the aircraft is loaded in a manner consistent with safe flight.

In order to qualify as an aircraft dispatcher, an individual must be at least twenty-three years of age, have a command of the English language, and complete an FAA-certified training program requiring at least 198 hours of classroom instruction. The formats for these courses vary from six-week intensive courses in which the student attends all day, every day to courses in which training is spread out over the course of six months to a year or more and students attend in the evenings or on weekends. At the end of the training, there is a comprehensive knowledge exam and a practical exam, administered by a representative of the FAA. Several colleges and universities around the country have specialized aircraft dispatcher training certification programs.

R. Kurt Barnhart

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See also: Commercial flight; Federal Aviation Administration; Military flight; Pilots and copilots; Safety issues

Trans World Airlines

Also known as: TWA

Date: Founded in 1930 by the merger of Western Air Express and Transcontinental Air Transport

Definition: A global airline that was a dominant U.S. international carrier for much of the twentieth century.

Significance: TWA was a pioneer airline, distinguished by its pattern of concentrating on both U.S. domestic routes and transatlantic routes. It lost much of its market to competition from several other domestic U.S. airlines, which expanded aggressively into the foreign market, and was bought in 2001.

Trans World Airlines (TWA), as a history of the company claims, is "Kansas City's Hometown Airline." It was founded in Kansas City, and although its headquarters resided in other places over the next seventy-five years, in the last years of TWA's existence its headquarters returned to the place of its birth. TWA began as a combination of two early companies, Western Air Express, formed in 1925, and Transcontinental Air Transport, formed in 1929. They joined together in 1930 to call themselves Transcontinental and Western Airlines, Inc. With St. Louis, Missouri, as its headquarters, the company had ambitious plans. In its initial year as TWA it began flying a route that was laid out by Charles A. Lindbergh and that extended from coast to coast, from New York to Glendale, a suburb of Los Angeles. The transcontinental service took 36 hours, which included an overnight stop in St. Louis. This auspicious beginning was followed by measured but impressive growth, with the company eventually providing a major world avenue for travel and commerce.

TWA's decline began in 1992, when the company filed for bankruptcy under Chapter 11. In 1994, its headquarters moved back to Kansas City from Mt. Kisco, New York, and its leaders, appointed by the company's employees and creditors, made courageous moves to regain financial security. Its problems continued through difficult times, however, until the company was acquired by American Airlines in 2001.

Crossing the Continent and the Atlantic

TWA began as a large-scale operation. Lindbergh's concept of an intercontinental airline captured the public's imagination and the company flourished. Recognizing the need for a larger, more comfortable airplane, it began working with the Douglas Aircraft Company, which was encouraged to build a twin-engine plane capable of carrying up to twenty passengers. This plan resulted in the DC-1, which was completed in 1933. Only one DC-1 was built, but the production model, the DC-2, was ready for delivery in 1934, when it began service for TWA and several other airlines, including KLM. The TWA DC-2 carried eighteen passengers and a crew of two. It began service on the TWA Columbus-Pittsburgh-Newark route. In the following year, the airline began assigning air hostesses to its DC-2 flights.

The year 1934 saw the beginning of a twelve-year period of growth under the presidency of Jack Frye, a well-known pilot. He was the first of three men to hold the reins of the company for long time spans, the others being Howard Hughes and Carl Icahn. Under Frye, the company expanded its routes and developed new concepts of passenger comfort, including sleeper berths, introduced in 1937, and in-flight audio, introduced in 1940. Flights in the four-engine Boeing 370, the Stratoliner, which was the

Events in TWA History

1930: Transcontinental and Western Airlines (TWA) is formed by the merger of Western Air Express (WAE) and Transcontinental Air Transport (TAT). The new airline inaugurates transcontinental service, with an overnight stop in Kansas City, Missouri.

1932: TWA enters into agreement with Douglas Aircraft to develop a twin-engine airliner, the DC-1.

1934: The DC-2 enters TWA service.

1939: Howard Hughes takes ownership control of TWA, controlling the airline for the next twenty-five years.

1940: TWA introduces the Boeing Stratoliner, the first pressurized, all-weather commercial aircraft, for transcontinental travel.

1946: TWA initiates transatlantic service from New York to Paris.

1950: TWA officially changes its name to Trans World Airlines.

1957: The airline becomes the first to offer freshly brewed coffee on its flights.

1962: TWA begins regularly using Doppler radar navigation systems.

1970: The airline is the first to offer nonsmoking sections on board all of its flights.

1979: TWA is reorganized under a holding company, Trans World Corporation, with other subsidiaries including Hilton International and Century 21 Real Estate.

1983: Shares in TWA are sold to the public in order to prevent a hostile takeover.

1988: TWA stockholders approve the privatization of the airline, and the ensuing arrangement increases TWA's debt to an amount of $539.7 million.

1991: The airline begins selling its routes to competitors such as American Airlines and USAir, and finds itself reorganizing under Chapter 11 of the Federal Bankruptcy Code the next year.

1993: As TWA completes its reorganization, the airline wins a coveted award for customer service.

1996: TWA plans the purchase of twenty new 757 aircraft, the first new acquisitions since the airline's financial difficulties of the 1980's.

1998: The last of the airline's Boeing 747's is withdrawn from service, and more modern 767's serve as the primary intercontinental wide-body aircraft.

2001: TWA is bought by American Airlines.

first pressurized all-weather commercial airplane, also began in 1940. The TWA Stratoliners carried thirty-three passengers at speeds in excess of 240 miles per hour.

Howard Hughes acquired a majority interest in TWA in 1940 and continued to hold control for twenty-five years, though he was never an officer of the company. He did take a strong interest in the company and even flew TWA planes on occasion. A notable flight occurred in 1944, when Howard Hughes and Jack Frye, the company president, flew a TWA Lockheed Constellation across the country from Los Angeles to Washington, D.C. in 6 hours, 57 minutes, to set a speed record. The relationship between the company and Hughes was not always smooth, however. The company sued him in 1961 and he finally divested himself of TWA stock in 1965.

A Worldwide Airline

After World War II, the airline began expanding its international service. In 1946, it introduced flights on the Lockheed Constellation from New York to Paris, with stops in Gander and Shannon. As soon as it could, it expanded its transatlantic service further with flights to Rome, Athens, Madrid, and Lisbon. By 1950, it was one of two premier U.S. airlines to Europe. In that year it decided to change its name to reflect that fact, so Transcontinental and Western Airlines officially became Trans World Airlines.

The 1950's were eventful for the airline. It began service with the Superconstellations, which made it possible to fly nonstop from New York to Paris and other European cities. It introduced polar flights so that passengers could fly directly from California to Europe. It also began jet flights, scheduling Boeing 707's across the United States and later to Europe. Less propitious events also occurred in the 1950's; the Kansas City airport and TWA facilities were severely damaged by the great 1951 flood, and in 1954 the company began moving its executive offices to New York.

In the mid-twentieth century, TWA was able to keep a pioneering role in its use of the latest and best airplanes, a role it was to give up later in the century. By 1967, it had converted entirely to jet planes, the first U.S. airline to completely abandon prop planes. In 1970, it began transcontinental flights in the Boeing 747, the first airline to use this jumbojet for the Los Angeles-to-New York route. Two years later it introduced the three-engine, medium-range Lockheed 1011, the third U.S. jumbojet to be developed. Almost thirty years later, it was one of the few U.S. airlines to still fly the L-1011, which had ceased production in 1983.

With the many multicomponent corporations that were formed in the 1970's and 1980's, TWA joined the trend. In 1979, the airline joined Hilton International, Century 21 Real Estate Corporation, Canteen Corporation and Spartan Food Services to make up the Trans World Corporation. This arrangement did not last, however, and the airline left Trans World Corporation four years later, to become public. During that era, the airline became one of the first to use the new Boeing 767 plane for long-distance flights. It first flew the two-engine 767 across the continent and then, when the plane was approved for ETOPS (extended twin engine operations) so that it could fly as far as three hours from the nearest suitable runway, TWA flew it on transatlantic runs.

Changing Ownership and Difficult Times

An ownership change occurred in 1985 when the financier Carl Icahn acquired a majority interest. In 1988, the airline became a private company wholly owned by Icahn, who moved the headquarters from New York City to his office building in Mt. Kisco, New York.

The good fortune enjoyed for years by the airline began to flag in the 1990's. To acquire needed cash, it sold several of its principal transatlantic routes to American Airlines in 1992, and later that year filed for bankruptcy under Chapter 11. TWA personnel agreed to various concessions in exchange for a 45 percent equity stake in the company. In the following year, Icahn resigned and the company was managed by a committee that was appointed by the employees and creditors. At that time the headquarters moved back to Kansas City, the site of the company's birth.

Recognizing that its fleet was more aged than that of its competitors, TWA began an ambitious program of new plane purchases in 1996, ordering Boeing 757's, 767's, 717's and Airbus A320's and A328's. These were their first orders for new planes since 1985 and they put the company back in the mainstream of airlines flying modern equipment.

The end of TWA came in the year 2001, with the purchase of the company by American Airlines. American agreed to a price of $500 million plus assumption of debts. TWA still flew after the sale, but it gradually changed as it was absorbed into its one-time competitor. The name TWA was no longer used on flights as of December 3, 2001.

Notable Losses

Because of its world prominence and its route that took it into the Middle East, TWA was plagued by incidents related to political problems having nothing to do with the airline. The first of these occurred in 1974, when a TWA 707 exploded and crashed into the Ionian sea as a result of a terrorist bomb. In 1985, also in Greece, a TWA 727 was hijacked, the passengers were held in the plane for several days, and one person was killed. Two years later a bomb exploded in a 727, tearing a hole in the fuselage through which four passengers were sucked out. Two other high-profile crashes affected the airline in those times. The first was the crash of a 727 in Virginia in 1974, when the plane missed the runway and crashed into a mountain, killing all on board. The most spectacular crash, however, was that of Flight 800, a 747 plane headed for Paris from New York, which exploded over the ocean near Long Island in 1996. After a long investigation, the official cause of the explosion was said to be a spark that ignited a fuel tank, but many people still believed that the real cause was something more sinister, such as a missile that was said to have been accidentally launched by a nearby U.S. Navy ship.

Paul Hodge

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See also: Accident investigation; Air carriers; Airline industry, U.S.; Airplanes; Airports; Boeing; Charles A. Lindbergh; Lockheed Martin; National Transportation Safety Board; Safety issues; Terrorism

Transatlantic flight

Definition: Flight between North or South America and Europe or Africa, across the Atlantic Ocean.

Significance: Flight between the New and Old Worlds was one of the first challenges facing early aviation; it was more dangerous than flying over land, as the opportunities to refuel or to land in case of mechanical emergency were limited. However, the possible benefits of reducing the amount of time needed to transport passengers and cargo between the continents were enormous.

Early Propeller-Driven Aircraft

Between May 8 and May 27, 1919, three Curtiss flying boats set out to complete the first transatlantic flight in history. On May 8, the NC-1, NC-3, and NC-4 took off from Rockaway, Queens, New York, for Halifax, Nova Scotia, on the first leg of the transatlantic journey. The flight was under the command of John Towers, who was also the commanding officer and navigator of NC-3. NC-4 was commanded by Lieutenant Commander Albert C. Read, and NC-1 by Lieutenant Commander Patrick N. L. Bellinger, all of the U.S. Navy. En route, the NC-4 developed engine trouble off Cape Cod and was diverted to Chatham, Massachusetts. The NC-1 and NC-3 arrived at Halifax without incident and, on May 10, continued on to Trepassey Bay, Newfoundland. On May 14, NC-4 flew to Halifax and arrived at Trepassey Bay on the next day. On May 16, NC-1, NC-3, and NC-4 departed Trepassey Bay for Horta in the Azores. On May 17, NC-4 arrived at Horta. NC-1 landed at sea and sank three days later. Its crew was picked up by the Greek freighter *Ionia*. NC-3 was badly damaged after landing off Horta.

On May 19, NC-3, battered and almost derelict, sailed into the harbor of Ponta Delgada in the Azores. On May 27, NC-4 departed Horta and arrived in Lisbon, Portugal, thereby completing both the first American transatlantic flight and the first transatlantic flight overall.

The flying boats had a wingspan of 126 feet, a length of 68 feet 3 inches, and a height of 24 feet 4 inches. Their operational weight was 27,386 pounds. They flew at a maximum speed of 91 miles per hour, and had a ceiling of 4,500 feet and a range of 1,470 miles. Their cruising speed was 14.8 miles per hour. Propulsion consisted of four Liberty 400-horsepower 12-cylinder Vee-type engines.

On June 15 and 16, Captain John Alcock and Lieutenant Arthur Whitten Brown, British fliers of World War I, made the 1,900-mile trip from St. John's, Newfoundland, Canada, to Clifden, Ireland, in 16 hours, 12 minutes. They flew in a Vickers-Vimy bomber with a length of 44 feet, a wingspan of 68 feet, and a height of 15 feet. The plane flew at a maximum speed of 100 miles per hour, cruised at 90 miles per hour, and could climb to 5,000 feet in 26 minutes. Its ceiling was 7,000 feet. Propulsion consisted of two 350-horsepower Rolls-Royce engines.

Lindbergh's Solo Flight

On May 21, 1927, Charles A. Lindbergh, an American, completed the first solo nonstop transatlantic flight in history, flying his Ryan NYP *Spirit of St. Louis* 3,610 miles between Roosevelt Field on Long Island, New York, and Paris, France, in 33 hours, 30 minutes. Although ninety-one persons on thirteen separate flights had crossed the Atlantic Ocean before him, he flew directly between two great world cities and did it alone. With this flight, Lindbergh won the $25,000 prize offered by New York hotel owner Raymond Orteig to the first aviator to fly an aircraft directly across the Atlantic between New York and Paris. When he landed at Le Bourget Field in Paris, Lindbergh became a world hero who would remain in the public eye for decades.

The aftermath of the flight was the "Lindbergh boom" in aviation: aircraft industry stocks rose in value and interest in flying skyrocketed. Lindbergh's subsequent U.S. tour in the *Spirit of St. Louis* demonstrated the potential of the airplane as a safe, reliable mode of transportation. Following the U.S. tour, Lindbergh took the aircraft on a goodwill flight to Central and South America, where flags of the countries that he visited were painted on the cowling. The *Spirit of St. Louis* was named in honor of Lindbergh's backers in St. Louis, Missouri, who paid for the aircraft. "NYP" is an acronym for "New York-Paris," the object of the flight.

The *Spirit of St. Louis* was designed by Donald Hall under the direct supervision of Lindbergh. It was a highly modified version of a conventional Ryan M-2 strut-braced monoplane, powered by a reliable Wright J-5C engine. Because the fuel tanks were located ahead of the cockpit for safety in case of an accident, Lindbergh could not see directly ahead except by using a periscope on the left side or by turning the airplane and looking out of a side window. This plane had a wingspan of 46 feet, a length of 27 feet 8 inches, and a height of 9 feet 10 inches. The gross weight of the aircraft was 5,135 pounds and propulsion consisted of one Wright Whirlwind J-5C 223-horsepower engine.

Post-Lindbergh Flights

On June 5, 1927, Charles A. Levine became the first passenger on a completed transatlantic flight when the Wright-Bellanca WB-2 airplane in which he had departed on the previous day from Roosevelt Field, New York, arrived in Eisleben, Germany. Clarence D. Chamberlin had piloted the airplane, which had a wingspan of 46 feet 4 inches, a length of 27 feet 9 inches, and a gross weight of 3,550 pounds. This aircraft, the *Columbia*, was powered by one Wright J-5 220-horsepower engine.

On April 12, 1928, the single-engine, all-metal Junkers monoplane *Bremen*, piloted by German Captain Hermann Köhl and carrying the German Baron Günther von Hönefeld and Irish Captain James Fitzmaurice, departed Dublin, Ireland, for New York City. After 36 hours the plane landed on Greenly Island, Labrador, Canada, after completing the first east-west transatlantic crossing. The *Bremen* had a wingspan of 18.35 meters, a length of 10.90 meters, and a height of 3.50 meters. Its gross weight was 3,700 kilos. The top speed of the plane was 195 kilometers per hour, while it cruised at 150 kilometers per hour. Its range was 7,700 kilometers. Propulsion consisted of one 360-horsepower Junkers L 5 engine.

On September 2 and 3, 1930, French pilots Dieudonne Coste and Maurice Bellonte flew a Hispano-powered Breguet biplane from Le Bourget Field in Paris, France, to Valley Stream, Long Island, New York, in 37 hours, 18 minutes, thereby completing the first Paris-to-New York nonstop flight.

Earhart's Solo Flights

On May 20-21, 1932, the American Amelia Earhart became the first woman, and only the second person, to make a nonstop solo flight across the Atlantic Ocean. The aircraft that she used was a bright red Lockheed Vega SB, a sleek new monoplane with a fully cantilevered wing and roomy cabin that was quickly welcomed by record-seeking pilots and the air transport industry. In June, 1928, Earhart had become the first woman to fly across the Atlantic, but she did so only as a passenger. She was frustrated because she did not sit at the controls for even one minute of that 20-hour, 40-minute flight, and she was determined to prove that she could fly on her own. She decided to use a Lockheed Vega.

This particular Vega had been manufactured on December 4, 1928, at Lockheed's Burbank, California, plant. Lockheed used it as a demonstrator until Earhart bought it on March 17, 1930. Her test flights began inauspiciously when, during a flight at Langley Field, Virginia, in September, 1930, a latch on her backrest gave way and she was thrown backward into the cabin. The plane nosed over on landing and was sent to Detroit Aircraft Corporation for repairs. The wings, landing gear, and tail surfaces were all in good condition, but the fuselage had to be replaced and repairs took over one year.

Earhart turned the repaired Vega over to Bernt Balchen, her technical advisor. He took the plane to the old Fokker Aircraft Company plant at Hasbrouck Heights, New Jersey. There he and mechanics Frank Nagle and Eddie Gorski reconditioned the plane for the upcoming flight. The fuselage was strengthened to take the extra fuel tanks that were added to provide a 420-gallon capacity.

On May 20, 1932, Earhart set off alone from Harbor Grace, Newfoundland, Canada. The weather posed a problem from the start, and at one point in the flight, ice on the wings forced her into a 3,000-foot unchecked descent. She finally managed to level off, and, constantly fighting fatigue, she landed in a field near Culmore, Londonderry, Northern Ireland. She had made the 2,026-mile flight in 14 hours, 54 minutes.

The Vega was the first airplane built by Lockheed Corporation, and was noteworthy in reintroducing the monocoque or shell fuselage shape, which had first appeared in a racing airplane in 1913. This shape, wherein the fuselage was essentially a shell, maximized both the load-carrying ability of the aircraft and its useful internal space. It subsequently became a standard design practice for transport aircraft. The Lockheed SB Vega flown by Amelia Earhart had a wingspan of 41 feet, a length of 27 feet 6 inches, and a height of 8 feet 2 inches. It weighed 1,650 pounds when empty.

Other 1930's Flights

On August 18, 1932, James A. Mollison, a British pilot flew a De Havilland Puss Moth from Portmarnock, Ireland, to Pennfield, New Brunswick, Canada. He thereby completed the first westbound transatlantic solo flight. The Puss Moth had a wingspan of 36 feet 9 inches, a length of 25 feet, and a height of 7 feet. Its gross weight was 2,050 pounds. It had a maximum speed of 128 miles per hour, a cruising speed of 108 miles per hour, and a range of 300 miles. It could climb at a rate of 610 feet per minute and had a ceiling of 17,500 feet.

Commercial and Helicopter Flights

On February 5, 1946, the U.S. commercial airline Trans World Airlines (TWA) began transatlantic service with the Lockheed Constellation, flying the route linking New York City with Gander, Newfoundland, Canada; Shannon, Ireland; and Paris, France. The Constellation had a wingspan of 123 feet, a length of 95 feet, 2 inches, and a height of 22 feet, 5 inches. It had a gross weight of 82,000 pounds, a top speed of 340 miles per hour, and a cruising speed of 280 miles per hour. The ceiling of the aircraft was 35,000 feet and it had a range of 4,300 miles. Propulsion consisted of four Curtiss-Wright Cyclone engines. The plane could accommodate four to five crew members and fifty-four passengers.

On January 30, 1947, TWA inaugurated transatlantic all-cargo service. This was the first regularly scheduled direct service ever operated over the North Atlantic.

Between July 15 and 31, 1952, Captain Vincent H. McGovern and First Lieutenant Harold W. Moore, both of the United States, completed the first transatlantic helicopter flight when they piloted two Sikorsky H-19's from Westover, Massachusetts, to Prestwick, Scotland. The two men covered the distance of 3,410 miles in five stops, with a flying time of 42 hours, 25 minutes.

The H-19 was the first of the Sikorsky helicopters with enough cabin space and lifting ability to allow satisfactory operation in troop transport or rescue roles. The engine was mounted in the nose, leaving the main cabin free for passengers or cargo. The prototype was first flown in November, 1949, and in 1951 the U.S. Air Force ordered production model H-19's. This helicopter had a rotor diameter of 53 feet, a fuselage length of 42 feet 4 inches, and a height of 15 feet 4 inches. Its gross weight was 8,400 pounds. It flew at a maximum speed of 112 miles per hour, and cruised at 92 miles per hour. Its range was 330 miles and it had a service ceiling of 15,000 feet. Propulsion consisted of one Wright R-1300-3 700-horsepower engine.

On May 31, 1967, two U.S. Air Force Sikorsky HH-3E "Jolly Green Giant" search and rescue helicopters departed New York on the first transatlantic nonstop helicopter flight, which ended 30 hours, 46 minutes later when the two aircraft landed at Le Bourget during the Twenty-seventh Paris Air Show. The helicopters were refueled nine times each by C-130 tanker planes at altitudes of between 1,000 and 9,000 feet and speeds of 125 miles per hour. The two helicopters had departed at 1:05 A.M., New York time, in order to arrive during the middle of "Helicopter Day" at 1:51 P.M. Paris time. Refueling helicopters from tanker planes was first attempted in 1965. After early success, the technique was refined, leading to the decision to produce all later HH-3E's with refueling probes that partially retracted into the fuselage until needed.

The HH-3E had a rotor diameter of 62 feet, a length of 73 feet, and a height of 18 feet 1 inch. The gross weight of this helicopter was 22,050 pounds. It flew at a maximum speed of 162 miles per hour and had a range of 625 miles. Propulsion consisted of two 1,400-horsepower General Electric T-58-GE-10 turboshaft engines.

On October 11, 1992, Venezuelan helicopter pilots Francisco Pacheco and Tomas Spanier flew a record-setting transatlantic trek from Venezuela to Spain on an MD-500D helicopter. They departed from Ft. Lauderdale, Florida, and ended at Palos de la Frontera, Spain, on December 16. The pilots recreated in reverse Christopher Columbus third voyage, marking that explorer's first landing in Venezuela. The MD-500D helicopter had a length of 30,84 feet, a main rotor span of 26.41 feet, and a height of 8.9 feet. Its service ceiling without supplemental oxygen was 12,500 feet, and with supplemental oxygen it could reach an altitude of 16,000 feet. The aircraft's gross weight was 3,000 pounds and its maximum speed was 156 knots. The normal range of the helicopter was 225 nautical miles, with a range of 300 nautical miles with auxiliary fuel.

Jet Aircraft

On September 22, 1950, Colonel David C. Schilling of the U.S. Air Force completed the first nonstop transatlantic jet flight when he flew 3,300 miles from the United Kingdom to Limestone, Maine, in 10 hours, 1 minute.

On August 26, 1952, a Canberra bomber of the British Royal Air Force completed the first transatlantic round trip in the same day when it flew from Aldergrove, Northern Ireland, to Gander, Newfoundland, Canada and back in 7 hours, 59 minutes. This bomber and visual attack aircraft had a wingspan of 64 feet, a length of 65 feet 6 inches, and a height of 15 feet 7 inches. Its gross weight was 53,000 pounds and its maximum speed was 605 miles per hour. Its range was 1,105 miles. Propulsion consisted of two 7,500-pound dry thrust Rolls-Royce Avon Mk 109 turbojets.

On October 4, 1958, the British airline BOAC inaugurated the first transatlantic jet passenger service with a link between New York City and London. Pan American World Airways started daily service between New York and Paris on October 26 of the same year.

On January 21, 1976, the first regularly scheduled commercial supersonic transport (SST) flights began with the French airline Air France and the British airline British Airways. Air France flew the Paris-Rio de Janeiro, Brazil, route while British Airways flew from London to Bahrain. Both airlines began SST service to Washington, D.C., on May 24.

Dirigibles and Balloons

On July 2, 1919, the British dirigible *R-34*, commanded by Major George H. Scott, departed Firth of Forth, Scotland, and touched down in Mineola, Long Island, New York, 108 hours later. Referred to as "Tiny" by members of its crew, the *R-34* was enormous and as large as a contemporary Dreadnought battleship. The *R-34* was a "peacetime airship." The original design had called for bomb racks and machine guns, but these were never fitted. In just over twelve months, it was completed by the Beardmore Company, located near Glasgow, Scotland, on December 20, 1918.

In midflight, it was discovered that one of the crew, William Ballantyne, who had been taken off of the flight crew in place of more important passengers, had stowed away on board and hidden between the girders of the ship along with the ship's mascot cat Whoopsie. Both were found tired, cold, and hungry, and Ballantyne was immediately put on duty to work his passage to the United States.

After completing the first lighter-than-air transatlantic flight traveling from east to west, the *R-34* was reprovisioned, regassed, and then began her homeward journey on July 10. The dirigible completed this eastbound trip in 75 hours. The *R-34* had a length of 643 feet, a diameter of 79 feet, and a volume of 1,950,000 cubic feet. It traveled at 62 miles per hour, and propulsion consisted of five 270-horsepower engines.

On August 16, 1978, Ben Abruzzo, Larry Newman, and Maxie Anderson, all of the United States, departed to complete the first transatlantic flight in a balloon, the *Double Eagle II*. On the following day they touched down in France.

On September 18, 1984, Joe W. Kittinger landed near Savona, Italy, in his helium-filled balloon *Rosie O'Grady's Balloon of Peace* after a flight of 3,535 miles from Caribou, Maine. He thereby completed the first solo transatlantic balloon flight.

On July 2, 1987, Richard Branson and Per Lindstrand departed from Sugarloaf Mountain, Maine, for Ireland in the hot-air balloon *Virgin Atlantic Flyer.* Two days later they arrived in Ireland, thereby completing the first transatlantic hot-air balloon flight.

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See also: Airline industry, U.S.; Airplanes; Balloons; Buoyant aircraft; Commercial flight; Dirigibles; Amelia Earhart; Helicopters; Charles A. Lindbergh; Pan American World Airways; *Spirit of St. Louis*; Trans World Airlines; Transglobal flight

Transcontinental flight

Definition: Flight across the United States from the Atlantic to the Pacific coast or from the Pacific to the Atlantic coast.

Significance: Flight from one ocean coast of the United States to the other has always been considered a benchmark of success, whether to simply make the flight, to make it nonstop, or to make it in record time.

Since the completion of the Louisiana Purchase by President Thomas Jefferson in 1803, traveling from one coast of the United States to the other has become a travel benchmark of sorts. The Lewis and Clark expedition, the crossing of the West by wagon trains and the Pony Express, and the completion of the first transcontinental railroad link have been celebrated events in American history. It is no surprise, then, that one of the goals of early aviators was to cross the country by airplane.

Early Records

The first transcontinental flight came in response to a $50,000 prize offered by William Randolph Hearst for a coast-to-coast flight in thirty days. Such prizes were often offered by those who wished to encourage early aviation in the United States to move beyond demonstration flights by exhibition groups such as those run by the Wright brothers and Glenn H. Curtiss. The prizes were efforts to convert aviation from dangerous, circuslike side shows and "meets" into a practical mode of transportation.

On September 17, 1911, Calbraith P. Rodgers, who learned to fly at one of the Wright's flying schools and had less than sixty hours of flight experience, took off from Brooklyn, New York, in a Wright Model B aircraft and headed for the West Coast using railroad tracks for navigation. Rodger's plane was named the *Vin Fiz* after a grape-flavored carbonated drink made by his primary sponsor, who paid him five dollars for every mile flown. The flight consisted of sixty-nine short segments, many ending in crashes, flying only as wind, weather, daylight hours, and recovery from injuries permitted. Rodgers was followed on the ground by a train carrying spare parts for his airplane, and so many were needed that at the conclusion of the flight, some three months after its beginning, the only things that remained of his original aircraft were a single wing strut and the rudder. He had crashed nineteen times and only managed to get into the air some forty-nine days during his journey to Long Beach, California. When he did reach the West Coast on November 5, it was with his head in a cast and a large scar on his forehead.

Despite his failure to make the trip in a month, Cal Rodgers had shown that transcontinental flight was possible and dreamers began to predict a future of regularly scheduled coast-to-coast airmail and passenger flights. However, Rodgers died in a crash after colliding with a seagull in an exhibition flight less than four months after completing his feat, further convincing critics that aviation was only for the foolhardy.

From 1911 until the mid-1920's, the only real motivation for transcontinental flight seemed to be to set new distance and time records, and many of these were set by U.S. Army aviators. Lieutenant James Doolittle became the first person to fly across the country in less than a day, making a one-stop journey from Florida to California in 21 hours, 20 minutes in September, 1922. The first nonstop transcontinental flight was made in 27 hours by Lieutenants John Macready and Oakley Kelly in 1923 in a Fokker T-2. In June, 1924, Lieutenant Russell Maughan flew from Long Island, New York, to San Francisco, California, in less than 18 hours in a Curtiss pursuit aircraft, making refueling stops on the way.

Transcontinental Airmail and Airlines

Airmail and airline travel in the United States was slow in developing compared to the situation in Europe. Airmail flights were started by the Army, and taken over by the Post Office in July, 1918. Starting on the East Coast and slowly adding westward routes, airmail reached as far west as Omaha, Nebraska, in September, 1920. That month, the

Image Not Available

Post Office announced the beginning of transcontinental airmail service, but it was actually a combination of train and airplane travel with the planes flying in daylight hours and the mail transferred to trains at night. It was, in reality, no faster than train mail but it enabled the construction of a transcontinental route of airports and lighting aids.

By 1926, a coast-to-coast string of airports with flashing beacons lighting the route had been built. Radio and weather stations were scattered along the route to make possible twenty-four-hour flight operations. This allowed the Post Office to begin contracting the mail to private operators, many of which later grew into major airlines.

Under Herbert Hoover's presidential administration, the Post Office established new rules for airmail contractors, strongly encouraging the use of larger, passenger-carrying airplanes on longer routes. Three transcontinental routes were established, leading to the beginnings of a nationwide airline structure, with TWA, American Airlines, and United Air Lines each serving one of the cross-country routes. TWA, then known as Transcontinental Air Transport (TAT), had the first coast-to-coast service with a combination of airplane and rail travel. Passengers left New York City by rail on an overnight train to Columbus, Ohio. After flying from Columbus to Waynoke, Oklahoma, passengers got on another train to Clovis, New Mexico, and completed the trip by airplane to Los Angeles. The Ford Trimotor was typical of the largest and fastest aircraft used on such flights. At its best, the Trimotor had a cruise speed of just over 120 miles per hour and a range of about 500 miles, and it could not fly at the altitudes needed to get over the Rocky Mountains. With only crude navigational aids available, only daytime flight in good weather was permissible, making flying very unreliable for anyone seeking to get somewhere on time.

The new airmail subsidy rules encouraged the new airlines to seek bigger and faster airplanes and this led to the development of planes like the Boeing 247 and the DC-2 and DC-3 which ultimately brought airline travel into a new era, making true transcontinental flight possible.

Increasing Reliability

The administration of Franklin D. Roosevelt, in 1933, upset over the airline/airplane manufacturer monopolies which resulted from the airmail subsidy policies of its predecessors, changed the rules and turned the airmail back over to the Army Air Corps. The Army, with less reliable planes and pilots than the airlines, proved incapable of safely flying the mail. Jack Frye of TWA and Eddie Rickenbacker of Eastern Air Lines wanted to prove the superiority of the airlines in airmail delivery. On February 18, 1934, the last day of the airline contract, they flew the original DC-1 (the prototype for the DC-2 and DC-3) from Los Angeles to Newark, New Jersey, with a full load of mail, setting a new transcontinental speed record (for transports) of just over 13 hours. The same airplane set a new 11 hour, 5 minute transcontinental record in 1935, beating the record set by Roscoe Turner in a specially built racing plane in 1933.

By 1937, the transcontinental flight record was cut to 7 hours, 30 minutes by Howard Hughes in his H-1 airplane. Transcontinental flight for the general public became a reality in the 1930's with planes such as the Boeing 247 and the DC-2 and DC-3, but none of these planes had the range for nonstop flight across the country. Newer four-engine airliners, such as the Lockheed Constellation, the DC-4 and 6, and the Boeing Stratoliner, had almost enough range to make it nonstop from coast to coast, but at that time the really long-range commercial aircraft were the amphibian or seaplane type airliners flown on overseas routes by airlines such as Pan American. It was not until after World War II that there was enough passenger demand to stretch the limits of these same designs to create planes such as the Lockheed Super Constellation, the DC-7, and the B-29-based Boeing Stratocruiser, which could fly from one coast to the other without stopping for fuel.

Even so, at top speeds of just over 300 miles per hour, these transcontinental flights took a long time, especially the flights from east to west which were slowed by prevailing winds. It took the advent of the jet airliner to make nonstop coast-to-coast commercial flight a real success. With the 1958 and 1959 introduction of the Boeing 707 and the Douglas DC-8 into airline service, commercial passengers could finally make a transcontinental trip in less time than Howard Hughes's record flight some twenty years earlier.

Transcontinental flight times have not changed much since the introduction of the jet to commercial service. Supersonic transports (SSTs) such as the Concorde could conceivably reduce the coast-to-coast flight time, but supersonic commercial flight is banned over the United States and most other land masses because of the noise they create. Shock waves coming from the leading and trailing edges of the aircraft's wings at supersonic speeds are heard on the ground as loud, explosionlike booms, and may be strong enough to cause structural damage to buildings. While the sonic booms from high-altitude SSTs are likely to be very weak at ground level, the fear of their effect has ruled out supersonic flight over land.

Modern Speed Records

Military supersonic aircraft have been used to set coast-to-coast flight records. On March 6, 1962, the U.S. Air Force set a new transcontinental flight record with the delta-winged B-58 supersonic bomber by flying round trip between Los Angeles and New York in 4 hours, 42 minutes. The New York-to-Los Angeles leg of the flight took 2 hours, 15 minutes, meaning that it arrived at a local time earlier than the time it left New York.

The current record transcontinental flight time from Los Angeles to Washington, D.C., was set by the Lockheed SR-71 supersonic aircraft on March 6, 1990, when it flew at an average speed of 2,153 miles per hour to cross the country in 64 minutes, 5 seconds.

While it is quite unlikely that airline passengers will ever match these record speeds on a transcontinental flight because of restrictions on overland sonic booms by commercial flights, coast-to-coast flight times may improve slightly with Boeing's plans to build an airliner that will fly at Mach 0.95, faster than any existing subsonic commercial jet. Unfortunately, such improved flight speeds may be needed simply to overcome the flight delays found in ever more crowded airline operations.

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See also: Airline industry, U.S.; Airmail delivery; Glenn H. Curtiss; High-altitude flight; High-speed flight; Jet engines; Military flight; Record flights; Supersonic aircraft; Wright brothers

Transglobal flight

Definition: Flight encircling the world.

Significance: Transglobal flight was a natural outcome of the desire to push aircraft technology ever further, creating craft with increasingly long-range flight capabilities. The capacity to fly around the globe began as an aviation challenge, but eventually developed into a profitable capacity for airlines transporting passengers to the ends of the earth.

The origin of transglobal flight lies in flight to link continents. Beginning in the 1910's, European and American fliers traveled in both fixed-wing aircraft and airships from continent to continent. On December 18, 1912, French aviator Roland Garros became the first pilot to bridge two continents in a single flight when he flew his Blériot monoplane from Tunis, Tunisia, to Trapani, Sicily, located halfway across the Mediterranean Sea between North Africa and Europe. The distance of 177 miles covered water all of the way. One week after this feat, Garros flew from Sicily to Rome, a further 345 miles, half of which lay over water as well.

World War I disrupted intercontinental travel, for nations that had aeronautics industries devoted their time and energy to harnessing aviation for military purposes. With the end of that conflict in November, 1918, however, aviators again began to fly across ever greater distances. On December 13, 1918, the first direct flight between the United Kingdom and British India began when the third prototype Handley Page V/1500 departed from Suffolk. Major A. S. C. MacLaren served as pilot, Captain Robert Hally as copilot, and Sergeants Smith, Crockett, and Brown as crew members. The plane flew in multiple stages to Otranto, Italy, picking up nine passengers for Malta and then making the 1,050-mile nonstop flight to Mersa Matruh in Egypt. The plane then flew on to Baghdad, Iraq, and across the north coast of the Persian Gulf. After several stops it reached Karachi, British India (present-day Pakistan), on January 15, 1919, after a journey of more than 6,000 miles.

Later that same year, a seaplane became the first aircraft to cross the Atlantic Ocean. On May 8, three Curtiss flying boats, known collectively as Seaplane Division One of the U.S. Navy, departed from the Rockaway Naval Air Station, New York, for a 950-mile trip to Trepassey, Newfoundland, Canada. Eight days later, the three flying boats departed from Trepassey Bay for Horta, in the Azores. NC-1 had to land on the water 100 miles west of Flores; it was lightly damaged and ultimately sank when the lines tied to the ship towing it into harbor broke. NC-3 landed on the water 45 miles southwest of Faial and taxied 200 miles into the harbor of Horta. It proved unable to continue the transatlantic journey. On May 20, the sole remaining Curtiss boat, NC-4, commanded by Lieutenant Commander A. C. Read, flew the 160 miles from Horta to Ponta Delgada, still in the Azores. Inclement weather delayed Read, and on May 27, he departed for Lisbon, Portugal. He covered the 925 miles on the same day, completing a journey of some 3,425 miles and thereby becoming the first man to fly across the Atlantic Ocean.

Nonstop Intercontinental Flight

The next major stage in intercontinental air travel involved nonstop flights. On June 14, 1919, British aviators Captain John Alcock and Lieutenant Commander Arthur Whitten Brown departed from Lester's Field near St. John's, Newfoundland, Canada, for the first nonstop flight across the Atlantic Ocean. They crash-landed in a bog near Clifden in the west of Ireland, 1,890 miles and 16 hours and 28 minutes later. The two men flew a Vickers Vimy modified with a fuel capacity expanded from 619 gallons to 1,038 gallons, which increased the plane's nominal range from 1,880 miles to 2,440 miles.

Airships began to play a role in intercontinental travel in the first year after World War I as well. On July 6, 1919, British flight lieutenant J. E. M. Pritchard became the first person to arrive in the United States by air from Europe when the airship *R-34* entered American skies. That vessel had departed from Scotland on July 2 to cross the North Atlantic. To organize preparations for the capture and mooring of the large vessel, Pritchard actually parachuted onto Long Island, New York, and thereby became the first European to touch American soil without traveling by boat. On July 13, the *R-34* completed the first two-way crossing of the Atlantic Ocean and established a new airship distance record of 6,330 miles when it returned to the United Kingdom. It had departed New York on July 10 and arrived in Norfolk, England, after little more than 75 hours of trouble-free flight.

The year 1919 also witnessed the first truly transglobal flight when Captains (and brothers) Ross and Keith Smith arrived in Port Darwin, Australia, on December 10. They had covered a distance of 11,340 miles from Hounslow, England, after flying 135 hours and 55 minutes at an average speed of 83 miles per hour. They won a prize of 10,000 Australian pounds for becoming the first Australians to fly directly between the United Kingdom and Australia. Their flight path took them via Lyons, Pisa, Cairo, Damascus, Ar Rāmadī, Basra, Karachi, Delhi, Allahabad, Akyab (present-day Sittwe), Rangoon (present-day Yangon), Bangkok, Singora, Singapore, Surabaya, and Bima.

During the 1920's, pilots set various records for transoceanic and transglobal travel. On March 30, 1922, Commander Sacadura Cabral and Captain Gago Coutinho of Portugal departed Lisbon in a Fairey IIID for the first attempted flight between Portugal and Brazil. They reached Grand Canary Island later that same day. On April 5, they flew on to São Vicente, Cape Verde Islands, covering 849 miles in 10 hours and 43 minutes. Inclement weather delayed their departure, and on April 17, the two men flew 170 miles to São Tiago. On the following day they covered 908 miles in 11 hours and 21 minutes and touched down on the Rocks of St. Peter and St. Paul. They had less than one gallon of aviation fuel left and their Fairey IIID sank in heavy seas. Undaunted, Cabral and Coutinho continued in a replacement aircraft of the same type, arriving in Rio de Janeiro on June 17. In total, they had covered 5,025 miles in a flight time of 60 hours and 14 minutes.

Circumnavigating the Globe

The first circumnavigation of the globe was completed on September 28, 1924, when two Douglas World Cruisers (DWCs) operated by the U.S. Army returned to Seattle, Washington. In a flight time of 371 hours and 7 minutes, at an average speed of 78 miles per hour, these airplanes had covered a distance of 26,503 miles. Originally three DWCs had flown from Calcutta, India, via the Middle East to Paris, France, where their wheels were changed to floats for transoceanic flight. The third DWC ditched after departing the Orkney Islands, north of Scotland, but the crew was picked up and joined the others in Washington, D.C., for a hero's welcome. The aircraft proceeded to cross the North American continent.

Light airplanes, those weighing less than 700 pounds, also played a role as aviation pioneers. The first light airplane flight from the United Kingdom to India began when T. Neville Sack and Bernard S. Lee departed Croydon, England, in two DH-60 Moths on November 15, 1926. Each of the two-seaters was modified into a single-seater, with extra fuel tanks in the space usually reserved for the front seat. The two men covered a distance of 5,540 miles in fifty-four days and landed in Karachi, British India, on January 8, 1927. Incidentally, these were the first Moths to reach India, and much joyriding took place in several Indian cities. The Moth rapidly became the most popular light plane of its day.

The first circumcontinental flight in the western hemisphere began on December 21, 1926, when five amphibious U.S. Army Air Corps Loening OA-1A biplanes departed from Kelly Field, Texas, for a goodwill tour of Central and South America. The crews flew through Mexico, Central America, and Colombia and along the west coast of Ecuador, Peru, and Chile. Subsequently they crossed over to Argentina and first flew north to Paraguay and then south to Uruguay. They then followed the coast through Brazil, French Guiana, Dutch Guiana (present-day Suriname), British Guiana (present-day Guiana), Venezuela, and up through the West Indies to Cuba and across to Florida. The flight ended at Bolling Field, Washington, D.C., on May 2, 1927.

Lindbergh and Others

The year 1927 occupies a special place in aviation history, with noteworthy flights across both the Atlantic and Pacific Oceans. On May 20, Charles A. Lindbergh took off from Roosevelt Field, New York, to become the first person to fly solo across the Atlantic Ocean and in so doing establish a new long-distance record. His 237-horsepower Ryan monoplane generated a top speed of 124 miles per hour. The aircraft was laden with 450 gallons of fuel and narrowly missed trees and power lines during takeoff. Struggling with violent winds, ice, poor visibility, and fatigue, Lindbergh landed at Le Bourget, Paris, France, 33 hours, 30 minutes, and 28 seconds after takeoff. He had crossed 3,590 miles at an average speed of 107 miles per hour. A mere two weeks after this historic flight, Americans Clarence C. Chamberlain and Charles A. Levin flew from Roosevelt Field to Eisleben, Germany. They covered a distance of 3,911 miles, and bad weather over the United Kingdom forced them to climb to an altitude of 20,000 feet without oxygen. Chamberlain and Levin broke the existing nonstop distance record with this flight.

The world's first intercontinental charter flight began on June 15, 1927, when American millionaire W. Van Lear Black hired a Fokker F-VIIa from the Dutch national airline KLM. The plane was commanded by Captain G. J. Geysendorffer with J. B. Scholte and K. A. O. Weber as crew. In a period of thirteen days, the plane flew 9,120 miles in 86 hours and 27 minutes between Amsterdam, the Netherlands, and Jakarta, Dutch East Indies (present-day

Indonesia). Less than two weeks later, on June 28, the first transpacific crossing between North America and the Hawaiian Islands began when Lieutenants Lester J. Maitland and Albert Hegenberger of the United States Army Air Corps departed from Oakland, California, for Honolulu. Their 220-horsepower Fokker C-2 airplane covered the distance of 2,407 miles in 25 hours and 50 minutes.

On October 15, five months after Lindbergh's flight, Captain Dieudonne Costes and Lieutnant Commander Joseph Le Brix completed the first nonstop flight across the South Atlantic. They departed from St. Louis, Senegal, West Africa, and covered 2,215 miles in 19 hours and 50 minutes before landing at Natal, Brazil.

The following year, 1928, witnessed historic flights as well. On February 7, the first successful light-plane flight between the United Kingdom and Australia began when Bert Hinkler took off from Croydon near London in an Avro 581E Avian prototype. His route took him to Rome, Malta, Tobruk, Ramleh, Basra, Jāsk, Karāchi, Cawnpore, Calcutta, Rangoon, Victoria Point, Singapore, Bandung, and Bima. Hinkler landed in Darwin, Australia, on February 22, having covered 11,005 miles in a flying time of 128 hours over less than sixteen days. One month later, the British aviatrix Lady Mary Bailey would become the first woman to fly round-trip between London and Cape Town, South Africa. On March 9, she took off from Croydon and reached Cairo ten days later. Her flight path took her via Khartoum and Lake Victoria to Tabora, Tangayika (Tanzania), where she crashed. However, she continued with a replacement aircraft supplied by the South African Air Force. On April 30, she reached Cape Town.

At the end of May, Captain Charles Kingsford-Smith and his copilot Charles Ulm began the first transpacific flight linking the United States and Australia. On May 31, the two men departed from Oakland, California, in a Fokker F-VIIB-3m on the first leg of their trip. They arrived in Honolulu, Hawaii, on June 1, covering 2,400 miles in approximately 27 hours. Two days later they flew on to Suva, Fiji, landing there after covering a distance of 3,200 miles in less than 35 hours. On June 8, they began the final leg of their journey, arriving in Brisbane, Australia, on the next day. In all, Kingsford-Smith and Ulm flew a total of 83 hours and 38 minutes.

In 1929, both fixed-wing aircraft and an airship entered the annals of aviation history. Two British aviators, Flight Lieutenants A. G. Jones-Williams and N. H. Jenkins, attempted to set a new nonstop distance record by flying from the United Kingdom to South America. However, delays prevented them from being able to take advantage of proper weather conditions for that route, so the two men decided to make the attempt by heading to India. Their Fairey Long Range monoplane departed from Cranwell on April 24 and landed in Karachi 50 hours and 37 minutes later. They had covered a distance of 4,130 miles, insufficient to break the record of 4,466 miles, but nevertheless completing the first nonstop flight between the United Kingdom and British India.

Airship Circumnavigation

On August 1, the first airship flight to circumnavigate the globe began when the *Graf Zeppelin* departed Friedrichshafen, Germany. The airship was under the command of Dr. Hugo Eckener and first flew to Lakehurst, New Jersey, to pick up passengers. Back in Friedrichshafen, the world trip proper began on August 15 with a direct flight to Tokyo, Japan, where the airship landed four days later. Between August 23 and August 26, the airship traveled from Tokyo to Los Angeles. It subsequently traversed the North American continent and the Atlantic Ocean before returning to Friedrichshafen on September 4. It had logged 21,000 miles in 21 days and 20 minutes of flying time, and thereby set a speed record.

The setting of both temporal and spatial records in air travel established standards that others sought to exceed. On June 23, 1931, the American Wiley Post and his navigator Harold Gatty departed from Roosevelt Field in New York in a Lockheed Vega 5B to fly around the world. Post and Gatty flew via Newfoundland, the United Kingdom, Germany, the Soviet Union, Alaska, and Canada to arrive back in New York on July 1. They covered 15,474 miles in 15 hours and 51 minutes and thereby beat the 21-day record set by the *Graf Zeppelin* by a handsome margin.

Transglobal Passenger Service

Advances in aircraft design and performance gradually led to the introduction of passenger service across intercontinental and ultimately transglobal distances. On April 27, 1932, the British civil carrier Imperial Airways inaugurated the first regularly scheduled passenger service between the United Kingdom and South Africa, using DH-66 aircraft. The other great European imperial power, France, was not slow to follow suit. On December 22, 1933, an Air France D-332 three-engine transport aircraft left Paris for a flight to Saigon (present-day Ho Chi Minh City, Vietnam) under the command of Maurice Nogues. The D-332 had a capacity of eight passengers and a range of 1,242 miles. The airplane arrived in Saigon on December 28, after a total flying time of 48 hours. This aircraft remained in service until the late 1940's.

Like World War I, World War II diverted the attention of those nations with significant aeronautical industries to the military application of aviation technology. Transglobal flight in the postwar period distinguished itself perhaps most saliently through the growth in the number of passengers traveling around the world and the introduction of the jet-engine passenger liner. On June 17, 1947, the American carrier Pan American began the world's first round-the-world commercial service when it started flying Lockheed Constellations and fully utilizing routes on which it held licenses to operate. Eastbound flights starting from New York were not true global circumnavigations because they terminated at San Francisco. The 21,642-mile flight included stops at Gander, Shannon, London, Istanbul, Karachi, Calcutta, Bangkok, Shanghai, Tokyo, Manila, Guam, Wake, Midway, and Honolulu before reaching San Francisco. In the inaugural flight, passengers were delivered back to New York on July 1.

Jets, Helicopters, and Experimental Craft

The jet airliner began to play a more important role in civil aviation in the early 1960's. On September 4, 1960, Captains J. M. B. Botes and S. Pienaar of South African Airways demonstrated the wide acceptance, sales potential, and superior performance of the Boeing jet airliner when they flew the first Boeing 707-344 to enter service with their airline from Seattle, Washington, to Johannesburg, South Africa. They covered the distance of 11,445 miles in 21 hours and 35 minutes. Boeing revealed the first jumbo jetliner to the public in 1969, and that aircraft in particular occupies a prominent place in the history of transglobal flight. Its large size and long range made it a virtual icon of long-distance air travel. On October 30, 1977, a Pan American Boeing 747SP completed a round-the-world flight over the North and South Poles, carrying 165 passengers a distance of 26,382.75 miles in 54 hours, 7 minutes, and 12 seconds. Flying from and to San Francisco, the aircraft stopped at London, England; Cape Town, South Africa; and Auckland, New Zealand, and set a record for circumnavigating the globe via the poles.

The 1980's witnessed record-setting flights by helicopters and other types of aircraft as well. On September 30, 1982, the world's first circumnavigation by helicopter was completed when American pilots H. Ross Perot, Jr., and Jay Coburn landed their Bell 206L LongRanger at Love Field, Dallas, Texas, from where they had departed on September 1. They had covered 26,000 miles in twenty-nine stages flying over twenty-three countries. Another milestone in aviation history was made when Dick Rutan and Jeana Yeager completed the first nonstop unrefueled flight around the world in a heavier-than-air flying machine. In a flight that began on December 14 at Edwards Air Force Base in California, the Rutan *Voyager* covered 24,986.664 miles in 9 days, 3 minutes, and 44 seconds, at an average speed of 115.8 miles per hour. Flying west, the machine traveled across the Pacific, the north coast of Australia, the Indian Ocean, the southern tip of Africa, the Atlantic, and up the coast of South America and Mexico.

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See also: Boeing; Commercial flight; Experimental aircraft; Jet engines; Charles A. Lindbergh; McDonnell Douglas; Wiley Post; Record flights; Burt Rutan; Seaplanes

Transport aircraft

Definition: Commercial aircraft designed to carry passengers and cargo in addition to a pilot and crew.

Significance: Early airplanes, which labored under severe weight restrictions, could only carry a pilot and perhaps a copilot or navigator. As aviation technology improved, planes could be built with increasing capacity for passengers and cargo, making flight a practical means of transportation.

Boeing B-1

The Boeing B-1 was a flying boat with its engine located at the rear. It could carry one pilot and two passengers, as well as mail or cargo. The hull consisted of laminated wood veneer, and the wing frames were spruce and plywood. It outlasted six engines in eight years of international airmail runs between Seattle and Victoria, British

Columbia. The maiden flight of this aircraft occurred in December 27, 1919. The civil flying boat had a wingspan of 50 feet 3 inches, a length of 3l feet 3 inches, and a gross weight of 3,850 pounds. Its top speed was 90 miles per hour and its cruising speed 80 miles per hour. Its range was 400 miles and its ceiling 13,300 feet. The propulsion system consisted of either one 200-horsepower Hall-Scott L-6 or one 400-horsepower Liberty engine.

Boeing Model 40A

The Model 40A used an air-cooled Pratt & Whitney Wasp engine that was about 200 pounds lighter than the water-cooled engines used to power its competitors. The biplane used welded-steel tubing throughout its fuselage but could still carry a heavier load and was less expensive to operate. This was the first Boeing airplane to carry passengers, with room for two people in a tiny cabin, as well as cargo space for mail. Twenty-four of the mail planes built were ready to fly on July 1, 1927, for their first day of airmail service between San Francisco and Chicago. The twenty-fifth was delivered to Pratt & Whitney as a flying testbed.

This commercial transport first flew on May 20, 1927. It had a wingspan of 44 feet 2 inches, a length of 33 feet 2 inches, and a gross weight of 6,000 pounds. Its top speed was 128 miles per hour and its cruising speed was 105 miles per hour. Its range was 650 miles and its ceiling 14,500 feet. Propulsion consisted of one 420-horsepower Pratt & Whitney engine. It could accommodate one pilot, two passengers, and 1,200 pounds of mail.

Boeing Model 80

In 1928, Boeing introduced America's first airliner designed specifically for passenger comfort and convenience. The Model 80's fuselage was made of welded-steel tubing covered with fabric, and its wooden wingtips were removable so that the airplane could fit into the hangars along its route. Despite complaints by pilots accustomed to flying in an open cockpit, the size of the Model 80 required a separate, enclosed flightdeck. The Model 80 carried passengers in a spacious cabin appointed with leather upholstery, reading lamps, forced-air ventilation, and hot and cold running water. The first version carried twelve people, and it was followed by the larger, eighteen-passenger Model 80A, which made its first flight on September 12, 1929. Ten Model 80A's flew for the Boeing airlines.

Ellen Church, a registered nurse, convinced Boeing managers that women could work as stewards, so nurses serving aboard the Model 80A became aviation's first female flight attendants. They earned $125 for flying one hundred hours per month. This commercial transport first flew on July 27, 1928. It had a wingspan of 80 feet, a length of 56 feet 6 inches, and a gross weight of 17,500 pounds. Its top speed was 138 miles per hour and it cruised at 125 miles per hour. It had a range of 460 miles and a ceiling of 14,000 feet. Propulsion consisted of three 525-horsepower Pratt & Whitney Hornet engines. It accommodated three crew, eighteen passengers, and 898 pounds of cargo.

Boeing Monomail

In 1930, Boeing created the revolutionary Monomail, which made traditional biplane construction a design of the past. The Monomail wing was set lower, was smooth, made entirely of metal, and had no struts. The retractable landing gear, the streamlined fuselage, and the engine covered by an antidrag cowling added up to an advanced, extremely aerodynamic design. The Monomail Model 200 was a mail plane, and the Model 221 was a six-passenger transport. Both were later revised for transcontinental passenger service as Model 221A's.

The major drawback of the Monomail was that its design was too advanced for the engines and propellers of the time. The airplane required a low-pitch propeller for take-off and climb and a high-pitch propeller to cruise. By the time the variable-pitch propeller and more powerful engines were available, the Monomail was being replaced by newer, multiengine planes that it had inspired.

This mail and cargo carrier first flew on May 6, 1933. It had a wingspan of 59 feet 1 inch, a length of 4l feet 10 inches, and a gross weight of 8,000 pounds. Its top speed was 158 miles per hour and it cruised at 135 miles per hour. It had a range of 575 miles and a ceiling of 14,700 feet. Propulsion consisted of one 575-horsepower Pratt & Whitney Hornet B engine. It accommodated one pilot and approximately 1,500 pounds of cargo.

Boeing Model 247

The Model 247, developed in 1933, was an all-metal, twin-engine airplane and the first modern passenger airliner. It had an autopilot, pneumatically operated deicing equipment, a variable-pitch propeller, and retractable landing gear. It took the Model 247 20 hours, with seven stops, to fly between New York and Los Angeles. However, because the 247 flew at 189 miles per hour, its trip was seven-and-a-half hours shorter than that made by any previous airliners.

Seventy-six Model 247 aircraft were built. Boeing Air Transport flew sixty Model 247's. United Aircraft Corporation flew ten, and the rest went to Lufthansa and to a private owner in China. The 247's remained in airline service until World War II, when several were converted into C-73 transports and trainers. Some were still in use in the late 1960's. Along with the Douglas DC-2 that supplanted it, the Model 247 ushered in the age of speed, reliability, safety, and comfort in air travel.

This Boeing commercial transport aircraft first flew on February 8, 1933. It had a wingspan of 74 feet, a length of 51 feet 7 inches, and a gross weight of 13,650 pounds. Its top speed was 200 miles per hour, while it cruised at 189 miles per hour. Its range was 745 miles and its ceiling was 25,400 feet. Propulsion consisted of two 500-horsepower Pratt & Whitney Wasp engines. It could accommodate three crew members, ten passengers, and four hundred pounds of mail.

Douglas DC-1

The introduction of the DC-1 in 1933 marked the beginning of sixty-four years of continuous production of passenger planes by the Douglas Aircraft Company. It was designed as a series prototype for TWA to compete against the revolutionary Boeing Model 247 ordered by Boeing subsidiary United Air Lines. The DC-1 exceeded all but one of the tough specifications set by its buyer—TWA wanted three engines; the DC-1 had only two. The DC-1 was very advanced for its day. Its fuselage was streamlined, as were its wings and engine cowlings. It featured all-metal construction and retractable landing gear. Variable-pitch propellers gave the plane remarkable takeoff and landing characteristics. With plush seats, a kitchen, and a comfortable restroom, the DC-1 set a new standard for passenger comfort.

Great efforts were made to insulate the passenger compartment from the noise of the plane's engines. The plane's passengers seats were mounted on rubber supports, while the cabin was lined with noise-absorbing fabric. Carpet covered the cabin floor and even the engines were mounted on rubber insulators.

The DC-1 carried twelve passengers (two more than the Model 247) and could fly as fast as 180 miles per hour. In April, 1935, it set a transcontinental speed record, covering the distance from Los Angeles to New York in 11 hours, 5 minutes. Pleased with the new plane, TWA placed an order for twenty-five larger aircraft, designated the DC-2. Enlarged once more, the DC-2's basic design evolved into the world-famous DC-3. For all of the DC-1's historical significance, only one was built.

The DC-1 first flew on July 1, 1933. It had a wingspan of 56 feet, a length of 60 feet, and a height of 16 feet. Its gross weight was 17,500 pounds. The plane had a ceiling of 23,000 feet and a range of 1,000 miles. Propulsion consisted of two 710-horsepower Wright engines and the plane flew at 190 miles per hour. It could accommodate two crew and twelve passengers.

Douglas DC-2

Inspired by the success of the DC-1, the DC-2 was introduced less than a year after the DC-1's first flight. The new plane was similar in shape to the DC-1 but had more powerful engines, was faster, and was capable of longer flights. More importantly, it was two feet longer and could carry two more passengers. The DC-2 was an instant hit. In its first six months of service, the DC-2 established nineteen American speed and distance records. In 1934, TWA put DC-2's on overnight flights from New York to Los Angeles. Called the Sky Chief, the flight left New York at 4 P.M. and, after stops in Chicago, Kansas City, and Albuquerque, arrived in Los Angeles at 7 A.M. For the first time, the air traveler could fly from coast to coast without losing the business day.

The DC-2 was the first Douglas airliner to enter service with an airline outside of the United States. In October, 1934, KLM Royal Dutch Airlines entered one of its DC-2's in the London-to-Melbourne air race. It made every scheduled passenger stop on KLM's regular 9,000-mile route (1,000 miles longer than the official race route), carried mail, and even turned back once to pick up a stranded passenger. Yet the DC-2 finished in second place behind a racing plane especially for the competition. After that, the DC-2's reputation was assured and it became the airplane of choice for many of the world's largest airlines. In 1935, the DC-2 became the first Douglas aircraft to receive the prestigious Collier Trophy for outstanding achievements in flight. Between 1934 and 1937, Douglas built 156 DC-2's at its Santa Monica, California, plant.

This transport aircraft first flew in 1934. It had a wingspan of 62 feet, a length of 61 feet 11.75 inches, and a height of 16 feet 3.75 inches. Its ceiling was 22,450 feet and it had a range of 1,000 miles. Gross weight of the aircraft was 18,560 pounds. Propulsion consisted of two 875-horsepower Wright Cyclone engines. The speed of the plane was 200 miles per hour. It accommodated three crew members and fourteen passengers and could carry 3,600 pounds of cargo.

Douglas DC-3

The DC-3, which made air travel popular and airline profits possible, is universally recognized as the greatest airplane of its time. Indeed, some would argue that it is the greatest airplane of all time. Design work began in 1934 at the insistence of C. R. Smith, president of American Airlines. Smith wanted two new planes, a longer DC-2 that would carry more day passengers, and one with railroad-type sleeping berths, to carry overnight passengers.

The first DC-3 built was the Douglas Skysleeper Transport, and it was the height of luxury. Fourteen plush seats in four main compartments could be folded in pairs to form seven berths, while seven more folded down from the cabin ceiling. The plane could accommodate fourteen overnight passengers or twenty-eight passengers on shorter daytime flights. The first was delivered to American Airlines in June, 1936, followed two months later by the first standard twenty-one-passenger DC-3.

In November, 1936, United Air Lines, which had been a subsidiary of Boeing until 1934, became the second DC-3 customer. The DC-2 had proved more economical than the Model 247 and United assumed the DC-3 would continue that lead. Initial orders from American and United were soon followed by orders from more than thirty other airlines in the next two years. The DC-3 was not only comfortable and reliable, it also made air transportation profitable. American Airlines' C. R. Smith said the DC-3 was the first airplane that could make money just by hauling passengers, without relying on government subsidies. As a result, by 1939, more than 90 percent of the nation's airline passengers were flying on DC-2's and DC-3's.

In addition to the 455 DC-3 commercial transports built for the airlines, 174 were produced as military transports during World War II. For both airline and military use, the DC-3 proved to be tough, flexible, and easy to operate and maintain. Its exploits during the war became the stuff of legend. This plane first flew on December 17, 1935. It had a wingspan of 95 feet, a length of 64 feet 5.5 inches, and a height of 16 feet 3.6 inches. Its ceiling was 20,800 feet, it had a gross weight of 30,000 pounds, and its range was 1,495 miles. Propulsion consisted of two 1,200-horsepower Wright Cyclone radial engines. Its speed was 192 miles per hour. It could accommodate three crew members and fourteen sleeper passengers, or twenty-one to twenty-eight day passengers, or 3,725 to 4,500 pounds of freight.

Boeing Model 314 Clipper

As airplane travel increased in popularity during the mid-1930's, passengers wanted to fly across the ocean, so Pan American Airlines asked for a long-range, four-engine flying boat. In response, Boeing developed the Model 314, nicknamed the "Clipper" after the great oceangoing sailing ships. The Clipper used the wings and engine nacelles (separate streamlined enclosures for housing the crew, cargo, or engines) of the giant Boeing XB-15 bomber on the flying boat's towering, whale-shaped body. The installation of new Wright 1,500-horsepower Double Cyclone engines eliminated the lack of power that handicapped the XB-15. With a nose similar to that of the modern 747, the Clipper was the jumbo airplane of its time.

The Model 314 had a 3,500-mile range and made the first scheduled transatlantic flight on June 28, 1939. By the year's end, Clippers were routinely flying across the Pacific. Clipper passengers looked down at the sea from large windows and enjoyed the comforts of dressing rooms, a dining salon that could be turned into a lounge, and even a bridal suite. The Clipper's seventy-four seats converted into forty bunks for overnight travelers. Four-star hotels catered gourmet meals served from its galley.

Boeing built twelve Model 314's between 1938 and 1941. At the outbreak of World War II, the Clipper was drafted into service to ferry materials and personnel. Few other aircraft of the day could meet wartime distance and load requirements. U.S. president Franklin D. Roosevelt traveled by Boeing Clipper to meet British prime minister Winston Churchill at the Casablanca conference in Casablanca, Morocco, in January, 1943. On the way home, President Roosevelt celebrated his birthday in the flying boat's dining room.

This commercial transport had a wingspan of 152 feet, a length of 106 feet, and a gross weight of 84,000 pounds. Its top speed was 199 miles per hour while its cruising speed was 184 miles per hour. Its range was 5,200 miles and its ceiling 19,600 feet. Propulsion consisted of four 1,600-horsepower Wright Twin Cyclone engines. It had a crew of ten and carried seventy-four passengers.

Boeing Model 307 Stratoliner

The Model 307 Stratoliner was the world's first high-altitude commercial transport and the first four-engine airliner in scheduled domestic service. With names like *Rainbow*, *Comet*, *Flying Cloud*, and *Apache*, the Stratoliner set new standards for speed and comfort. Its pressurized cabin allowed the airplane to soar above rough weather at an altitude of 20,000 feet—higher than any other transport of its time. Its circular fuselage provided maximum space for the five crew members and thirty-three passengers. The nearly twelve-foot-wide cabin had space for comfortable berths for overnight travelers.

The Stratoliners attracted the attention of multimillionaire Howard Hughes, who bought one for himself and transformed it into a "flying penthouse" with a master bedroom, two bathrooms, a galley, a bar, and a large living room. Hughes sold it to a Texas oil millionaire, and it ended its days as a palatial, Florida-based houseboat. The Stratoliner was the first airplane to have a flight engineer as a member of the crew. The engineer was responsible for maintaining power settings, pressurization, and other subsystems, leaving the pilot free to concentrate on other aspects of flying the aircraft. Boeing built ten Stratoliners. In 1940, the 307's started flying routes to South America and from New York to Los Angeles. Production stopped at the onset of World War II, and flyers were drafted into the Army Transport Command as C-75 military transports.

This commercial and military transport first flew on December 31, 1938. It had a wingspan of 107 feet 3 inches, a length of 74 feet 4 inches, and a gross weight of 42,000 pounds. Its top speed was 246 miles per hour and it cruised at 220 miles per hour. It had a range of 2,390 miles and a ceiling of 26,200 feet. Propulsion consisted of four 1,000-horsepower Wright Cyclone engines. It accommodated a crew of five and thirty-three passengers.

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See also: Airplanes; Boeing; Commercial flight; DC plane family; McDonnell Douglas; Military flight

Triplanes

Definition: An aircraft design employing three wings, usually stacked one atop another.

Significance: The triplane was an unconventional airframe design built during World War I, providing superior lift, rate of climb, and maneuverability compared to its monoplane and biplane contemporaries. The triplane is considered to have been one of the most radical designs in aviation history.

Development and Design Characteristics

By the end of 1915, aerial combat had defined itself enough to give aircraft designers a working knowledge of combat aircraft requirements. Combat aircraft needed the best possible combination of fast rate of climb, tight maneuverability, strength, and as much speed as available engines could provide.

In 1916, in an attempt to counter highly effective German aircraft designs, the British Sopwith Company decided to try a radical new design: the three-winged airplane. Though a departure from conventional designs, the three-winged triplane proved to be light, fast, and a good climber. Pilots found the Sopwith Triplane to have phenomenal maneuverability, and its narrow-chord wings gave pilots a good field of view, while the combined area of the three wings gave enough lift to out-climb and out-turn any aircraft in production by either side. The Sopwith Triplane was also 15 miles per hour faster than its nearest competitor, and was the first Allied fighter plane to have two forward-mounted, synchronized machine guns. Raymond Collishaw, a Canadian pilot flying with the Royal Naval Air Service, used a Sopwith Triplane to down sixty enemy aircraft, ranking him third on Britain's ace list. Only 150 Sopwith Triplanes were built, and by the end of 1917 they were replaced by the biwinged Sopwith Camel.

The Fokker Triplane

The Fokker Dreidecker (three-winger) was designed by Reinhold Platz in response to the Sopwith Triplane. The Fokker was lightly loaded, fast-climbing, and highly maneuverable and first saw service in August, 1917, by Lieutenant Werner Voss, one of Germany's leading aces and a member of *Jagdgeschwader Nr 1*, nicknamed the Flying Circus. Apart from the Sopwith Camel, the diminutive Fokker Dr-I triplane was the only other World War I fighter plane to hold the public's imagination. Its fame was due largely to the exploits of another member of the Flying Circus, Germany's leading ace, Baron Manfred von Richthofen, the "Red Baron," who fought and died flying his crimson Fokker Dr-I. The Dr-I had a relatively short combat life. Only about 320 Dr-I's were built before it was withdrawn from service due to structural failures.

Other fighter triplane designs that were less successful during the war were the British Blackburn triplane, which never saw production; and the German two-seater Pfalz Dr.1, of which only ten were manufactured. A successful triplane not put to fighter use was the Italian Caproni Ca.42 heavy bomber. Introduced in 1918, thirty-two Caproni Ca.42's were built, six of which saw service with the British. The airplane had a wingspan of 98 feet and stood nearly 21 feet tall. Its slow top speed of only 78 miles per hour made it vulnerable to fighter attack, limiting its use to night-time bombing raids.

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See also: Airplanes; Bombers; Fighter pilots; Fokker aircraft; Manfred von Richthofen; Sopwith Camels; Wing designs

Konstantin Tsiolkovsky

Date: Born on September 17, 1857, in Izhevskoye, Russia; died on September 19, 1935, in Kaluga, Russia, Soviet Union

Definition: Russian scientist who is considered the founding father of rocket theory.

Significance: Tsiolkovsky was the first scientist to discover the mathematical theories of rocketry and astronautics upon which modern space travel is based.

Born in 1857 in the remote village of Izhevskoye, Russia, Konstantin Eduardovich Tsiolkovsky would become the founding father of modern rocketry. Growing up in a modest family with a Polish father and Russian mother, he was an avid reader and had an early interest in mathematics and science. As young child, he contracted scarlet fever, which resulted in his near deafness. When he was sixteen, he was sent by his father 600 miles away to Moscow, where he combined university studies with a self-taught education. He later moved to Kaluga to become a teacher and remained there until his death in 1935.

Tsiolkovsky first became interested in both aeronautics and astronautics, or cosmonautics as it is known in Russia, in Moscow, but he did not follow up on his interests until he accepted a teaching post in Borovsk. At this time, he began a life-long investigation of the theory of gases and reactive motion. In 1897, he built the first Russian wind tunnel in Kaluga to examine the aerodynamic forces on dirigibles, and he completed extensive wind-tunnel tests on various dirigible and aircraft designs. His aviation work did not meet with much scientific interest, however, and it was only after he began publishing his thoughts on space travel in the 1890's that he seriously turned his attention to rocketry.

Tsiolkovsky developed his first rocket design in 1903. It was a liquid-fueled design using one liquid for fuel and another as the oxygenator. His favored propellant mixture, combining liquid hydrogen and liquid oxygen, is still used today on the space shuttle. Tsiolkovsky's design included several advanced concepts, such as regenerative cooling, whereby the fuel was ducted around the hot exhaust nozzle prior to combustion to both cool the nozzle and preheat the fuel, and directional control, using exhaust guide vanes and gyroscopes.

Tsiolkovsky's later work included theoretical calculations of launch trajectories, escape velocities, travel times to planetary bodies, multistage rockets, and atomic- and solar-powered satellites. This work included the derivation of the rocket equation, in which Tsiolkovsky showed that rocket velocity was a function of exhaust velocity and change in rocket mass due to expended fuel. He designed extensive systems for crewed spaceflight, including living quarters and greenhouses for extended trips. He also published many science fiction stories focusing on space travel. Although he continued to develop theories for rocket design and spaceflight throughout his lifetime, he never actually built a rocket himself.

Although Tsiolkovsky was acknowledged by the Soviet Union after his death as the father of cosmonautics, his theories were not widely publicized and his contributions not well known, particularly because Hermann Oberth and Robert H. Goddard had arrived at similar derivations independently in Germany and the United States, respectively. However, for his many theories on rocket design and his realistic but creative concepts of spaceflight, Tsiolkovsky is widely attributed as the first of the three founding fathers of modern rocketry.

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See also: Aerodynamics; Astronauts and cosmonauts; Crewed spaceflight; Robert H. Goddard; Hermann Oberth; Rocket propulsion; Rockets; Russian space program; Satellites; Spaceflight; Wind tunnels

Andrei Nikolayevich Tupolev

Date: Born on November 10, 1888, in Pustomazovo, Russia; died on December 23, 1972, in Moscow, Soviet Union

Definition: The foremost aircraft designer of the Soviet Union.

Significance: Tupolev was the first to design all-metal aircraft in the Soviet Union. During World War II, his team developed several medium and heavy bombers that contributed to the defeat of Germany. After the war, he developed Soviet jet engines and the world's first supersonic plane, the Tu-144.

Born in 1888 to a middle-class provincial family, Andrei Nikolayevich Tupolev entered the Imperial Moscow Higher Technical School in 1908, where he studied under famed Russian aerodynamist Nikolai Zhukovsky. While a student there, Tupolev and a group of friends formed a small syndicate and built a series of gliders. In the 1917 Russian Revolution, Tupolev sided with the Bolsheviks, who seemed to embrace modernity and technological progress more than other political groups. In 1918, Tupolev graduated and, with his mentor Zhukovsky, set up the Central Aerohydrodynamic Institute (abbreviated TsAGI). From 1918 to 1935, Tupolev served as the assistant director of TsAGI and as its chief designer. His ANT-2, produced in 1924, was the first Soviet all-metal aircraft. In the 1920's, Tupolev was the main Soviet proponent of heavy long-range aircraft and, during the 1930's, Tupolev's design bureau developed the long-range ANT-25, a plane that was used to set several long-distance aviation records. In 1936, Tupolev traveled to both Germany and the United States in order to study their aircraft industries.

On October 21, 1936, Tupolev was arrested as part of Stalin's purges. He was charged with selling blueprints to Germany for the Messerschmitt Bf-110 and, from 1939 to 1941, Tupolev worked in a special prison aviation workshop. The prison team developed several airplanes that eventually played a great role during World War II, such as the Pe-2 and the Tu-2 attack bomber. He was freed when Nazi Germany invaded the Soviet Union in 1941 and in 1943 his Tu-2 airplane was awarded a Stalin Prize.

After World War II, Tupolev was charged with developing a copy of the American B-29 Superfortress. The resulting Tu-4 was the first Soviet strategic bomber. In the 1950's, Tupolev designed a series of jet bombers as well as large civilian passenger aircraft for the Soviet airline, Aeroflot. He was also responsible for the Tu-144, the world's first supersonic transport.

Tupolev died on December 23, 1972, and in 1988 he was inducted into the International Aerospace Hall of Fame.

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See also: Aerodynamics; Aeroflot; Airplanes; Bombers; Manufacturers; Superfortress; Supersonic aircraft; World War II

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Turbojets and turbofans

Definition: Turbojets are jet engines that are turbocharged. Turbofans are turbojets onto the front end of which a large fan is added.

Significance: Turbojets are used in most airplanes that are large and travel for long distances. They are also used in military applications such as bombers and special surveillance aircrafts. Turbofans generate more thrust than turbojets. For this reason, they are used to power jumbojets.

Propeller engines are suited for small airplanes that travel for short distances. Turbojets provide transport capabilities that propeller engines cannot. The McDonnell FH-1 Phantom was the first all-jet airplane ordered by the U.S. Navy and the Navy's first airplane to fly 500 miles per hour. Its first flight took place on January 26, 1945. On July 21, 1946, an FH-1 Phantom became the first jet-propelled combat aircraft to operate from an American aircraft carrier. The Phantom weighed 10,035 pounds, could accommodate one crew member, had a range of 695 miles, and was powered by two turbojets, the Westinghouse J30-WE-20, each of which could deliver 600 pounds of thrust. A year later, the thrust delivered by turbojets had doubled. By the end of the 1950's, the turbojets could deliver thrusts that were twenty times that delivered by the J30-WE-20.

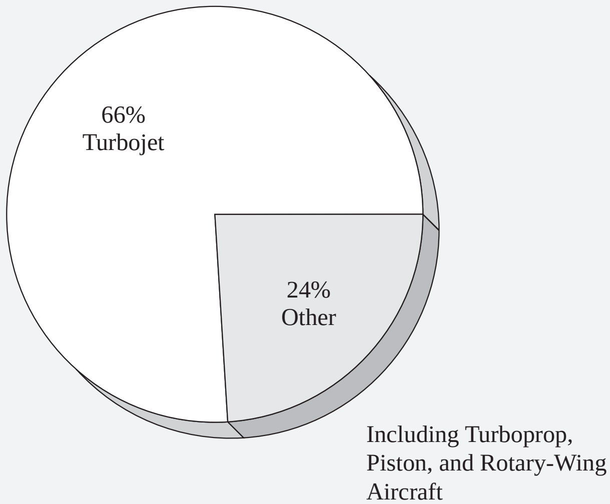
Basic Operation of a Jet Engine

An appreciation of how a jet engine works requires understanding Bernoulli's principle, Sir Isaac Newton's third law of motion, and how these two ideas from physics come into play in the operation of a jet engine.

For ordinary commercial and pleasure flights, air is treated as an incompressible substance that has no viscosity, and the level flight is treated as steady. Under these circumstances, a principle of physics called Bernoulli's principle states that the sum of three forms of energy remains constant. These three forms are kinetic energy (energy associated with the motion of air), potential energy (that associated with weight and elevation above or below a reference level), and the energy associated with pressure. Air is a very light substance; it is conventional to neglect its potential energy because its contribution is typically very small compared to those of the other two forms of energy. Accordingly, when kinetic energy increases, pressure energy must decrease by the same amount, and vice versa.

Sir Isaac Newton formulated three laws of motion. Propulsion generated by a jet engine operates according to Newton's third law of motion. It states that for every action there is a reaction. The reaction is equal to the action in magnitude but opposite to it in direction. This law can be seen in operation in many ordinary ways. For instance, walking involves planting a foot and pushing backward

Percentage of Turbojets Among All Aircraft Reported in Operation by Air Carriers, 1996



Source: Federal Aviation Administration, *Statistical Handbook of Aviation*, 1996.

(action). The ground provides the reaction by pushing forward against the foot in order to create the thrust that makes walking possible. When a surface is slippery, this really means that its ability to provide a reaction is limited and that walking on that surface has become treacherous. As another example, if one inflates a small balloon but does not tie the open end shut before releasing the balloon, after release, the air inside the balloon will want to rush out of it. As it does so, a thrust will be created, helping the balloon sail forward for some time until most of the air has escaped. A jet airplane works a little bit like the inflated balloon. In a jet, a mechanism must be created to introduce air into the plane and release it in such a way that thrust is continuously created.

A jet engine utilizes jet propulsion, which is a kind of propulsion in which the force needed to move the body of the aircraft comes from discharging a jet of fluid from the body at high speed. As the fluid jet leaves the body, it produces a reaction force against the body and it is this force that propels the body forward, according to Newton's third law of motion.

Jet engines include turbojets, turboprops, ramjets, scramjets, and rockets. Rockets carry all they need with them to generate combustion. Therefore, they can operate in space because they do not need air to function. The other jet engines require air to operate properly. It is for this reason that they belong to a class called air-breathing propulsion, or simply air-breathing machines. They utilize the mechanical behavior of air in their operation.

The propulsion system of a jet engine consists of an inlet diffuser, a compressor, a fuel injection system, a combustion chamber (also called a combuster), a turbine, and an exhaust nozzle. A jet engine slows down incoming air as it enters the engine; that is, it causes a decrease in kinetic energy. Thus, the air pressure increases according to Bernoulli's principle.

The air goes through a series of compressor blades that look somewhat like fan blades. These blades help push the air forward, giving it new energy by doing work on them. This work increases the pressure energy of the air and thereby adds to the total energy. This high-pressure air enters the combustion chamber, where it is mixed with fuel, ignited, and burned. The hot gases resulting from this combustion want to expand and they leave the combustion chamber at very high speed and pressure. On their way out of the engine, the hot gases go through the blades of a turbine. They drive the turbine by pushing against its blades like a high wind blowing past a windmill. The turbine drives the compressor because the two units are connected to each other by a shaft. The movement of the compressor compresses the air that enters the engine. As the exhaust gases leave the engine, they exert a thrust that propels the airplane forward while the gases travel backward, again in accordance with Newton's third law of motion (action equals reaction). These exhaust gases leave the airplane in a fast-moving stream commonly called a jet. That is why this is called a jet engine.

Different Kinds of Engines

There are many different kinds of engines. They are classified a number of different ways. Classification hinges upon how the essential components are designed and the role they play. For example, if combustion takes place inside an enclosure, the engine is called an internal combustion engine. However, if it occurs in the open, the engine is called an external-combustion engine. Internal combustion engines are very common. They are used in planes. They are designed to produce work at high efficiencies. The two main types of internal combustion engines are spark-ignition engines and compression-ignition engines. In spark-ignition engines, the fuel-air mixture is ignited using a spark. In compression engines, there is no spark at all and ignition of the fuel-air mixture is achieved spontaneously. This is achieved by increasing the temperature and pressure of the air inside the combustion chamber using compression. Spark-ignition engines are also called gasoline engines (petrol engines in Great Britain). Compression-ignition engines are also called diesel engines. In order to achieve satisfactory performance of compression-ignition engines, one must control the air motion and the fuel injection in a proper manner. Propeller engines are well suited for low-speed flights, but they do not work as well for high-speed flights for two important reasons: as the forward speed of an aircraft increases, the thrust that propellers provide to move the craft forward decreases and the drag resistance associated with their operation increases. Jet engines do not have these limitations. They were introduced to provide power to aircraft that move at high speeds because they work better at these speeds. Direct-injection engines have less air motion than indirect-injection engines, so, to compensate for this, direct-injection systems use multiholed nozzles with high (three times as high) pressures during the injection process. Ideally, internal combustion engines should have high efficiency, high output and rapid combustion, generate no pollution, and be very quiet. It is very challenging to design engines that would achieve all of these goals. In compression-ignition engines, volume requirements are higher but the combustion process is slower than in spark-ignition engines. For these reasons, the maximum speeds of compression-ignition engines are much lower than those of spark-ignition engines.

Supercharging and Turbocharging

Two effective techniques were found to increase the output of compression-ignition engines: supercharging and turbocharging. An engine is supercharged by supplying pressurized air to it. When the air at the inlet to an engine is pressurized, the mass flow rate of air into the engine increases. Typically, this is associated with an increase in the flow rate of fuel to the engine. These two factors lead to increases in power output and efficiency. Compressors need power to do their work. When a compressor is driven from the crankshaft of an engine, the arrangement is called a supercharger. However, when it is driven by the turbine, the arrangement is called a turbocharger, and the affected engine is said to be turbocharged. Thus, turbocharging is a particular form of supercharging in which a compressor is driven by an exhaust gas turbine. There are thermodynamic advantages to turbochargers over superchargers, principally because the former utilize exhaust gas energy during the so-called blow-down. Turbocharging also reduces the weight per unit output and increases fuel economy.

Work done by the turbine is just sufficient to drive the compressor. Hot gases enter the turbine where they are expanded to a pressure that allows the work done on the turbine to equal that done by the compressor. The pressure of the exhaust gases for the turbine is greater than that of the surrounding air, so the hot gases are expanded further in a nozzle so that their pressure will be lowered to that of the surroundings. The gases leave at high velocity, and thrust is generated by the change in momentum that the gases undergo.

Characteristics and Performance of Turbojets

Nine characteristics are used to describe a turbojet: its weight, its length, its diameter, the number of stages its compressor has, the number of stages its turbine has, the thrust it can deliver at takeoff, the best thrust it can deliver at cruising speeds, its speed range, and its specific fuel consumption. The specific fuel consumption of a turbojet is the amount (in weight) of fuel it consumes per unit weight of thrust delivered, per hour.

The characteristics of the latest models of turbojets are protected carefully by manufacturers because these machines are used for purposes of defense and surveillance. However, older models are available in museums of flight. For example, in the late 1950's, Pratt & Whitney designed the J-58 turbojet engine to be used by the U.S. Navy. Its axial compressor had nine stages, its turbine had two stages, it had an afterburner, and it could provide a takeoff thrust of 32,500 pounds. It weighed 6,000 pounds and operated above 85,000 feet at speeds three times that of sound (Mach 3). The J-58 is currently in the museum of flight at Wright-Patterson Air Force Base.

Turbofans

The turbojet is very successful at increasing the speed of the air that enters the engine, which increases its kinetic energy, but another way to increase the total energy of the air is to increase the amount of air that enters the engine. A turbofan achieves this by mounting a large fan at the inlet to the engine. The design of the turbojet is modified accordingly. The addition of the fan creates two different paths that the incoming air can use to travel through the engine before leaving it. Some of the air follows the path that it would use in a conventional turbojet: from the inlet diffuser, it goes successively through the compressor, or compressors, the combustion chamber, the turbine, and the exit nozzle. The remaining air bypasses the compressor altogether: it goes from the inlet diffuser, around the engine, and directly to the back of the plane. In doing so, it converts the pressure that it stored in the inlet diffuser directly into kinetic energy. Here, again, air leaves the engine traveling faster than when it entered it, and as this air leaves the fan, it exerts thrust on it. This mechanism provides a second thrust that is added to that due to the operation of a turbofan as a conventional turbojet. If one looks at modern jumbojets at airports, their engines look like huge fans. Chances are very high that these engines are turbofans.

Josué Njock Libii

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See also: Airplanes; Jet engines; Manufacturers; Military flight; Turboprops

Turboprops

Also known as: Propjets, jetprops

Definition: A variation of the gas turbine engine that develops thrust with propellers instead of the exhaust duct.

Significance: The turboprop is a very popular aviation engine designed to be fuel-efficient and to propel airplanes at moderately high speeds and altitudes.

History

The idea for using a gas turbine engine to drive an airplane's propeller was first thought of by Sir Frank Whittle. His graduate thesis, written at the RAF Staff College at Cranwell in 1928, predicted the use of turboprops even before the first gas turbine engine had been built. Turbojet engines were developed first and then adapted by adding more turbine blades, a reduction gearbox, and a propeller to become turboprops. The first flight of a turboprop airplane occurred in England on September 20, 1945. The engine was a Rolls-Royce RB50 Trent. It was installed in a modified Gloster Meteor aircraft. The first flight of the Vickers Viscount was made on December 6, 1948. The Viscount became the first turboprop-powered airplane to go into passenger service. The Tupolev Tu-95 was the former Soviet Union's primary nuclear bomber from the mid-1950's into the early 1990's. This Bear bomber set the speed record for a turboprop airplane by flying at 575 miles per hour at 38,000 feet. Many different models of turboprop engines and airplanes are still being manufactured, such as the Raytheon King Air and the Lockheed C-130.

Theory of Operation

Gas turbine engines consist of a compressor, a combustion chamber, and a turbine. These components are collectively referred to as a gas generator, a name arising from the purpose of the parts, which is to generate a stream of high-velocity gas. A turbojet generates all of its thrust from having high-pressure and high-velocity gases leaving the exhaust duct at the back of the engine. A turbojet only has enough turbine blades to extract energy to drive the compressor. A turboprop converts most of the exhaust pressure and velocity into rotational energy by adding extra turbine blades. The extra turbine blades extract energy to drive a reduction gearbox. This reduction gearbox is required so the large propeller will spin at a slower, more efficient speed. The reduction gearbox reduces the revolutions per minute (RPM) of the turbines, typically ten thousand to forty thousand RPM, down to two thousand. The turboprop engine's thrust produced by the exhaust is about 10 percent of the total thrust of the engine. The other 90 percent comes from the propeller. Turboprop and turboshaft engines are nearly identical except for their purpose. Turboprop engines drive propellers to provide forward thrust. Turboshaft engines drive helicopter transmission gearboxes which provide horsepower to drive rotor blades.

Advantages

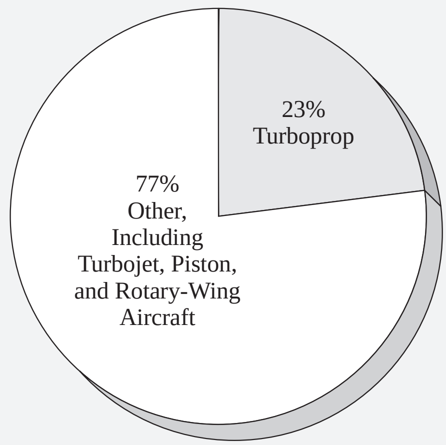
The greatest advantage of the turboprop engine is its high fuel efficiency. It is more fuel-efficient than the two other types of gas turbine engines that propel airplanes: turbojets and turbofans. A turboprop acquires this efficiency from accelerating a large mass of air to only a slightly higher velocity. Turbojets accelerate a small mass of air to a much higher velocity. Less energy from fuel is required to affect mass than to affect velocity. Several advantages for using a turboprop engine to propel an airplane come from the propellers themselves. Turboprops have the shortest takeoffs of any airplane. This capability is provided by the variable pitch of the propeller blades. The use of variable-pitch blades is similar to the use of low gears in a car at slow speeds and the use of higher gears when reaching higher speeds. Unlike a car, this blade pitch is infinitely variable, so the propeller always has the perfect gear ratio. Turboprops can also put the propeller blades into reverse pitch. Although the blades continue to turn in the same direction of rotation, the pitch or angle of the blades change from blowing air backward to blowing air in a forward direction, thereby dramatically slowing the aircraft during landing. When the blade pitch is reversed, more fuel is sent to the engine to increase the amount of reversed airflow. This causes the engine to produce more noise during landing when the blades are reversed. This increase in noise and reversed airflow is similar to thrust reversers used during landing with turbojet and turbofan engines.

Disadvantages

A turboprop airplane's greatest disadvantage is being limited in forward airspeed. This limit is imposed by the use of a propeller. By the time the airplane has reached Mach 0.6, which is 60 percent the speed of sound, the propeller blades have lost much of their aerodynamic efficiency. This efficiency is lost because there is much greater drag on the blade tips at high forward speeds than at slow forward speeds. The combination of speed of the rotating blade with the forward speed of the airplane produces speeds at the blade tips that are close to Mach 1.0. Aerodynamic drag when approaching Mach 1.0 becomes extremely high. To keep the propeller blade tips at slow enough speeds to be efficient, turboprops typically fly at speeds of less than Mach 0.6 (412 miles per hour at 25,000 feet and minus 35 degrees Celsius). Since turbojets and turbofans do not have propellers, most commercial and corporate jets can easily fly at Mach 0.8 to 0.9. In the late 1990's, some smaller airlines started replacing their turboprop-powered airplanes with turbofan-powered airplanes, even though the fuel efficiency of turbofans is not quite as good. This replacement was for two major reasons: passengers feel more comfortable flying in "jets" than in "props," and more revenue-generating flights can be accomplished per day if the airplanes can travel faster.

John C. Johnson

Percentage of Turboprops Among All Aircraft Reported in Operation by Air Carriers, 1996



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See also: Airplanes; Jet engines; Turbojets and turbofans

Tuskegee Airmen

Definition: The 992 African American World War II fighter pilots, and the first African American U.S. military pilots, were so named because they trained at a segregated airfield near Tuskegee, Alabama, and at the Tuskegee Institute in Alabama.

Significance: The Tuskegee Airmen, who served in four fighter squadrons that comprised the 332d Fighter Group, escorted American bombers over North Africa, Italy, and parts of Europe during World War II and garnered an unparalleled record of never having lost one of their escorted bombers to enemy fighters. Their heroic performance was an important factor in President Harry S. Truman's 1948 decision to integrate the U.S. armed forces.

Background

In the late 1930's, American civil rights activists began to campaign for the desegregation of all branches of the U.S. military. Congress passed Public Law 18 in April, 1939, which authorized civilian training of military pilots, with an amendment to apply the law to African Americans. The U.S. Army Air Corps, however, refused to comply with the new law. Congress passed the Civilian Pilot Training Program (CPTC) in June, 1939, and several African American colleges implemented the new program. Almost three thousand African American pilots graduated in just a few years; nevertheless, the Air Corps continued to boycott the acceptance of African American pilots into their program. By 1940, members of an African American pilot organization enlisted the help of Missouri senator Harry S. Truman to sponsor a congressional bill that would allow African American pilots to participate in the CPTC. First Lady Eleanor Roosevelt was committed to the cause of racial equality and helped to convince her husband, President Franklin D. Roosevelt, that the Air Corps should admit African Americans as pilots.

By late 1940, the War Department agreed to the formation of an African American fighter squadron, and in January, 1941, the Corps accepted its first group of African American cadets. The Air Corps plan, in an effort to determine whether African Americans were skillful and intelligent enough to become military pilots, called for the men to train at the Tuskegee Institute at Tuskegee, Alabama, and to do their combat flight training at Tuskegee Army Air Field, then under construction. The Tuskegee Institute, founded by Booker T. Washington in 1881 as a training school for African American teachers, was recognized as

Image Not Available

an ideal location for a flight school because the weather was good for nearly year-round flying and the grounds had ample room for an airfield.

The Ninety-ninth Pursuit Squadron was formed with an initial thirty-three African American officer pilots, who were all college graduates, and four hundred support crew. The first class, led by Lieutenant Colonel Benjamin Davis, Jr., graduated on March 7, 1942; subsequent classes graduated every five weeks. Less than two months later, a second fighter squadron, the One Hundredth, was activated. Because the War Department had no specific plans for the Tuskegee pilots after they completed their training, the Ninety-ninth and One-Hundredth fighter squadrons were not sent overseas after they graduated. Disappointed that they had not yet been sent into combat, morale among the men was low. In March, 1943, Eleanor Roosevelt again intervened and contacted Secretary of War Stimson. By the following month, the Ninety-ninth was deployed to North Africa, more than a year after they had earned their Army Air Corps wings.

Role in World War II

Based in Tunis, Tunisia, the pilots of the Ninety-ninth escorted B-17 and B-24 bombers over the Italian islands in the Mediterranean south of Sicily. The first Tuskegee pilot to shoot down an enemy aircraft was Captain Charles B. Hall, who downed a German Focke-Wulf 190 on July 2, 1943.

Lieutenant Colonel Davis was ordered to return to Tuskegee, Alabama, in September, 1943, to command the three African American squadrons, the 100th, the 301st, and the 302d, that would comprise the 332d Fighter Group. After the 332d Fighter Group had completed training, the three squadrons, under the command of Davis, were deployed in February, 1944, to an air base near Naples, Italy. The 332d was attached to the Fifteenth Air Force in June, 1944, at which time the 99th joined the 332d as the fourth squadron of the fighter group. The African American fighter pilots were assigned to escort U.S. bombers in their missions over the Balkans and parts of Germany, France, Italy, and Spain. Because the pilots of the 332d painted the tails of their P-47 Thunderbolts red, the bomber crews called the pilots the “Red Tails” and later the “Red-Tail Angels” because of the Tuskegee Airmen’s growing reputation for protecting the bombers.

As the end of the war approached, the 332d was involved in the final Allied offensive. The Tuskegee pilots escorted the B-17’s of the Fifteenth Air Force from Italy to Berlin and back. They flew their last mission in April, 1945, one month before the end of the war in Europe. Altogether the 452 pilots that had been sent overseas had flown more than 15,000 sorties and 1,500 missions with the Twelfth Tactical U.S. Army Air Force and the Fifteenth Strategic U.S. Army Air. They had suffered the loss of sixty-six pilots, and thirty-three others were prisoners of war. The group received more than 150 Distinguished Flying Crosses, 1 Legion of Merit, the Red Star of Yugoslavia, 8 Purple Hearts, 14 Bronze Stars, 744 Air Medals and clusters, and 3 distinguished unit citations. They had flown the most combat missions in Europe with the impressive distinction of never having lost one bomber to the enemy.

African American bomber pilots of the 477th Bombardment Group, a program that had begun at Tuskegee in September, 1943, were training for duty in the Pacific, but the war ended before these pilots could enter combat. The 477th is nevertheless remembered for its challenge to the harsh segregationist policies at Freeman Field, Indiana. More than one hundred African American officers entered the segregated officer’s club on the base. They were arrested but later released; the three men who were court-martialed were found not guilty. In 1995, the Air Force finally cleared the records of the African American men involved in the April, 1945, incident that came to be known as the “Freeman Field Mutiny.”

The War’s Aftermath

The 332d Fighter Group was deactivated after the war, but the 477th was renamed the 477th Composite Group under the command of Colonel Davis and remained a segregated part of the Air Force until July 26, 1948, when President Truman issued Executive Order 9981 mandating the desegregation of the U.S. armed services. African Americans were gradually accepted in all branches of the military and later fought alongside whites in the Korean, Vietnam, and Gulf Wars. In 1988, the U.S. Air Force Academy dedicated a life-sized bronze statue of a Tuskegee Airman in the academy’s Honor Court to commemorate the valiant Tuskegee Airmen of World War II.

Ellen Elghobashi

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See also: Air Force, U.S.; Bombers; Fighter pilots; Military flight; World War II

U

UFOs

Definition: Aerial objects or optical phenomena seen by an observer who has no explanation for the sighting, even though it may later be rationalized.

Significance: UFOs, or unidentified flying objects, became a subject of major interest and considerable controversy in the decades following World War II. Many sightings, unexplained at the time, caught the public fancy and inaugurated a still-unresolved scientific controversy. Nonscientific explanations of UFO phenomena have ranged from alien visitors, to secret Soviet aircraft, to mass hallucinations. Alleged cases of alien abduction and government secrecy about crashed UFOs recovered and surreptitiously studied have perpetuated the controversy.

Brief History

Although unexplained aerial phenomena have been reported for millennia, the first documented sighting of unidentified flying objects deemed to be aircraft occurred on June 24, 1947. Veteran pilot Kenneth Arnold was flying a private plane over the state of Washington when he observed what appeared to be nine intensely bright objects traveling at extraordinarily high speeds toward Mt. Rainier. He later reported that the objects "flew like a saucer would if you skipped it across the water." News reports picked up the story, headlining the objects as "flying saucers," a misnomer that remained in use until the U.S. Air Force introduced the term "UFO" six years later. Due to the publicity generated by Arnold's sighting, a rash of similar sightings soon broke out over the North American continent.

As stories of flying saucers and potential alien invasions continued to grow, the U.S. Air Force began taking an interest because of possible risks to national security. Commencing in 1948, it began compiling a file of UFO reports termed Project Blue Book. When radar was able to supplement visual sightings of UFOs over Washington, D.C., in July, 1952, the U.S. government established a panel of scientists, under the auspices of the Central Intelligence Agency (CIA), to investigate the information in Project Blue Book. Although its report was classified at the time, later declassification revealed its conclusion that 90 percent of the sightings could be explained as misapprehended natural phenomena such as astronomical bodies, meteorological effects, aircraft, balloons, and birds seen under unusual conditions.

Continuing criticism of the Air Force for allegedly covering up important UFO information or bungling investigations led to the formation of a second panel of scientists in February, 1966, to determine if UFO phenomena warranted further investigation. After several years of intensively studying the most puzzling cases, the team of experts, led by renowned physicist E. U. Condon, published its results as "A Scientific Study of UFOs." Known as the Condon Report, this investigation concluded that, due to a lack of compelling evidence, further extensive study of UFOs could not be justified and any expectation that science would be advanced thereby was misconstrued. Based on the recommendations of the Condon Report, the Air Force officially terminated Project Blue Book in 1969, the same year the report was released; by this time the Air Force had amassed records on 12,618 sightings or related mysterious events.

Because the Condon Report left a number of sightings admittedly unexplained, however, several scientists, principally James McDonald, a University of Arizona meteorologist, and J. Allen Hynek, a Northwestern University astronomer, remained unconvinced by its conclusions. Extremely critical of the cavalier manner in which puzzling cases were explained away and inexplicable sightings summarily dismissed, they believed that the conclusions of the Condon Report were unwarranted and premature. According to Hynek, the residual core of unexplained sightings (about 5 percent) remaining after natural explanations and hoaxes were eliminated constituted some extraordinary new phenomena which should receive serious scientific attention. Although neither McDonald nor Hynek claimed that the unexplained sightings proved the existence of extraterrestrial visitors, they did believe that some novel natural phenomenon was involved which, under proper investigation, could significantly advance the frontiers of science.

Types of UFO Reports

Sightings may be classified into four broad categories: visual sightings in daylight, visual sightings at night, radar sightings, and close encounters or physical evidence. The final category may be subdivided into three types of close encounters. Close encounters of the first type are those in which an observer reports a close-at-hand experience without tangible physical effects; close encounters of the second type, where there are physical effects on objects or people but no contact with the occupants of a UFO; and close encounters of the third type, in which live entities are sighted or contact is made with UFO occupants.

A classic case of a daylight sighting occurred in the early afternoon of January 7, 1948, in Louisville, Kentucky. The State Highway Patrol, responding to calls of residents who reported a strange object moving west at high speeds, alerted officials at nearby Godman Air Force base. The object was soon spotted, but could not be identified. Captain Thomas Mantell, approaching the base in a P-51 plane, saw the object and climbed to 25,000 feet in pursuit. He radioed the control tower that he was chasing a large metallic object moving at 180 miles per hour. Soon after, radio contact with Captain Mantell was lost; an hour later, his crashed plane was found. Although there were rumors at the time that he had been shot down by an alien aircraft, later investigation proved that he had been chasing a 100-foot Skyhook balloon, a classified project then being tested by the U.S. Navy. It was concluded that because the airplane had no oxygen equipment, the captain had lost consciousness at 25,000 feet; without his control, the plane eventually spiraled into a fatal dive.

A classic nighttime sighting is the case of the Lubbock Lights. On the evening of August 25, 1951, three professors in the town of Lubbock, Texas, were observing meteors when they noticed fifteen to twenty lights passing silently overhead from north to south. The lights were yellowish-white with a diffuse glow, moving through a 30-degree arc in about one second. There were no reference points to gauge size and distance, and the professors initially assumed that the objects were flying at an altitude of at least one mile, implying that they were of immense size and moving incredibly fast. The sightings were reported to a news service, which released a sensationalist article with an accompanying, probably faked, photograph completely different from what the professors had observed. Over the next several weeks, the professors made additional sightings and even attempted to obtain the objects' true height by coordinating observations from widely separated observers in the surrounding countryside. Although this experiment failed due to a lack of data (the lights did not appear to the observers), a rancher thirty miles from Lubbock inadvertently solved the mystery when, during his third observation of the lights, some flew low enough for him to recognize them as birds flying south. When one emitted a cry, he identified the familiar call of the plover. Flying overhead for their yearly migration, their oily white undersides reflect the city lights beneath them as a shiny glow. Their glowing breasts created an illusion of large, rapidly moving objects at high altitude.

Although radar images of UFOs are believed by some to be incontrovertible proof of alien spacecraft, several effects can produce false radar echos. These include electronic interference and reflections from ionized layers or cumulus clouds. The most famous case of radar phantoms was the "invasion" of Washington, D.C., on the nights of July 19 and July 26, 1952. At 11:40 P.M. on July 19, a group of seven unidentified, erratically moving targets appeared on the radarscope at the Washington National Airport. Although visual sightings from ground and air were attempted, no strange aircraft were spotted. The next day, the press reported that a fleet of flying saucers had invaded Washington, intensifying the UFO mania sweeping the nation that summer. The entire process occurred again one week later, but this time the Air Force dispatched fighter planes to search out the invaders. No visual counterpart to the radar images could be found. Eventually the facts were sorted out, and it was determined that the radar images had been caused by weather. A severe drought and unrelenting heat wave had produced intensely hot days followed by rapid cooling at night, creating temperature inversions with abnormal distributions of moisture; these conditions readily generate false radar images. Although such images had been observed many times before, it was probably the flying saucer mania then sweeping the United States which allowed these events to escalate to the status of a UFO "invasion."

Close Encounters

One of the most famous examples of a close encounter of the third kind is the UFO sighting and alleged abduction story of Barney and Betty Hill on the night of September 19, 1961. About 11:00 P.M., while driving through the White Mountains of New Hampshire, the couple saw a large, disk-shaped object in the sky which they stopped to observe. They had no further memories of the event, but upon returning home at 5:00 A.M. they could not account for two hours of their trip. Ten days later, Betty began having repeated nightmares in which she and her husband were taken aboard a UFO and subjected to physical examinations, and Barney suffered from insomnia and severe anxiety. Because the feelings and dreams were so vivid and so frightening, the Hills sought psychiatric help, eventually coming under the care of Dr. Benjamin Simon, a prominent psychiatrist specializing in hypnotic therapy. After six months of treatment by time-regression hypnosis, what appeared to be memories of the two lost hours emerged. Hypnosis seemed to confirm Betty's dreams, in which the Hills were abducted by the occupants of an alien spacecraft, undressed, and thoroughly examined by a group of humanoids who even collected skin and hair samples.

In Simon's professional opinion, the abduction story was a hallucination, transmitted so thoroughly from Betty to Barney by recounting her dreams that Barney later remembered it as real. Simon was also convinced, however, that the Hills had indeed experienced something unusual and frightening that night. Some real, but unknown, physical stimulus apparently triggered a psychological response: the terrifying fantasy that produced the repressed memories. Although many natural explanations, such as freak plasma emissions from high-voltage lines, have been proposed to explain this sighting, a lack of collaborating data keeps this case firmly ensconced in the "unknown" category.

Because, in a close encounter experience, there is little chance of mistakenly identifying common objects as UFOs, such cases are extremely important in attempting to understand UFO phenomena. There are only three possible explanations for close encounter reports: hoaxes and practical jokes, hallucinations or psychotic aberrations, or real experiences, accurately and truthfully reported. Unfortunately, modern science has no foolproof method for evaluating the truth or falsity of witnesses' claims; current investigative techniques, including truth serum and hypnosis, have limitations. Until new, more reliable scientific methods evolve, there will always be an element of uncertainty associated with even the most reliable of testimonies.

Photographs of UFOs

Most of the photographs of alleged UFOs offer no compelling evidence that these are alien spacecraft under intelligent control. Some common problems that cause serious researchers to reject the majority of these photographs are poor quality of the images; suspicious circumstances associated with taking the photographs, suggesting fraud; the lack of original negatives; incompatibility of witnesses' stories with the photographic image; and inconsistencies in the photograph, suggesting a double exposure or montage.

Several techniques can be used to check whether a photographic image is genuine. The color contouring method generates a colored map of brightness variations in an image; a tiny model, being relatively close to the camera, would appear brighter than a UFO in the sky—the closer the object, the brighter the image. The edge enhancement technique suppresses all bright and dark regions to a common shade, greatly exaggerating the boundaries between tones; a thin wire used to suspend a model may thereby be made visible. By digitizing an image into pixels, the approximate distance of an image may be gauged because the closer the object, the sharper the pixel. Other photographic verification techniques include subjecting negatives to microscopic analysis and granulation tests.

IFOs (Identified Flying Objects)

The J. Allen Hynek Center for UFO Studies (CUFOS) keeps detailed records on most UFO reports. Their files contain simple, ordinary explanations for 92 percent of all sightings. The remaining cases cannot be identified due to insufficient data.

Many daytime sightings can be explained by research balloons, such as the Skyhook balloon. These giant plastic bags, hundreds of feet in diameter and laden with heavy instruments, are launched from Air Force bases to collect meteorological information about the upper atmosphere (above 30,000 feet) where, because of their size and reflectivity, they are clearly visible from earth. Other daytime sightings include lenticular shaped clouds and the rare but eerie phenomenon of ball lightening.

Nighttime sightings include Venus, the brightest planet, bright stars or planets seen through atmospheric turbulence produced by low-flying military jets, aerial jet refueling operations, and satellite debris reentering the lower atmosphere.

Because radar is an electronic device, radar sightings of UFOs are mistakenly believed to be infallible proof of physical objects invading the skies. In point of fact, interpreting radar signals requires considerable technical training and experience, leaving open the possibility that human operators can misunderstand phantom echoes. Under normal circumstances, radar reflections do not confuse an experienced operator, but unusual meteorological conditions, such as bubbles of warm air surrounded by cool air, can create erratically moving radar phantoms.

Occasionally, objects alleged to have been left by alien UFOs or to have been recovered from a crash site are presented to researchers for analysis. Eliminating blatant hoaxes, which have included small mummified humanoids and "little green men," the supposed objects of extraterrestrial origin have all proven to be pieces of mundane earth objects or meteorites. Some common objects submitted for examination by genuinely puzzled citizens have include mangled parts of batteries and old radios, corroded lead pipe, tangles of wire, and chunks of aluminum. No fragment ever studied by reliable analysts shows any evidence of having been grown or produced on an alien world.

Abduction by Aliens

Following the publicity generated by the Betty and Barney Hill case, millions of Americans have reported being abducted by aliens; many also have reported being subjected to physical examinations as part of some ongoing genetic study. Women have claimed to have had eggs or embryos removed or to have had a fertilized embryo implanted in their wombs; men have reported having sperm extracted. The veracity of these claims is supposedly supported by the similarity of the alleged abductees' stories, as well as by scratches and cuts purportedly verifying that painful, invasive examinations were indeed performed. It is, however, not surprising that abduction stories are remarkably similar, given that accounts of UFO abductions are pervasive in American popular culture, appearing in novels, movies, television shows, and comic books.

The detailed testimony provided by alleged abductees under regressive hypnosis offers no verification of their claims since hypnosis is not a truth serum. People can willfully lie while under hypnosis, or provide plausible details derived from unconscious fantasies to please the hypnotist. Forgotten knowledge stored in the subconscious mind may be recalled as a pseudomemory under hypnosis. The stories of Betty and Barney Hill, for example, may have included subconsciously stored information from the movies and television programs about alien invaders that were popular at the time.

Lie detector tests used to assess the truthfulness of alleged abductees' stories are also subject to interpretation. Although useful in criminal investigations, the results of lie detector tests are not considered reliable enough to be admitted in courts of law as definitive evidence of truth.

The Nature of Scientific Evidence

Most scientists would agree that life is probably found in abundance on planetary systems throughout the galaxy and that intelligent life has evolved on many of these planets. Although based on known science, this is still speculation and provides not one iota of support to the oft-stated corollary that intelligent aliens are visiting Earth. When contemplating UFO phenomena, scientists must first consider the facts they are attempting to explain, then ask whether the alien spacecraft hypothesis is a better explanation than ordinary explanations already available. In the study of UFO phenomena, it is crucial to carefully distinguish an observed fact (evidence) from an interpretation of the fact, which is not evidence no matter how reasonable the inference seems.

Hypotheses about the facts may be conceived, but to be considered science, the hypothesis must lead to predictions which can be tested through experimentation. When more than one hypothesis can explain the same observation, science employs Occam's razor to decide between them. Occam's razor, named after the fourteenth century English philosopher William of Occam, states that lacking sufficient experimental evidence for making a choice among competing hypotheses, the simplest hypothesis is the one most likely to be correct. Extraterrestrial visitation as an explanation for UFOs is a hypothesis more complex than warranted to explain the extant observations. More and better data will be required to justify accepting UFO phenomena as evidence of alien visitation.

The alien visitation hypothesis also requires abandoning well-tested laws of science without clear evidence to justify it. The stars in the galaxy are so far apart that alien visitors, even traveling close to the speed of light, would invest an enormous amount of time, not to mention the expenditure of energy required, just to get here.

In conclusion, although humans are most likely not the only intelligent life in the universe, and although extraterrestrial beings may visit Earth sometime in the future, at this time there is no compelling evidence that earth has been or is being visited by aliens. In science, extraordinary claims require extraordinary evidence. The extraterrestrial hypothesis is an extraordinary claim unsupported even by ordinary evidence, much less extraordinary evidence. Therefore, the extraterrestrial hypothesis is currently implausible and insupportable.

George R. Plitnik

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See also: Accident investigation; Air Force, U.S.; Satellites; Spaceflight; Weather conditions

Ultralight aircraft

Definition: A minimal aircraft, requiring minimum power and with slow cruise and landing speeds.

Significance: Minimal aircraft, whether purchased or home-built, are the least expensive entry into the pleasures of flight—an affordable option for experiencing the sheer exhilaration of bird-like freedom in the air.

In the United States, the Federal Aviation Administration (FAA) in Part 103 of the Federal Aviation Regulations (FARs) has defined a basic powered ultralight vehicle as one that has a single seat, an empty weight of less than 254 pounds (with exemptions for pontoons and an emergency parachute), has a fuel capacity of 5 gallons or less, has a maximum calibrated airspeed of 55 knots (63 miles per hour), and a power-off calibrated airspeed of 24 knots (28 miles per hour) or less. For training purposes only, Exemption 3783 of July, 1983, permitted the use of two-place ultralights for in-flight instruction. The structure, control system, and stability of an ultralight are the responsibility of the designer and builder because an ultralight is not a certificated aircraft. In Europe, this type of minimal aircraft is called a microlight, A microlight is defined as a one-or two-seat airplane with a specified takeoff weight, wing loading (number of pounds of weight per square foot of wing area), and fuel capacity.

In the United States, an operator of an ultralight is not required to possess either a medical certificate or a pilot's license, and this has opened up the possibility of flight for thousands of pilots who either cannot afford the expense of certificated aircraft or who are no longer able to pass the medical exam. Because they have such short takeoff and landing capabilities, ultralights can be stored and flown from small grass strips in the country, further reducing the cost of owning and flying them. In England and in Europe, on the other hand, a microlight pilot must possess a valid Declaration of Health and must have passed an examination on applicable regulations, flight procedures, navigation, and weather. Tens of thousands of ultralights and microlights have been sold and are being flown.

Origins

Perhaps history's first ultralight was Alberto Santos-Dumont's 1909 *Demoiselle*; it had an empty weight of about 215 pounds and a 35-horsepower engine. Plans for the *Demoiselle* were offered in the 1910 issue of *Popular Mechanics*, but the machine required a very light pilot to get off the ground because of its very small wing. A little later, in the Great Depression, the United States could point to Bernie Pietenpol's 1929 homebuilt *Air Camper*, powered by a Model A Ford engine, as a practical minimal aircraft.

However, the modern ultralight/microlight movement had its origins in a reinvention of the airplane, repeating in the early 1970's the hang gliding pioneered by Germany's Otto Lilienthal in the 1890's. (Hang gliding relies on weight shift by the pilot hanging below the wing for control of its flight path.) The revival was started by the invention of the Rogallo wing, a flexible-wing glider intended for space or military applications, by Francis Melvin Rogallo of the National Aeronautics and Space Administration (NASA). It was quickly adopted for sport flying in Australia and came to the United States as a towed glider behind a speedboat. Hang gliding became very popular and thousands were sold, especially on the West Coast where winds flowing up seaside hills generated lift and the seashore sand cushioned hard landings.

However, fliers soon tired of lugging their gliders back up the hill after what sometimes were very short flights; the ultralight movement can be said to have begun with John Moody's flight demonstrations at the July, 1976, Experimental Aircraft Association Fly-In of an Icarus II biplane hang glider powered by a 12-horsepower engine strapped to his back. When the December, 1976, issue of *Popular Science* magazine featured this powered hang glider, the revolution was on. The *Icarus II* became the *Easy Riser* when an engine was added, and thousands were sold.

Initially, the FAA decided to exempt powered hang gliders from the certification and pilot requirements of the FARs so long as they were foot-launched, or at least foot-launchable. That was not very practical, as powered gliders inevitably became more sophisticated and used larger engines (mostly adapted chain-saw and snowmobile engines). In October, 1982, Part 103 became effective and established the basic ultralight definition, requirements, and flight restrictions, and these continue in effect.

The early ultralight pilots taught themselves to fly much as did pioneer pilots; they gradually increased taxi speeds, then made short straight-ahead hops, and then made their first tentative turning flights. The slow speeds involved usually minimized injuries. However, the FAA realized that instruction by a competent instructor in a two-place ultralight would certainly increase safety, and authorized the production and sale of uncertificated, two-seat ultralights so long as only authorized instructors used them for instruction or proficiency and their weight did not exceed 350 pounds and their stall speed did not exceed 29 knots (49 miles per hour).

By 1982, the hang-glider manufacturer Quicksilver was selling two thousand ultralights a year and had introduced a model that used three-axis control (the MX) in place of the much less effective weight-shift control used by unpowered hang gliders. Chuck Slusarczyk had introduced his CGS Hawk with a fully-enclosed cockpit, standard flight controls, and flaps, and was selling an average of forty ultralights every month.

In the United States, however, the bubble burst in November, 1983, when the television program *20/20* aired an exposé of ultralight aircraft in which an ultralight suffered a structural failure, resulting in the death of the pilot. That caused ultralight sales to plummet by about a factor of eight. However, it also caused marginal designs to go out of business, and since then ultralights have continued a healthy growth. In addition to original "lawn chair under a wing" designs such as the Quicksilver, many airplanelike designs such as the Mini-Max are available. Ultralights can be built from plans (least expensively), from kits, or (most expensively) purchased ready-to-fly.

Structure

A very low wing loading (the ratio of weight to wing area) is the key to the ultralight's very slow stall speed, and therefore its ability to land in very short, unpaved fields. A legal ultralight, with a 175-pound pilot and full fuel, requires a wing area of around 160 square feet, about the same as a much heavier, certificated two-seat trainer. This very low wing loading means that even moderate air turbulence and surface winds can make for unpleasant and potentially hazardous ultralight flying, and so most ultralight pilots prefer to fly in the early morning or late evening.

Excellent short takeoff performance is added to this short field landing capability by matching the low wing loading with a lightweight, powerful engine, yielding a low power loading. This has made the two-stroke engine the engine of choice for most ultralights, but engines more powerful than about 35 horsepower quickly put an ultralight over the weight limit. Two-stroke engines are more sensitive to the fuel mixture, the installation may not be well engineered, and deterioration can occur during winter storage, causing many ultralight pilots to become familiar with forced landings. These should not be a problem so long as the pilot is ready to transition to a steep nose-down attitude for gliding and a suitable short landing area is available. The steep glide angle is required because ultralights have a great deal of airframe drag from wing bracing and unstreamlined cockpits.

Safety

Many thousands of ultralights are now flying in the United States, but the absence of registration means that the exact number is not known. Similarly, because there is no reporting requirement, it is not known how many ultralight accidents occur. Some ultralights, perhaps especially those with engines behind the pilot, may not provide very good protection for the pilot in the event of a sudden stop. However, there is no doubt that a careful ultralight pilot with a carefully maintained flying machine, flying in good weather with light winds and always within gliding distance of a suitable landing area, can fly safely and with a great deal of personal pleasure and satisfaction. A good helmet and a ballistic parachute also enhance safety. Good hearing protection is vital because the engine is very close to the pilot.

The FAA's 5-gallon fuel limitation was intended to insure only local flying by ultralights, so they and their pilots would not be exposed to the navigation and weather challenges of cross-country flight. However, challenge is just what stimulates and inspires some fliers, and by 1979 two ultralights had successfully been flown from coast to coast. Short cross-country trips have become very common. Ultralights need to be extra alert for the faster certificated aircraft because they often are not very visible from the air.

The greatest legal threat to ultralight flying is probably the liability problem, because most are not insured. Furthermore, almost all single-seat ultralights are much heavier than allowed by Part 103 and the more popular two-place ultralights are mostly used for passenger carrying rather than for the instruction of students. Some of these problems may be solved by sport pilot and sport airplane proposals that promise to extend low-cost flying into the two-place, lightweight, four-stroke powered, relatively slow planes, such as the first Cubs, while retaining minimal aircraft and pilot requirements.

Trikes and Power Parachutes

Trikes are flexible-wing, delta-shaped, powered hang gliders that are controlled by weight shift, using a bar that extends in front of the pilot. The operation of a control bar works opposite to that of a control stick: The nose is raised by forward motion ("pushing it up"). There are even fewer easy attitude references for the pilot than in the usual ultralight, and the pilots's senses can provide initially conflicting information. Using a pusher engine, trikes are particularly vulnerable to anything that gets blown back from the structure and into the propeller. Handling turbulence is a considerably different and demanding task. Trikes are particularly popular in Europe but are also becoming more common in the United States.

Latecomers in the ultralight field, powered parachutes have established themselves as a popular form of recreational flying. They are very sensitive to atmospheric turbulence, requiring smooth air and very light winds for safe operation. With such a lightweight "wing," the parachute "cart" for the pilot can be extra strong and still be legally ultralight, although the high drag of the parachute requires a relatively large engine. When ready to fly, the parachute is behind the cart and must be carefully inflated by a blast of air from the propeller before a commitment to a takeoff is made.

Other Applications

Thanks to their ability to fly very slowly and safely at low altitudes, ultralights have proved to be very useful for photography and for law enforcement all around the world. They are also the only piloted flying machine that flies as slowly as birds. In a well-publicized experiment (dramatized in the film *Fly Away Home*), Canada goose goslings were raised alongside an ultralight, taught to fly behind it, and then led on a desired migration pattern from Toronto, Canada, to Virginia in 1993. The same experiment has been successfully accomplished with sandhill cranes, and it is hoped that the population of the rare whooping crane can be increased through similar imprinting techniques.

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See also: Airplanes; Experimental aircraft; Federal Aviation Administration; Parachutes; Weather conditions

Uncrewed spaceflight

Definition: Since 1950, humankind has used robotic spacecraft such as satellites, probes, and telescopes both to gather strategic intelligence and to explore the outer reaches of the solar system.

Significance: During the course of the Cold War, space satellites provided important strategic intelligence concerning the number and location of intercontinental ballistic missiles that allowed both the Soviet Union and the United States to control the use of these weapons of mass destruction. These uncrewed spacecraft also enhanced the exploration of the outer planets of the solar system.

The Cold War

It became quite obvious by late 1945 that a significant political and strategic rift was forming between the Soviet Union and its wartime allies. During the course of the German retreat from Russia, Soviet troops had occupied most of the nations of Eastern Europe. In time, the United States and Great Britain accepted the fact that the Soviet Union was intent upon creating a strategic buffer zone out of these nations by making them satellites of the Soviet Union. The Soviet Union gave military and economic support to the Marxist groups in these countries, and by 1948 the entire Eastern bloc was under Soviet control. Concurrently, World War II had unleashed the atomic age and introduced the use of long-range weapons of destruction. Both the United States and the Soviet Union recognized the potential strategic power of placing atomic bombs on intercontinental ballistic missiles

(ICBMs). The economic and political pressures of the Cold War necessitated that each side have a clear understanding of the strategic capabilities of its opponent. The Soviet Union and the United States created a system of spy satellites that was used as an important tool in curtailing the spread of nuclear weapons. Soviet premier Nikita Khrushchev and U.S. president Dwight D. Eisenhower expanded the use of robotic spacecraft because they were less expensive to build and maintain than conventional weapons. Spy satellites had the added advantage of taking the human factor out of the military equation. If a robotic spacecraft crashed in enemy territory there was no danger of the embarrassment of a pilot standing trial before the international community.

Early Space Exploration

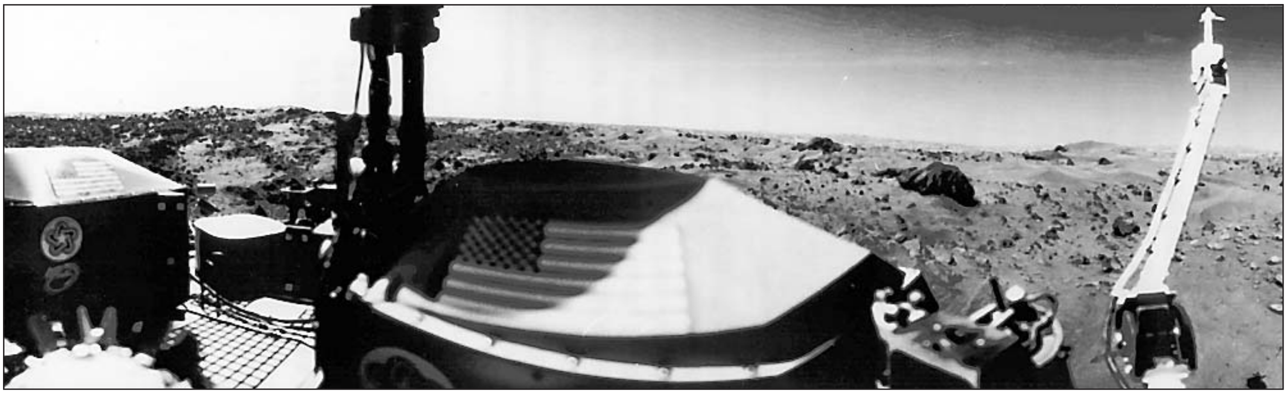
During the first years of the space race, human knowledge of the solar system came from a series of robotic explorers. On January 31, 1958, the United States successfully launched the Explorer 1 satellite that discovered the existence of belts of radiation around Earth. This phenomenon would eventually be designated the Van Allen Belt, named for the chief scientist of the Explorer Program. This discovery took the American scientific establishment by surprise; initially it was believed that the radiation was the result of a Soviet nuclear test. The National Aeronautics and Space Administration (NASA) continued to expand its understanding of this radiation when Explorer 4 mapped the region of the belts between July and September, 1958. The Moon was the next target of uncrewed spaceflight. By the late 1950's, scientists in both the United States and the Soviet Union were seriously considering the possibility of landing humans on the Moon, but extensive environmental information about the Moon was necessary before such a landing could be made. Beginning in August, 1958, the United States sent a series of probes designated Pioneer 1 through 4 toward the Moon, but all four failed to reach their destination. The Russian Luna probes were more successful. On September 15, 1959, Luna 2 reached the Moon, but the force of its impact destroyed the spacecraft. The Soviets were finally successful with Luna 3. This probe made a successful landing and sent back the first pictures of what astronomers refer to as the "dark side" of the Moon. By the early 1960's, the Soviet Union and the United States were actively involved in the exploration of the inner planets. The United States' Mariner Program was developed to collect data from Venus. The first attempt at a flyby of the 4planet was made in July, 1962. Unfortunately, the spacecraft experienced a major malfunction and crashed soon after takeoff. NASA was more successful in December, 1962, when Mariner 2 successfully landed on the surface of Venus. Astronomers discovered that the cloud cover that made Venus the object of planetary beauty was actually a toxic collection of poisonous greenhouse gases that had created a hot, deadly environment. The Soviets were also successful in their attempts to explore Venus, and their spacecraft sent back some of the first accurate topographical details of the planet's surface. Throughout the mid-1960's, both the Soviet Union and the United States were successful at using robotic spacecraft to expand human knowledge of the inner planets.

The Planetary Grand Tour

In 1965, two American space scientists, Michael Minovitch and Gary Flandro, published scientific reports that described a technique for the exploration of the solar system's outer planets described as gravity propulsion. The centerpiece of this new theory was the giant of the solar system, Jupiter. Minovitch and Flandro described how the gravitational force of Jupiter could be used to act as a slingshot to propel a probe to the far reaches of the solar system. The two scientists continued to work on this theory, and in 1966 they issued a second paper that stated that the best planetary alignment for such an endeavor in the next 179 years would be in 1977 and 1978. The vast majority of the United States' space community was interested in this new theory, and despite its focus on the Apollo Program, NASA made plans to explore the outer reaches of the solar system and beyond. In 1972, the program was momentarily sidetracked when President Richard M. Nixon, focusing upon the importance of crewed spaceflight in the struggle against the Soviet Union, approved the beginning of the space shuttle program. In 1972, the United States was suffering an economic slowdown as a result of the large expenditures of the Vietnam War. The federal budget was already under considerable strain; therefore, the space program was pushed to make choices that would have both a scientific and political impact. Fortunately, the cost of the trip to the outer planets was modest and funding was restored.

The Politics of Space Exploration

The first series of probes to attempt the Grand Tour were designated Pioneers 10 and 11. Most of the scientists involved with the project believed that if the spacecraft made it out of the solar system without any significant damage, there was an excellent chance that the probes could explore the universe for centuries. A small but significant sector of this scientific community also believed



Uncrewed space vehicles can send information back to Earth from locations not yet reachable by humans. This is the first photograph of the surface of Mars, taken by the Viking 1 on July 23, 1976. (NASA)

that there was other intelligent life in the universe. The Cornell University astronomer Carl Sagan and his wife Linda designed a plaque that was to be attached to each probe. These plaques were intended to be a message of peace and discovery to any other intelligent life. Each plaque contained a model of our solar system, which communicated that the craft originated on the third planet from the Sun. There was also a prelaunch blueprint of the entire spacecraft designed to show the rocket that had launched the probe into space. This, along with a diagram representing the location of fourteen pulsars, was included to show the extent of human scientific knowledge and capabilities. Finally, the plaque contained a representation of a naked man and woman depicting the physical characteristics of the species that had constructed the probe. The male figure held his right hand up in a gesture of peace, and the woman was situated next and slightly behind her male counterpart. The plaque turned out to be the most controversial aspect of the program, and it united various groups from both sides of the political spectrum. The cultural and religious conservatives were upset with the fact that the man and woman were naked. A number of prominent newspapers, including the *Chicago Sun-Times*, removed the genitalia from both figures when it published a picture of the plaque in their newspapers. The decision to place the woman slightly behind the man outraged American feminists. These women perceived the diagram as another example of America's unequal, male-dominated society. Because the silhouettes were represented with racial features of European Americans, minority communities also took objection to the plaque. In time, the controversy calmed down and this symbolic message of peace and hope accompanied the spacecraft on its journey.

The Journey to Jupiter and Saturn

Two robotic probes were launched toward Jupiter and Saturn by the United States in the early 1970's. Pioneer 10 began its journey in mid-July, 1972, and successfully navigated the potentially dangerous asteroid belt located between the orbits of Mars and Jupiter. It then sent back the first photographs of the solar system's largest planet. Astronomers learned that Jupiter had at least twelve moons and that its atmosphere contained deadly levels of radiation. In its travels around the giant planet, Pioneer 10 also confirmed that the famous Giant Red Spot was actually a massive storm six times the size of Earth. Astronomers were also able to acquire important pictures of three of the four Galilean moons. Finally, the space probe confirmed a long-held belief that, like its neighbor Saturn, Jupiter possessed a system of rings. With its mission accomplished, Pioneer 10 traveled to the planet Pluto and then into interstellar space.

Pioneer 11 flew by Jupiter long enough to take a second look at the Giant Red Spot and then proceeded to its primary destination, Saturn. The spacecraft spent a total of ten days mapping Saturn's great system of rings. Astronomers discovered that the planet also emanated large amounts of radiation and possessed a very strong magnetic field, as well. Finally, Pioneer 11 gave scientists a close-up look at the largest moon in the solar system, Titan. Many astronomers believe that Titan might one day be the location of a space colony.

The Space Telescope

Most scientists believe that the most important robotic instrument launched into space in the last decade of the twentieth century is the Hubble Space Telescope. This sophisticated instrument was sent into space on April 25, 1990, and it has the potential to initiate the most significant scientific and philosophical discussions in the first decade of the third millennium. The telescope has the ability to look deep into the farthest reaches of outer space. This has allowed astronomers to study the conditions that existed moments after the beginning of the universe, described by cosmologists as the Big Bang. The Hubble telescope has allowed scientists to observe the process by which both stars and planets originate. Many cosmologists believe that humankind is on the verge of discovering how the universe was created. The great debate over a "grand design" could be settled with the information discovered by the Hubble telescope.

The Future of Uncrewed Spaceflight

One of the great debates in the U.S. scientific community revolves around the question of whether or not the United States should make the commitment to continue highly sophisticated space travel. Many scientists believe that the United States should concentrate its energies and financial resources on robotic spaceflight. The success of these uncrewed programs, especially the first Mars Lander and the Hubble telescope, confirms their belief that the frontiers of human knowledge can be served best by creating new missions for these highly reliable spacecraft.

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See also: Astronauts and cosmonauts; Crewed spaceflight; Missiles; National Aeronautics and Space Administration; Rockets; Russian space program; Space shuttle; Spaceflight; Vanguard Program; Viking Program

Uninhabited aerial vehicles

Also known as: UAVs, uncrewed aerial vehicles, unmanned aerial vehicles, drones

Date: First used by Germany during World War II; used by the United States beginning in the 1950's

Definition: An airborne vehicle that operates without a pilot by either a preprogrammed system or an overriding command system operated from the ground.

Significance: Uninhabited aerial vehicles (UAVs), such as the Tagboard, Ryan BQM-34, Pioneer, Predator, Global Hawk Tier II+, Darkstar Tier III-, and Cypher, provide defense capabilities such as reconnaissance, aerial photography, signals intelligence collection, and laying decoy chaff corridors for striking aircraft while eliminating the risk of loss of life. Advanced UAVs provide offensive capabilities such as the deployment of missiles. Used for intelligence gathering behind enemy lines, uninhabited aerial vehicles allow the U.S. Air Force to obtain near-real-time information that assists ground commanders and allows them to implement effective tactical maneuvers. UAVs have both military and civilian applications.

Development of Uninhabited Aerial Vehicles

During World War II, Germany developed and deployed the first uninhabited aerial vehicle (UAV) known as the V-1. Built to attack a specific target, the V-1 was used once and was destroyed along with its target. The United States began developing uninhabited aircraft during the 1950's to supplement crewed aircraft under Strategic Air Command (SAC). Capable of achieving intercontinental-range flight, the UAV, like its predecessor, also destroyed itself on contact with the target. After the Soviet Union launched Sputnik and then shot down a U-2 spy plane in the early 1960's, the United States embarked on a reconnaissance program developed around the use of uninhabited aircraft. Ryan Aeronautical Company flew the first of these remote-controlled aircraft under the code name of "Red Wagon" and effectively demonstrated the ability to use UAVs for aerial photographic missions. In addition to being flown over the Soviet Union and Cuba, these vehicles were also deployed over China.

By 1962, Lockheed and the Central Intelligence Agency (CIA) developed the supersonic reconnaissance D-21, known as the Tagboard. Launched from the A-12 or the B-52H airplane, the Tagboard was capable of achieving a speed of Mach 3.3 and could fly at high altitudes over 90,000 feet for a distance of 3,000 miles. After photographs were taken of the targeted area, the film was released and recovered by another aircraft. The Tagboard was retired in 1971 due to several mission failures and high costs.

During the Vietnam conflict, the United States Air Force relied on the Ryan BQM-34 Lightning Bug for both high- and low-altitude missions. High-altitude flights operated at heights of 60,000 feet and above, while low-altitude sorties flew at an altitude below 500 feet. Capable of flying for 7.8 hours without landing, the Lightning Bug was used for photographic reconnaissance, leaflet dropping, picking up enemy signals, and providing assistance to crewed aircraft by releasing chaff corridors as a decoy maneuver. On an average, each Lightning Bug flew just over seven missions, for a total of 3,435 missions between 1964 and 1975. In 1971 and 1972, Ryan Aeronautics experimented with the use of the Lightning Bug as an armed vehicle capable of dropping an electro-optically guided bomb. Several of these modified UAVs flew with crewed aircraft on missions over Vietnam. After the United States withdrew from Vietnam, interest in the use of drone aircraft diminished but other countries, such as Israel, continued to develop the technology.

The rebirth of the UAV in the United States occurred during the Persian Gulf War of 1991 when the Navy and the Army deployed the Pioneer uninhabited aerial vehicle. Based on the designs of the Israeli Scout and the Mastiff UAV, six Pioneers were deployed during Desert Storm. The three systems used by the Marines assisted AV-8B Harriers during air strikes while the systems deployed by the Navy provided gunfire spotting for the battleships, located mines in the Persian Gulf, and pinpointed antiship missile sites in Kuwait and Iraq. Used for targeting, reconnaissance, and battle damage assessment, the Pioneer flew 533 missions and logged over 1,688 hours in the air. After the war, the Pioneer was used for reconnaissance in Bosnia and Kosovo beginning in 1993. In the Western Hemisphere, the Pioneer has been used during Operation Uphold Democracy in Haiti and in conjunction with the U.S. Customs Service to spot illegal immigrants crossing the border and to combat the smuggling of illegal drugs. The Pioneer provides real-time video within line-of-sight and flies low- to medium-altitude missions. The aircraft is capable of operating on totally preprogrammed instructions or can receive commands while in flight. After the mission is over, the Pioneer can land in one of three different ways: by using an arresting cable across the runway, much like the type used on an aircraft carrier; flying the aircraft into a recovery net; or a traditional landing. Measuring 14 feet in length and weighing 460 pounds, the Pioneer can fly for five hours at speeds of up to 100 knots with a payload of 55 pounds.

Endurance UAVs

The usefulness of the uninhabited aerial vehicles prompted the United States to enhance the technology, making the aircraft capable of longer flight times for increased coverage during periods of conflict. The Predator is a medium-range altitude endurance uninhabited aerial vehicle (MAE UAV) capable of remaining in flight at loitering speed for twenty-four hours at a time at its 500-nautical-mile range. The cost per unit is $3.5 million. Each Predator system consists of four aircraft, one ground station, and one Trojan Spirit II SATCOM system. The aircraft is designed like the Gnat 750, with a slender fuselage 320 inches in length and 72 inches high, with a span of 580.8 inches. Manufactured by General Atomics, the Predator operates within line-of-sight of GSC (ground control station) and virtually anywhere by satellite. The midwing monoplane, powered by a four-cylinder Rotax engine, carries an electro-optic/infrared (EO/IR) Versatron Skyball Model 18 and a zoom and spotter lens, as well as a Westinghouse 783R234 synthetic aperture radar. The Predator is easily recognized because of its inverted-V tails. Transportation of the Predator by C-5, C-141, and C-130 aircraft allows the system to be highly mobile and its easy assembly allows the UAV to be operational within six hours of arrival. Data is gathered through the Trojan Spirit II (TS II) SATCOM system that transmits and receives messages simultaneously from a variety of sources including satellites, joint surveillance target attack radar system (Joint-STARS), U-2's, Rivet Joint, and airborne warning and control system (AWACS).

The first deployment of the Predator occurred in Gjader, Albania, in 1995. After Serb air-defense gunners shot down one of the aircraft and another was destroyed as a result of ground fire, the Predators were removed from the European theatre. The second deployment occurred in Taszar, Hungary, in March, 1996, when U.S. European Command engaged in Operation Nomad Endeavor. That same year, the Air Force ordered thirteen Predator systems with four aircraft each, scheduled for delivery between 1996 and 2002 at a cost of approximately $118 million. All of the systems are operated by the Eleventh and Fifteenth Reconnaissance Squadrons located at Indian Springs Air Force Auxiliary Field, 40 miles northwest of Las Vegas. The Joint Requirements Oversight Council has issued a requirement for several system upgrades, which will be retrofitted on existing Predators, including a deicing capability, a UHF radio link, and Mode IV IFF transponders. In addition, a contract has been signed with General Atomics Aeronautical Systems to expand operations from line-of-sight to beyond-line-of-sight capability, using a Predator as a communications relay.

The effectiveness of the Predator for intelligence gathering and the reduction of human risk led the United States military to explore the possibility of arming the Predator. General John P. Jumper, Air Combat Command's top commander, proposed equipping Predator with weapons, and in February, 2001, the first successful live missile test took place at Nellis Air Force Base Range, Nevada. The armed Predator, controlled through a Ku-band satellite link and traveling beyond the controllers' line of sight, flew to 2,000 feet before identifying its target and launching a live Hellfire missile, blowing a track off a tank. Air Combat Command and Aeronautical Systems Center continue to evaluate and analyze the test results with the goal of achieving the capability of firing missiles from the Predator at heights between 10,000 to 15,000 feet.

Although the Predator fulfilled medium-range altitude requirements, the Air Force required an uninhabited aircraft that could conduct high-altitude reconnaissance for longer periods of time. Teledyne Ryan Aeronautics developed the conventional high-altitude endurance uninhabited aerial vehicle (CHAE UAV) and flew the aircraft for the first time in 1997. The aircraft, commonly referred to as the Tier II+ or the Global Hawk, flies at altitudes above 60,000 feet at speeds of up to 340 knots. The Global Hawk performs high-resolution reconnaissance over a 40,000-square-mile area in twenty-four hours at loitering speed at a range of 3,000 miles. With a payload of 2,000 pounds, the Global Hawk can operate from conventional 5,000-feet runaways. Cost per unit is $10 million.

Rounding out the endurance vehicles is the DarkStar. Manufactured by Lockheed Martin and Boeing, the DarkStar flies low observable high-altitude endurance (LOHAE) missions above 45,000 feet and is capable of loitering for eight hours and can travel 5,000 miles from its base of operation. Equipped with either high-resolution synthetic aperture radar (SAR) or electro-optical (EO) sensors, the DarkStar images well-protected, essential targets. The first flight of a DarkStar occurred in March, 1996, and each aircraft costs $10 million. Operation requires the use of runways under 4,000 feet in length and the aircraft is able to fly in all types of weather conditions. The aircraft is half the span of the Global Hawk and one-third the length. The development program of the DarkStar, administered by Defense Advanced Research Projects Agency (DARPA), was cancelled in 1999 due to budget cuts, with the Department of Defense opting for longer range as opposed to the stealth of the DarkStar.

The latest development of an uninhabited aerial vehicle is the Cypher aircraft, manufactured by Sikorsky Aircraft Corporation. Designed to meet military needs such as reconnaissance, communication relay, and countermeasure missions, the Cypher also meets civilian needs in areas such as counternarcotics, ordinance disposal, forestry, utilities, law enforcement, and search-and-rescue. The use of a differential Global Positioning System (GPS) allows the Cypher to navigate autonomously. The aircraft is capable of vertical takeoff or landing (VTOL), is 6.5 feet in diameter, carries a payload of 50 pounds, and cruises at 80 knots. The rotor system is shrouded to prevent damage to the high-speed rotors and possible risks to personnel. Equipped with a 50-horsepower engine, the Cypher has a ceiling altitude of 8,000 feet and can fly for three hours without landing. The onboard sensors relay information to control stations on land, sea, or in the air via digital telemetry uplink. Information about flight status, data gathered during the mission, as well as video images are downloaded simultaneously.

The development of uninhabited aerial vehicles continues to advance with new capabilities and systems continuously being added or modified to increase the performance of the aircraft. The intelligence gathering designed to assist tactical commanders remains the primary function of the uninhabited aerial vehicles, but as the industry develops lower-cost units, the number and variety of applications have increased.

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See also: Air Force, U.S.; Airplanes; Gulf War; Missiles; Reconnaissance; Rescue aircraft; Sputnik; Strategic Air Command; Vietnam War; World War II

United Air Lines

Date: Officially formed on March 28, 1931

Definition: The largest commercial airline in the world.

Significance: United is the largest and arguably the oldest surviving airline in the United States. United presently operates more than six hundred aircraft with a route structure circling the globe.

Early History

The Air Mail Act of 1925, championed through Congress by Pennsylvania congressman Clyde Kelly, mandated the U.S. Post Office to award airmail contracts to private companies. These contracts served as an incentive for the formation of numerous fledgling airlines. Among the first successful bidders were four companies—Boeing Air Transport (BAT), Pacific Air Transport (PAT), Varney Air Lines, and National Air Transport (NAT)—that would later merge to form what is now United Air Lines. One of these companies, Varney Air Lines, successfully bid on Contract Airmail Route 5 (CAM 5), from Pasco, Washington, to Elko, Nevada. United celebrates as its birthday the date on which Varney began operating, April 6, 1926, making United the oldest airline in the United States.

United Air Lines was not officially formed until March 28, 1931, when it was incorporated as a management company designed to coordinate the activities of its subsidiary airlines. The addition of National Air Transport in 1930 allowed United to operate the first true transcontinental air route, from San Francisco to New York. The resulting company united the individual airlines into a major power in the air transportation industry.

The driving force behind United Air Lines was William Boeing, whose Boeing Air Transport had in 1929 changed its name to United Aircraft & Transport Corporation (UATC). Under Boeing's leadership, UATC acquired a number of additional companies, including Pratt & Whitney, Hamilton Standard Propeller Company, and Chance Vought Corporation. As a result, United became one of the three large conglomerates that came to dominate early commercial aviation. Boeing's manufacturing prowess allowed United to address one of the major problems caused by the merger of the four airlines, each of which used a different type of equipment. United standardized its fleet by purchasing fifty-nine Boeing 247's. This radical Boeing design employed Pratt & Whitney engines and Hamilton propellers. At the time, it was the one of the largest and fastest transport planes in service, carrying ten passengers at a speed of 160 miles per hour. Because Boeing aircraft was a part of the United family, no other airline was allowed to purchase the 247. Thus, United alone operated the most advanced design aircraft in the world, until the Douglas DC-2 arrived on the scene in 1934.

Because passengers were few and flying was expensive, the survival of early airlines depended on the winning of government airmail contracts. Airlines relied on mail contracts that began at three dollars per pound for the first one hundred miles and thirty cents per pound for each additional one hundred miles. In 1929, airmail contributed almost 95 percent of United's revenue. The rates were modified in 1930 with the passage of the Air Mail Act of 1930, also also known as the McNary-Watres Act, which amended payment based on aircraft capacity. The postmaster general, Walter Folger Brown, had a vision for the air transportation system in the United States. Convinced that only well-established, well-financed companies such as United should receive airmail contracts, he held a series of meetings in Washington, D.C., at which he awarded the contracts. Because he only awarded contracts to certain airlines, these conferences came to be known as the spoils conferences. United participated in these conferences and was awarded the northernmost transcontinental route, which it had been operating since 1930.

Politics and the Airlines

After the Republican Party lost the 1932 presidential election, Walter Folger Brown was replaced as postmaster general, with a devastating effect on the airline industry. The Hoover administration had been very favorable to business interests and had supported the airline cartels through the awarding of lucrative mail contracts. Brown had openly favored large companies at the expense of the smaller airlines.

With the election of Franklin D. Roosevelt, this support vanished. There was an outcry in the press about political favoritism and collusion in the awarding of airmail contracts. There were also a number of disgruntled airline owners who had not been invited to the spoils conferences and did not receive mail contracts. In response to these complaints, a committee was established to review the process of airmail-contract awarding. Although this committee, chaired by Senator Hugo Black, found little that was illegal and no evidence that Brown had violated any laws or profited in any way from his decisions, Roosevelt ordered the cancellation of all existing airmail contracts.

On February 9, 1934, the contracts were cancelled, and on February 20, 1934, the Army began flying the mail. This was disastrous for the airline industry. United president William A. Patterson ordered that the airline continue operating even though projected losses were estimated to be $300,000 per month. The first-quarter losses totaled $852,000. The airline and its 1,400 employees were in dire straits. The airline's stock suffered, dropping from thirty-five to fourteen points.

It soon became obvious that the Army was not capable of flying the mail. There was outrage over the deaths of twelve army pilots in fewer than two months. The Post Office responded by advertising for new bids on most of the precancellation routes. No company that had participated in the spoils conferences was eligible to bid. United was allowed to submit bids on the condition that three executives who had been at the spoils conferences resign. A technicality in the original mail contract, which had been issued under the name of Boeing Air Transport rather than that of United, made United eligible. In April, 1934, Patterson submitted bids for all of United's precancellation routes and won back all but one.

Events in United Air Lines History

1931: United Air Lines is incorporated as a management company to coordinate the operations of four original subsidiary airlines, Boeing Air Transport, Pacific Air Transport, Varney Air Lines, and National Air Transport.

1934: After the government cancellation of all air mail contracts, United is restructured to avoid the conflicting interests of other aircraft-manufacturing subsidiaries.

1940's: Freed from purchasing solely from Boeing, United begins operating DC-3 and DC-4 aircraft. The airline plays a major role in troop transport during World War II.

1946: United orders thirty-five new pressurized DC-6 aircraft and total employment increases to more than 16,000.

1955: The airline orders its first jet-powered aircraft, the DC-8.

1960's: After United's purchase of the 737, designed for a two-person cockpit crew, the airline experiences the first of a decades-long series of labor disputes.

1961: United acquires Capital Airlines and becomes the largest airline in the world.

1969: Carrying increasing numbers of passengers, United purchases the DC-10 wide-body transport.

1983: United continues to expand its route network, initiating service to Tokyo.

1991: Increasing fuel prices, low-fare competition, and the fear of terrorism combine to produce a financially difficult period for United.

1994: The airline begins the operation of Shuttle by United along the West Coast.

1995: United introduces the Boeing 777.

2001: As part of what is termed the worst acts of terrorism in world history, two United Air Lines jetliners are hijacked; one is flown into New York City's World Trade Center, and another crashes outside of Pittsburgh, Pennsylvania. All on board both planes are killed.

Additional difficulties soon arose when Congress passed the Air Mail Act of 1934, which prohibited airlines holding mail contracts from being connected with other aviation-related enterprises. This, in effect, meant that the four airline operating divisions of United had to be separated from the parent company. This resulted in a major restructuring of the organization. United Air Lines Transport Corporation (UALTC) was formed on July 20, 1934, combining the four subsidiary airlines into one organization, which was totally independent of the nonairline subsidiaries.

The separation from the cartel actually had some hidden benefits for United. Because it was no longer connected with Boeing, United was free to purchase aircraft from other manufacturers, allowing the airline's purchase of the Douglas DC-3, arguably the most successful airliner in history. This aircraft allowed United to develop its passenger-carrying potential and to reduce its reliance upon airmail contracts. United was also instrumental in working with the Douglas Aircraft Company to design the DC-4 and later ordered twenty of the four-engine aircraft. However, World War II intervened before United could take delivery of these new airliners. United did not operate the DC-4 commercially until 1946, when it received twenty-five aircraft.

World War II

United, as did every other U.S. airline, served in the war effort by providing transport services to the government. In an effort to separate the military role from the commercial role, a subsidiary, the United Air Lines Victory Corporation, was formed. At the end of the war, Patterson ordered an audit and discovered that an excess profit had been made. United submitted a refund of $296,000 to the government.

United played a major role in air transport services during the war, flying more than 50 million miles and carrying 156,000 passengers and 18,000 tons of freight. In addition to its transcontinental domestic routes, United also operated in Alaska and across the Pacific Rim. The company undertook additional tasks, such as the training of thousands of ground crew and flight personnel for the Army and the Navy. It modified thousands of military aircraft, primarily Boeing B-17's, at its Cheyenne, Wyoming, maintenance base. By the war's end, United had modified almost 6,000 combat aircraft.

Post-World War II

In addition to military airlift responsibilities, United maintained a commercial schedule with what remained of its DC-3 fleet. By 1944, domestic passenger load factors exceeded 95 percent. By 1946, United was operating seventy-seven DC-3's and twenty-five DC-4's. The company required increasingly larger and faster aircraft, and in 1946, placed an order for thirty-five pressurized DC-6's, of which it eventually had a total of eighty-eight. In order to service long-haul routes, particularly the San Francisco-to-Hawaii route, Douglas DC-7's were ordered.

Total employment at United increased to over 16,000 by the end of 1946. Within two years, however, the postwar boom had ended, and the airline was forced to reduce employment by 25 percent. Despite the fluctuating economy, United strengthened its route structure by adding service to additional cities throughout the country. After an unsuccessful merger attempt, United purchased a Los Angeles route from the financially troubled Western Air Express in 1947. In 1950, United received a Los Angeles-to-Hawaii route, eventually displacing the once dominant Pan American Airways.

Prior to World War II, United had been the second-largest U.S. airline, behind American Airlines. This situation would change on April 3, 1961, when United acquired Capital Airlines. The acquisition was the largest airline merger in history up until that point, and it transformed United into the largest airline in the world, with 264 aircraft and more than 30,000 employees. United's route system exceeded 18,000 miles, serving 118 cities. The merger also moved United deeper into the jet age by transferring ownership of Capital's jet and turboprop aircraft.

The Jet Age

Realizing the need for jet-powered transport, in 1955 United placed an order with Douglas for thirty DC-8's. The cost was $175 million. By the late 1960's, United was operating more than 270 jet aircraft, including 150 Boeing 727's. The Boeing 737 was ordered in 1963.

As efficient as the Boeing 737 was, it presented a major problem for United. The aircraft was designed for a two-person crew, eliminating the position of the flight engineer. The pilot's union, however, was unwilling to accept the elimination of the third crew member position, arguing that it represented a compromise in safety. Management countered that the cost to the company of the third crew member would be $6 million per year. Negotiations were unsuccessful, and a trial using the three-person crew was initiated. Arbitration was unsuccessful, and the three-person crew experiment was extended. This was the beginning of a series of labor-management troubles that would plague United for decades.

By the close of the initial phase of the jet age in 1969, United was carrying 30 million passengers per year. At the same time, another technological breakthrough occurred in the form of the wide-bodied jets, the Boeing 747 and Douglas DC-10. The years between 1966 and 1969 were extremely profitable for the airline industry and especially for United. Profits exceeded $200 million for the four-year period. In 1969, United opted to purchase the Douglas DC-10 wide-body transport, which seated 250 passengers. This was United's entrance into what has been called the second jet age.

United from the 1970's

The profitability that had accompanied the original jet age was conspicuously absent from the second. Economic problems, from which United was not immune, plagued the industry. In 1970, United posted a loss of $46 million. Government insistence on lowering passenger fares culminated in the passage of the Airline Deregulation Act of 1978, which changed the face of the industry and had serious consequences for United. Despite its problems, United continued to expand, receiving permission to service Tokyo in 1983. In 1985, United purchased the troubled Pan Am's Pacific division. By 1987, United had established six hubs and carried 2.5 million passengers. By 1990, United had carried 40 million passengers and had become a truly global airline, with around-the-world service.

Despite these successes, trouble was on the horizon. Increasing fuel prices, low-cost competition, and fears of terrorism led to a revenue loss of $322 million in 1991, followed by a $400-million loss in 1992. More than 60 percent of United's routes faced competition from low-cost carriers. United's labor-management problems also continued, with two of the most bitter strikes in the history of the airline industry. Cost-containment policies initiated by management finally resulted in the approval of an employee-ownership plan in which the employees purchased 55 percent of the outstanding stock. This agreement made United the world's largest employee-owned company.

The new United negotiated partnerships with other major airlines that became known as the Star Alliance. In October of 1994, the Shuttle by United began operating along the west coast and in June, 1995, United introduced the first Boeing 777 service. By 1999, United was operating 612 aircraft flying 125,372 million revenue-passenger miles with total revenues of $1,358 million. United had entered the new century as the world's largest airline with ambitious plans for further expansion. A proposed merger with US Airways in 2001, however, was terminated following an antitrust investigation by the U.S. Department of Justice.

Facing an Uncertain Future

United's plans were dramatically shaken by the tragic events of September 11, 2001. On that morning, four commercial jets, two of them from United's fleet, were hijacked by Islamic fundamentalists and then crashed. United Flight 175, a 767 out of Boston's Logan Airport, was flown into one of the Twin Towers of the World Trade Center in New York City, causing the building to collapse a short time later. United Flight 93, a 757 out of Newark, New Jersey, went down in a field near Pittsburgh, Pennsylvania, when passengers heard about the attacks by phone and chose to fight the terrorists. Thousands died on the planes and on the ground.

The U.S. government ordered a national ground stop until the situation could be assessed. When commercial flights resumed later that week, air traffic had lessened considerably. The loss of revenue over the following weeks forced United to lay off approximately twenty thousand employees, 20 percent of its workforce. President George W. Bush signed a multibillion-dollar emergency aid package, of which United expected to receive eight hundred million dollars. The measure also limited the airline's liability in any federal lawsuits resulting from the hijackings. Nevertheless, the future of United Air Lines was placed in doubt.

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See also: Air carriers; Airline industry, U.S.; Airmail delivery; Boeing; Jumbojets

US Airways

Definition: A large U.S. air carrier of passengers and cargo, serving mainly the East Coast.

Significance: US Airways is one of the ten largest air carriers in the United States.

Although few U.S. airlines have achieved the status of a major carrier (those with revenues over $1 billion per year) without acquiring some or all of the assets of another airline, most carriers have significant periods of internal growth and development. During these periods, the airline grows using money generated by their operations or raised through loans or stock issues to acquire new aircraft, add new routes, or expand existing service. US Airways is an exception to the rule. Its growth has come almost entirely through the acquisition of other carriers. The modern US Airways represents the consolidation of more than ten regional earners into a single network.

The Acquisition Years

US Airways traces its beginnings to a company called All American Aviation. Like many modern U.S. airlines, All American Aviation started as a mail carrier providing airmail delivery to western Pennsylvania and the Ohio Valley in 1939. In 1949, All American Aviation changed its name to All American Airways and began its first passenger service. As its route network expanded, the airline changed its name again in 1953 to Allegheny Airlines, in recognition of the mountains and river that lay at the heart of its operations.

By 1967, Allegheny had begun operations that would link many of the smaller communities in the Northeast. Other carriers operating under contract to Allegheny to provide service included Reading Aviation Service, which joined the commuter service in 1973 and became a wholly owned subsidiary in 1986, and Pennsylvania Commuter Airlines, formerly Clark Aviation Corporation, which also joined in 1973 and was purchased in 1985. In 1968, Allegheny itself merged with Lake Central Airlines. Lake Central was based in Indianapolis, Indiana, and serviced a network of destinations including Dayton, Columbus, and Cincinnati, Ohio, and St. Louis, Missouri. The next acquisition was Mohawk Airlines in 1972. Mohawk Airlines served cities through New England from its base in Utica, New York. With this acquisition, Allegheny became the sixth-largest airline in the world as measured by passenger boarding.

Now serving markets as far away as Arizona, Texas, and Florida, Allegheny changed its name to USAir in 1979 to reflect the growth in its service area. USAir did not make another acquisition until May, 1987, when Pacific Southwest Airlines, based in San Diego, became a wholly owned subsidiary.

In early 1987, USAir had begun negotiating with Piedmont Airlines regarding a possible merger. The company originally known as Piedmont Aviation was authorized to begin service from the Ohio Valley to North Carolina in April, 1947. However, protest from unsuccessful applicants for the route had prevented them from taking off until February 20, 1948. By this time, the airline had changed its name to Piedmont Airlines. Piedmont continued to expand along the east coast of the United States, eventually opening one hub at Charlotte, North Carolina, in 1981 and another in the Baltimore/Washington, D.C., area in 1983. Along the way, Piedmont became the first airline to send an all-female crew on board a jet aircraft on May 10, 1982. In 1983, Piedmont became the first airline to own its own regional carrier when it purchased Henson Airlines. Piedmont was honored as "Airline of the Year" for 1984 by the magazine *Air Transport World*. Two years later, Piedmont acquired a new hub at Syracuse, New York, and ten new cities to their route structure by purchasing Empire Airlines. In May, 1986, Piedmont became the sixth U.S. carrier to board over two million passengers in a single month. When final approval was granted for the USAir-Piedmont merger, it became the largest airline merger in U.S. history.

Events in US Airways History

1939: US Airways' predecessor, All American Aviation, begins operations flying air mail to western Pennsylvania and the Ohio Valley.

1949: All American Aviation changes its name to All American Airways and introduces passenger service.

1953: With an expanded route system, All American again changes its name, to Allegheny Airlines.

1966: Allegheny introduces the first jet, a DC-9, to its fleet.

1968: Allegheny merges with Lake Central Airlines, based in Indianapolis, and expands its network into the Midwest.

1972: Allegheny acquires Mohawk Airlines, based in Utica, New York, and expands its network into New York and New England.

1979: To reflect its continually expanding route network, with new service to Arizona, Texas, Colorado, and Florida, Allegheny changes its name to USAir.

1984: USAir inaugurates its first frequent-traveler program, a system of rewards for loyal customers.

1988: USAir acquires Pacific Southwest Airlines of San Diego, gaining routes throughout California.

1989: In the largest merger to that date in airline history, USAir joins with Piedmont Airlines, established in 1948, gaining Piedmont's international routes and routes to Baltimore, Maryland; Charlotte, North Carolina; Dayton, Ohio; and Syracuse, New York.

1992: USAir begins a partnership with the Trump Shuttle; the renamed USAir Shuttle makes hourly flights between New York and Boston and New York and Washington, D.C.

1993: USAir enters into an alliance with British Airways.

1997: USAir officially adopts its new corporate identity by changing its name to US Airways.

1999: US Airways adopts the first of as many as four hundred new Airbus 320 aircraft, in an attempt to update and streamline its fleet.

2001: A proposed merger with United Air Lines is terminated following an antitrust investigation by the U.S. Department of Justice.

Changing Times

The acquisition of Piedmont was not only, at $1.59 billion, the largest deal in U.S. aviation history, it was also the most expensive. After the acquisition, USAir began to incur large operating losses. The value of its stock dropped, and the company spent the next few years hovering on the brink of bankruptcy. A major problem was the difference in labor costs between the two airlines. To avoid employee unrest, the salaries of former Piedmont employees were raised to match those of their USAir counterparts. These difficulties appeared to be over when the U.K.'s British Airways agreed in 1994 to purchase 24.6 percent of the shares of USAir. This is the highest level of investment allowed a foreign carrier in the United States. As part of the new alliance, USAir gave up its right to the London Heathrow route and began code sharing on sixty-four U.S. destinations with British Airways. A code-share flight divides a route into two or more segments, with a different carrier flying each segment. A flight might be listed as a USAir trip from Chicago to London; however, USAir would only fly the segment from Chicago to New York and British Airways would fly the segment from New York to London.

In 1995, USAir posted its first profit since 1988. Unfortunately, by December, 1997, British Airways had announced the end of the alliance and the sale of its stock. USAir, now called US Airways, which had announced earlier that year one of the largest single aircraft orders in history, was again struggling with high operating costs and a weak international alliance of partners. The airline that had once formed itself through acquisition became the rumored target of acquisition by other carriers as it faced increasing competition from lower-cost carriers. A proposed merger with United Air Lines in 2001 was halted by a U.S. Department of Justice investigation.

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See also: Air carriers; Airline Deregulation Act; Airline industry, U.S.; British Airways; Mergers

V

Vanguard Program

Date: Beginning on March 17, 1958

Definition: The U.S. program to launch an artificial Earth satellite during the International Geophysical Year (1957-1958).

Significance: The explosion of the booster on the first Vanguard satellite launch, just two months after Sputnik 1 was placed in orbit, was a severe blow to American prestige. Later Vanguard satellites mapped the earth's magnetic field and demonstrated infrared imaging of clouds.

The Beginning of the Vanguard Program

On July 29, 1955, James C. Hagerty, the White House press secretary, announced that the United States would launch small Earth-orbiting satellites as part of its participation in the International Geophysical Year (IGY), an eighteen-month period running from July 1, 1957, to December 31, 1958, and dedicated to the scientific study of the earth. President Dwight D. Eisenhower decided not to use one of the military rockets then under development in the United States to launch America's first satellite. A new rocket, to be called Vanguard, was to be developed for the American artificial satellite project.

The Vanguard Launch Vehicle

The Vanguard launch vehicle required the development of innovative technology. After a series of negotiations between the Glenn L. Martin Company (GLM), which was to manufacture the rocket, and the Naval Research Laboratory (NRL), which managed the project for the U.S. government, the design was completed on February 29, 1956.

The Vanguard launch vehicle was to be a three-stage rocket. The first two stages of Vanguard used liquid-propellant rocket engines, whereas the third stage used a solid-propellant engine. The first stage was based on the Navy's Viking rocket, the second stage was a modified version of the Aerobee-Hi sounding rocket, and the third stage was developed specifically for the Vanguard project.

GLM had developed the Viking rocket, on which the design of the first stage of the Vanguard was derived, for the U.S. Navy in late 1940's. The rocket engine, designed by General Electric (GE), produced 27,000 pounds of thrust. The first stage used kerosene as the fuel and liquid oxygen as the oxidizer. The fuel and oxidizer were delivered to the combustion chamber by an unusual system in which hydrogen peroxide decomposed producing steam, which drove the pumps, and oxygen.

The second stage of the Vanguard was derived from the Aerobee-Hi sounding rocket, built by Aerojet General Corporation. However, the Aerobee-Hi engine produced only four-fifths of the 7,500 pounds of thrust required for Vanguard, so the combustion chamber was redesigned to increase the thrust, and the fuel tanks were lengthened to carry more propellant. To save weight, the second stage carried the guidance system for both the first and the second stages, including a gyroscopic reference system used to ensure that the third stage was oriented so that it would fire along a path leading to an orbit. In addition, the second stage carried the mechanism to jettison the protective nose cone that shielded the satellite from the intense heat and air pressure during the launching phase of the flight. The second stage also carried a mechanism to spin the third-stage rocket, providing stability, and a device to detach the third stage from the second after burnout. The second stage also carried a radar beacon and receiver to cut off the fuel flow and detonate the rocket in case of a serious deviation from the planned flight path.

The third stage of the Vanguard was a solid-fuel rocket motor produced by Grand Central Rocket Company (GCR). It developed about 3,000 pounds of thrust. The takeoff weight of the three-stage Vanguard launch vehicle was about 22,600 pounds.

The Vanguard Satellite

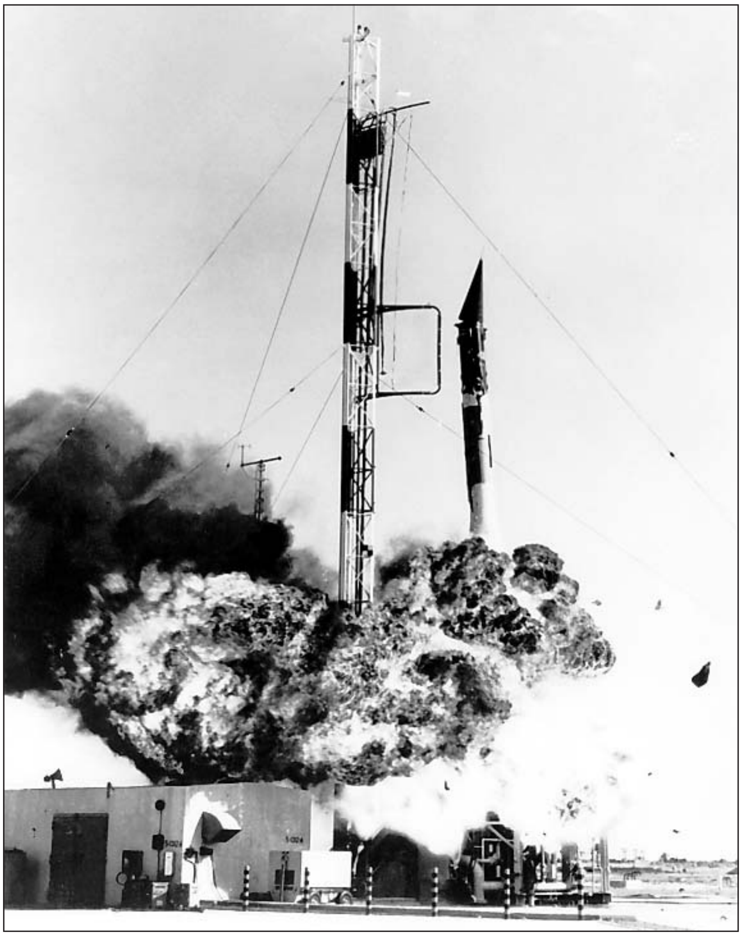
The NRL developed the Vanguard satellite. Although GLM had favored using the rocket's nose cone as the satellite, the NRL decided that the satellite would be spherical. One of the objectives of the Vanguard Program was to determine the atmospheric density at the orbital altitude of the satellite. The effects of air drag on a sphere in flight would be easier to measure than those on a cone-shaped body, making it easier to measure the density of the air. In addition, the National Academy of Sciences planned to use an optical tracking system, and a cone was more likely to tumble and be lost to sight. The National Academy of Sciences preferred a 30-inch-diameter spherical satellite, but 20 inches was the minimum diameter that could be easily tracked with the optical system. The NRL made the sphere of 0.020 aluminum with a 0.001 coating of aluminum oxide. The antennae were four wires that retracted during ascent of the launcher and released to spring outward after separation of the satellite from the burned-out third-stage rocket.

The Vanguard Flights

The first rocket in the Vanguard Program, designated TV 0, was launched from the Cape Canaveral Air Force Station in Florida, the site of all the Vanguard launches, on December 8, 1956. This launch was a test of the liquid-propellant first stage, a refurbished Viking rocket, Viking 13, left over from the Navy's Viking test program. The purpose was to evaluate the performance of the telemetry system, the attitude control system, and the rocket engine. The flight was a complete success. The rocket reached an altitude of 126.5 miles and impacted in the Atlantic Ocean about 97.6 miles from the launch site.

The second flight in the Vanguard Program, a two-stage vehicle designated as TV 1, was launched on May 1, 1957. Vanguard TV 1 used the last of the leftover Viking rockets, Viking 14, which had been slightly modified, as its first stage. A solid rocket engine destined to become the third stage of the satellite launch vehicle was its second stage. The major objectives of TV 1 were to test the mechanism that would spin the solid rocket prior to separation and to test the separation and ignition mechanisms. TV 1 reached an altitude of 121 miles. This flight successfully tested the upper-stage rocket engine and the techniques used to separate the two stages in flight.

Vanguard TV 2 was launched on October 23, 1957. This rocket had the external appearance of the full Vanguard rocket, but only the first stage was a functioning rocket. The second and third stages had the same shape and weight of the real rockets, but they were inert. This was the first flight test of an actual Vanguard first stage, rather than a leftover Viking. The test was successful, reaching an altitude of 109 miles and flying 335 miles down the test range.



The first attempt to launch the Vanguard satellite, on December 6, 1957, failed when the rocket exploded on the launch pad. (NASA)

The first test of the full, three-stage Vanguard launch vehicle, designated as TV 3, occurred on December 6, 1957. Originally only a simple nose cone was to be carried on the TV 3 flight, but in July, 1957, it was decided that a small test satellite, weighing 3.25 pounds, would be carried to allow a test of the radio tracking stations that had been established around the world. The test satellite was simply a 6.4-inch-diameter sphere, made of aluminum and carrying two radio transmitters operating at frequencies near 108 megahertz.

The TV 3 flight was intended as an "all-up systems engineering test," the major objective being to test the performance of all three stages of the Vanguard rocket. The launching of a satellite with minimal capabilities was a secondary objective. However, with the launch coming only two months after the Soviet Union had successfully launched Sputnik, the world's first satellite, the world was watching this first American attempt to launch a satellite. The Vanguard TV 3 rocket exploded only two seconds after liftoff and collapsed back on the launching pad in an eruption of flames. The small satellite, recovered after the fire was extinguished, is now in the collection of the Smithsonian Institution in Washington, D.C.

Although the TV 3 backup vehicle, designated TV 3BU, was in the hangar when TV 3 exploded, damage to the launching pad from the TV 3 explosion delayed the flight of this next Vanguard rocket. The backup vehicle was launched on February 5, 1958. The first-stage engine performed well, but the control system of TV 3BU malfunctioned at an altitude of about 1,500 feet, 57 seconds into the flight, and the vehicle broke up.

The first successful satellite in the Vanguard Program, called Vanguard 1, was was launched by TV 4 on March 17, 1958. Vanguard 1 was a duplicate of the test satellites that TV 3 and TV 3BU had failed to launch. The 6.4-inch-diameter satellite, weighing only 3.25 pounds, was placed into an elliptical orbit. Its high point was 2,465 miles above the earth's surface, and its low point was 406 miles above the earth's surface. Vanguard 1 circled the earth once every 134 minutes. The objectives of the test satellite were to evaluate the performance of the solar cells that provided electrical power and to test the onboard transmitter and the worldwide tracking stations. The only instrument on Vanguard 1 was an internal temperature monitor.

The last of the Vanguard test vehicles, TV 5, was launched on April 28, 1958. This flight was the first that was designed to carry a full-size, 20-inch-diameter Vanguard satellite into orbit. The liftoff proceeded as planned, and the second stage fired normally. However, an electrical problem resulted in the failure of the third stage to separate and ignite, and the satellite fell into the ocean.

Following the test program, a series of Vanguard satellite launch vehicles (SLVs) were flown. The first flight, SLV 1, lifted off on May 27, 1958, carrying a 21.5-pound satellite. However, the launch vehicle failed at second-stage burnout, and the satellite failed to orbit.

SLV 2, carrying another 21.5-pound satellite, was launched on June 26, 1958, and again, the launch vehicle failed. SLV 3, launched on September 26, 1958, also carried a 21.5-pound satellite. The second-stage guidance system failed to provide proper pitch control, and the satellite completed less than one orbit of the earth before it reentered the atmosphere.

With passage of the National Aeronautics and Space Act of 1958, the civilian National Aeronautics and Space Administration (NASA) was created to direct the U.S. space program. NASA took over management of the Vanguard Program in 1958. The first of the NASA-directed launchings, SLV 4, lifted off on February 17, 1959. All three stages fired properly, placing the Vanguard 2 satellite into orbit. Vanguard 2, which will remain in orbit for about 200 years, was the first of the 20-inch-diameter, fully instrumented Vanguard satellites to achieve orbit. Vanguard 2 weighed 20.7 pounds, carried the first instrument to photograph the earth from orbit, and radioed data to Earth for twenty-seven days. SLV 5, launched on April 13, 1959, failed to achieve orbit because of a problem with the separation of the second stage from the launch vehicle.

The last launch of the Vanguard program, SLV 6, used the refurbished TV 4BU backup vehicle. On September 18, 1959, SLV 6 placed the Vanguard 3 satellite into orbit. Vanguard 3 consisted of two spheres connected by a small cylinder. The weight of the satellite was 50.7 pounds. The larger sphere, measuring 20 inches in diameter, contained instruments that measured the micrometeorite impacts and solar radiation, while the smaller sphere, 13 inches in diameter, carried a magnetometer to map the earth's magnetic field. Vanguard 3 transmitted until December 8, 1959.

Results of the Vanguard Program

Despite its small size, Vanguard 1 returned significant scientific results. Precise tracking of the orbital path of Vanguard 1 demonstrated that the earth is not a perfect sphere, but is slightly pear-shaped. Measurement of the air drag on Vanguard 1 demonstrated that the upper regions of the earth's atmosphere were significantly more dense and more variable than previously suspected. Its solar cells proved so durable in the space environment that the transmitter continued to function until March, 1964.

Vanguard 2 obtained the first photographs of the earth from orbit, but the satellite wobbled so much that the photographs were blurred. Nontheless, Vanguard 2 pioneered the development of infrared-sensor technology, later used in the TIROS series of weather satellites to obtain infrared photographs of the earth's cloud cover for use in weather forecasting.

Vanguard 3 accomplished its main task of mapping the earth's magnetic field and measured the intensity of solar X rays.

American embarrassment over the Vanguard TV 3 explosion on December 6, 1957, drew attention to the Soviet lead in space exploration and initiated the space race. U.S. senator Lyndon B. Johnson called the failure "most humiliating," and a *New York Times* headline noted that the failure to launch the test satellite was a blow to U.S. prestige. The American response led to an invigorated satellite-launching effort and the development of U.S. efforts at crewed spaceflight.

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See also: Aerospace industry, U.S.; Crewed spaceflight; National Committee for Aeronautics; Rocket propulsion; Rockets; Satellites; Spaceflight; Uncrewed spaceflight

Jules Verne

Date: Born on February 8, 1828, in Nantes, France; died on March 24, 1906, in Amiens, France

Definition: Prolific French author of novels, short stories, plays, and essays, considered by many to be the father of science fiction.

Significance: Verne was one of the first authors to write about rockets and the possibility of spaceflight. He also popularized the concept of hot-air ballooning with such novels as *Le Tour du monde en quatre-vingts jours* (1873; *Around the World in Eighty Days*, 1873).

Jules Verne was born into a prosperous French family with deep occupational traditions on both sides. His father, Pierre Verne, came from a long line of lawyers, and his mother, Sophie Allotte de la Fuye, came from a family with a strong military history. Verne's formal education began in 1838 at College Saint-Stanislas, where he excelled in geography, Greek, and Latin. Between 1841 and 1846, Verne attended Petit Seminaire and later the Lycée Royal de Nantes, where he began writing short essays and prose pieces. While studying law in Paris, he wrote his first play, *Alexandre VI*, in 1847.

Verne remained in Paris and received his law degree in 1849. He worked as a stockbroker and served as secretary at the Theatre Lyrique from 1852 to 1854, all the time continuing to write. In 1856, he met Honorine de Viane, a widow with two children, and married her the following year. Together they had a son, Michael, who was born in 1861.

Verne's initial foray into adventure stories came when "Un Voyage en ballon" (1851; "Voyage in a Balloon," 1852) appeared in a children's magazine in 1851. Twelve years later, Verne published *Cinq semaines en ballon* (1863; *Five Weeks in a Balloon*, 1876), the first of what would be called his scientific romances. Other books in this vein included *Voyage au centre de la terre* (1864; *A Journey to the Centre of the Earth*, 1872), *De la terre á la lune* (1865; *From the Earth to the Moon*, 1873), *Vingt mille lieues sous les mers* (1869-1870; *Twenty Thousand Leagues Under the Sea*, 1873), *Around the World in Eighty Days*, and *L'Île mystérieuse* (1874-1875, 3 vols., including *Les Naufrages de l'air*, *L'Abandonné*, and *Le Secret de l'île*; *The Mysterious Island*, 1874).

Using a blend of fantasy and science, Verne introduced the concept of space travel using rockets, as well as such futuristic products as television, the submarine, and the Aqua-Lung. He continued writing up until his death in 1904 from the complications of diabetes. For the next ten years, his son continued the publication of his remaining manuscripts.

P. S. Ramsey

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See also: Balloons; Hot-air balloons; Rockets; Spaceflight

Vertical takeoff and landing

Also known as: VTOL

Definition: Aircraft that are capable of taking off and landing without the benefit of a ground run.

Significance: Because VTOL aircraft do not require runways or airfield infrastructure to take off or land, they are flexibile aircraft that can be used in a variety of situations.

History

During World War II, the airplane proved its value for both commercial and military applications. The helicopter also began to prove valuable, but it remained the only type of vertical takeoff and landing (VTOL) aircraft that had been flown successfully. However, the helicopter's relatively slow cruise speed motivated aircraft designers to create new and innovative designs. The main objective of these designs was to create an aircraft with a cruise speed near that of fixed-wing aircraft, but that retained the ability to take off and land vertically.

VTOL aircraft are usually categorized by the means they use to generate power for hover and forward flight. On this basis, VTOL aircraft can be separated into four classes. The first class uses a single propulsion system that alters the direction of the thrust or alters the attitude of the aircraft itself for hover and cruise flight. The second class has a separate group of power plants for hover and cruise. The third class uses its primary power plant for both hover and cruise but also has a separate propulsion system for additional hover lift. The fourth and final class of VTOL aircraft uses its primary propulsion system to drive auxiliary devices for additional vertical thrust in hover.

Single Propulsion System

Aircraft in this first class use the same propulsion system for both hover and cruise functions. They include tilt-shaft/rotor, tilt-prop, tilt-duct, tilt-wing, tilt-rotor, tilt-jet, deflected-slipstream, vectored-thrust, and tail-sitter aircraft types. The first two types use rotating blades that function like rotors in hover and propellers in cruise. Their power plants remain stationary, while the rotor shafts tilt from vertical to horizontal. The basic difference between these two types is that the rotors on the tilt-shaft/rotor aircraft are similar in size to helicopter rotors, and the rotors on the tilt-prop aircraft are the size of propellers.

Examples of tilt-shaft/rotor aircraft include the Transcendental Model 1G (1954-1957) and the Bell XV-3 (1958-1965). Tilt-duct aircraft were proposed to take advantage of the phenomenon of increased thrust that occurs when a propeller is enclosed in a duct. The Doak VZ-6 first flew in 1958 and completed more than fifty hours of flight-testing. Between its first flight in 1966 and 1980, the Bell X-22 completed more than two hundred hours of flight and set a record by hovering at more than 8,000 feet.

In tilt-wing aircraft, the entire wing is tilted to minimize loss of lift in hover; as a result, these aircraft have control problems. The Vertol VZ-2 was quite successful, making more than 450 flights between 1957 and 1965. However, the Hiller X-18, which first flew in 1958, only completed twenty flights before being grounded. The five LTV-Hiller-Ryan XC-142 aircraft that were built accrued more than 450 flight hours beginning in 1964. The smaller Canadair CL-84 made its first flight in 1965, but did not generate sufficient interest from either the United States or Canada.

One of the two types of tilt-shaft/rotor aircraft that resulted in a production aircraft is the tilt-rotor. Tilt-rotor aircraft tilt their rotors from vertical to horizontal and, like the tilt-wing aircraft, tilt the engines as well. In 1977, the Bell XV-15 made its first hovering flight. As of 1986, the two prototype aircraft had accumulated more than 530 flight hours and 1,500 conversions. The National Aeronautics and Space Administration (NASA) is still using it for flight research and development. The success of the XV-15 led directly to the development of the Bell-Boeing V-22 Osprey, which became operational in 2000.

Deflected-slipstream aircraft use flaps to change the direction of the propeller slipstream and create vertical thrust. The first of these aircraft was the Robertson VTOL, which made only tethered flights in 1957. Other, largely unsuccessful, designs included the Ryan VZ-3 Vertiplane (1959-1961) and the Fairchild VZ-5 Fledgling (1959).

A similar, and vastly more successful, type of single-propulsion-system VTOL is the vectored-thrust aircraft, which changes the direction of jet exhaust for hover or cruise flight. The first of these aircraft was the Bell X-14, which first flew in 1957 and remained in use as a flying test bed until 1981. In England, the Hawker P.1127 Kestrel made its first flight in 1960 and became the forerunner of the McDonnell Douglas/British Aerospace Harrier. The first flight of the Harrier took place in 1966, and it entered service with the Royal Air Force (RAF) and the U.S. Marine Corps in 1969, as the first production vertical-or-short-takeoff-and-landing (V/STOL) aircraft. In the Soviet Union, the Yakolev Yak-36 made its first untethered flight in 1963. Although it was never put into production, it led directly to the operational Yak-38 Forger.

Tail sitters are aircraft that produce vertical thrust by changing the aircraft attitude. Therefore, they take off and land on their tails. Although taking off in this manner is routine, landings are much more problematic. Aircraft developed in the 1950's using this concept include the Lockheed XFV-1, the Convair XFY-1 Pogo, the Ryan X-13 Vertijet, and the SNECMA C-450 Coleoptere. None were particularly successful, and the concept was not pursued.

Separate Propulsion Systems

VTOL aircraft with separate propulsion systems use lift engines for hover and separate engines for cruising flight. The lift engine is mounted vertically, and optimized to produce a large amount of thrust for takeoff and landing. In 1954, work began in England on the Short Brothers SC-1, which made its first untethered vertical flight in 1958. Despite a crash of the second prototype, which was repaired, both aircraft flew though 1963.

During the same time period, a French company built the Dassault Balzac V using the airframe of a Mirage III. The craft made its first conventional flight in 1963, but two fatal crashes in 1964 and 1965 effectively ended this program. However, Dassault built a new aircraft, the Mirage III-V, which achieved its first hover in 1965. Both prototype aircraft were eventually lost, but not before setting the speed record of Mach 2.04 for V/STOL aircraft in 1966.

Combined Propulsion System

Aircraft in the combined propulsion system class of V/STOL vehicles use one set of engines for lift only and another set of engines for lift and cruise. One such aircraft, the EWR VJ-101C (1963-1964), became the first supersonic V/STOL aircraft. Others, such as the Dornier Do-31 (1967-1970), the Lockheed XV-4B Hummingbird II (1964-1969), and the VFW VAK 191B (1971-1972), achieved only limited success because of the complexity of their designs. However, the Yakolev Yak-38 Forger, which first flew in 1971, eventually became operational in the Soviet Union. By 1988, when production ended, 231 total aircraft had been built. The Russians also developed the Yakolev Yak-141 Freestyle, which was flight-tested between 1991 and 1995, but never reached production.

Another type of aircraft in this class are tip-jet rotorcraft, which are essentially compound autogyros that transmit full power to the rotor in hover, then transfer power to auxiliary engines for cruise. Powered by jets on the tips of the rotor blades, only two of these aircraft, the McDonnell XV-1 (1954-1957) and the Fairey Rotodyne (1953-1962), were developed. Neither led to operational aircraft.

Augmented Propulsion Systems

Augmented propulsion system aircraft use their power plants to drive auxiliary devices to achieve additional lift in hover. One auxiliary device is the ejector, which was employed on the Lockheed XV-4A Hummingbird (1962-1964) and the Rockwell XFV-12A (1978-1981). The ejector channeled hot exhaust gases into an augmentor, which accelerated cooler air for additional thrust. Another device used was the lift fan, a propeller mounted horizontally in the aircraft fuselage or wing. The Vanguard Omniplane (1959-1962) and the GE-Ryan XV-5A Vertifan (1964-1968) used a lift fan. Aircraft that use rotors for hover flight and auxiliary propulsion for cruise flight are often referred to as compound helicopters. Such aircraft include the Kamov Ka-22 Vintokryl (1960-1964), the Piasecki 16H-1 Pathfinder (1962-1966), and the Lockheed AH-54 Cheyenne (1967-1972).

Donald L. Kunz

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See also: Aircraft carriers; Experimental aircraft; Helicopters; Military flight; Osprey; Propulsion; Rescue aircraft; Rotorcraft

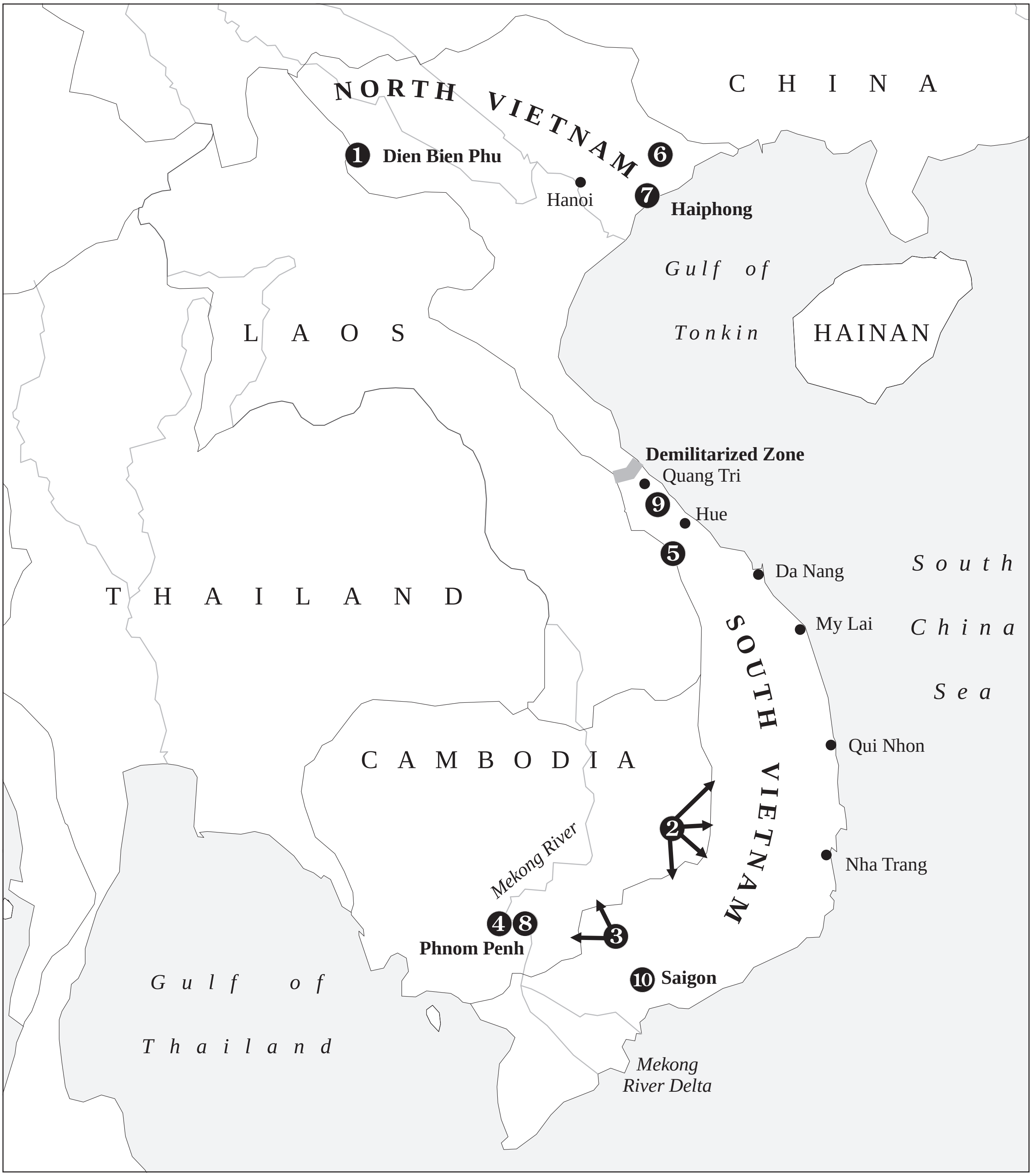
Vietnam War

Date: From 1961 to 1975

Definition: Late twentieth century conflict between U.S.-backed South Vietnam and communist North Vietnam-supported rebels known as the Viet Cong.

Significance: The Vietnam War was one of the most contentious wars in the United States' history. Due to heavy jungle terrain, the U.S. Air Force played an especially important role in U.S. military operations in the region.

Vietnam Conflict, 1954-1975



(1) France falls, 1954. (2) Tet Offensive, January, 1968. (3) Cambodian invasion, April-May, 1970. (4) Sihanouk falls, April, 1970. (5) Laotian incursion, February, 1971. (6) Areas of U.S. bombing, 1972. (7) Mining of Haiphong Harbor, May, 1972. (8)Lon Nol falls, April, 1975. (9) North Vietnamese offensive, spring, 1975. (10) South Vietnam surrenders, April 30, 1975.

Background

The air war in South Vietnam had been in continuous operation before the United States entered the conflict. The U.S. Air Force had been participating in a low-key manner in Vietnam since 1956, actively training and equipping special combat units to deal with counterinsurgency warfare, long before President Lyndon Johnson set the United States upon a course of conflict in that region. It was not until the South Vietnamese government was no longer able to handle their situation that the U.S. presence was increased. The Gulf of Tonkin Resolution gave the president tacit approval to take whatever action in the region he felt necessary. One such action was to wage major air operations into both North and South Vietnam. After the Gulf of Tonkin incident in August, 1964, the U.S. Air Force began armed reconnaissance missions from Thailand and South Vietnam.

Early Combat

The types of aircraft available for air combat in Southeast Asia in the 1960's included transports, fighters and fighter-bombers, bombers, and reconnaissance aircraft. Among the transports were World War II-era C-47's, C-119's from the mid-1950's, C-7 Caribous, C-124's, and C-130A's and C-130B's. Eventually, the C-141A replaced the C-124's. The first three were used in-country, whereas the latter were used to transport heavy equipment and large numbers of personnel over longer distances.

Among the U.S. Air Force's fighters and fighter-bombers were A-1E's and A-1H's, large piston-engine attack aircraft of Korean War vintage. The F-100C Super Sabre, F-102A Dagger, F-104A Starfighter, and the F-105D Thunderchief were also available. The F-102 and F-104, ineffective for this type of war, were removed after a few months in the theater. The F-105 was the Air Force's only deep-strike fighter-bomber, and the F-100 was its predecessor. The U.S. Navy aircraft included the F-8U Crusader (renamed the A-4D during this period), the AD (the same craft as the U.S. Air Force A-1H), and the F4H-1 Phantom (renamed the F-4B during this period). The A-4D was a small, single-engine, single-place attack aircraft. The F-8U was an air-to-air fighter. The F-4B Phantom replaced the F-8.

Bomber aircraft included B-26's (formerly A-26's from World War II), B-57 Canberras, and B-52D's. The B-52 was used over South Vietnam between 1965 and 1972. The B-57's were used until they were replaced by units of new Air Force F-4C's. The B-26 was used in counterinsurgency roles.

RF-101's and RA-5J's served as reconnaissance aircraft. Later in the air war, the RF-4C replaced the almost-depleted inventory of RF-101's.

Numerous air bases in South Vietnam and Thailand supported these aircraft. The bases supporting air strikes against North Vietnam were large; Danang was located on South Vietnam's northeast coast, and Takhli and Korat were located in Thailand. Operations out of Thailand were kept secret until *Time* magazine broke the story in the winter of 1966.

On February 7, 1965, the U.S. base at Pleiku was attacked by mortar rounds and enemy demolition teams; the damage was fairly extensive. Twenty aircraft were destroyed, and there were a number of American casualties. This attack gave the Johnson war team the excuse to launch the next and more extensive phases of the air campaign. Until this time, missions had consisted only of armed reconnaissance in the lower regions of North Vietnam, with some strikes by the U.S. Navy on coastal targets further north. In addition, other Viet Cong (VC) and North Vietnamese Army (NVA) actions made it clear that Hanoi was not going to back down against the limited bombing campaign.

Soon thereafter, U.S. secretary of defense Robert McNamara announced that the United States was bombing North Vietnam for three reasons: to retaliate for the bombing of U.S. and South Vietnamese bases; to prevent the North from supplying the VC in the south; and to improve the morale of the South Vietnamese Army. McNamara made no mention of defeating the North Vietnamese by destroying their war-making capacity. On March 2, 1965, Operation Rolling Thunder began in earnest and would become the air campaign that President Johnson used to punish the enemy and retaliate for North Vietnamese aggression.

Operation Rolling Thunder

Operation Rolling Thunder was a stratagem of the National Security Council, the president's key advisers on the Vietnam War. The campaign was a follow-up for the failure of a plan to keep the pressure on the Viet Cong and North Vietnamese without increasing the commitment of U.S. combat personnel. Early Rolling Thunder missions involved both the U.S. Air Force and U.S. Navy. Targets were primarily those of interdiction, blocking the routes, known as the Ho Chi Minh Trail, by which the North Vietnamese moved personnel and supplies into South Vietnam. Suspected storage areas were also targeted. U.S. Air Force fighter-bombers and U.S. Navy attack aircraft were the principle means of carrying out missions of interdiction.

The F-105D, the only U.S. Air Force deep-strike fighter-bomber, was well suited for the job of carrying out missions against North Vietnam. The U.S. Navy had always used its attack aircraft for coastal operations, and the A-4 was the preferred attack aircraft. The F-4 was the other fighter-bomber used by both the Navy and Air Force in this role. Because the Air Force F-105 had the speed and payload suited for hitting targets deep within North Vietnam, it flew 85 percent of the bombing sorties over the region between 1965 and 1969.

In 1965, the Joint Chiefs of Staff, under the direction of the president, had placed a restricted no-bombing area around Hanoi and Haiphong, a heavily defended region of western North Vietnam where mountains could shield large strike forces from surface-to-air missiles (SAMs) and multiple-gun emplacements. However, strike aircraft faced a problem in getting safely to any target near Hanoi. The route most often used was to refuel off tankers in northern Thailand and then proceed over northern Laos and turn in over the Red River where it came out from the mountains. This route took advantage of a ridgeline that ran from the northwest directly toward Hanoi, which helped to shield the flights from the radar and SAMs. Where the ridge ended, the attack aircraft would have a shorter run toward the highly defended targets around Hanoi. This ridge was named Thud Ridge, for it was there that most missions made ingress to Hanoi, and many F-105's were lost in this area.

Air Operations in the South

While Operation Rolling Thunder was conducted over North Vietnam, air combat operations were flown over South Vietnam in support of the ground operations. Close air support (CAS) missions were those in which fighter-bomber and attack aircraft were directed by ground controllers or airborne forward air controllers (FACs). Thousands of such vital missions were flown by the Air Force, Navy, and Marines in support of both U.S. and South Vietnamese troops engaged with VC or NVA regulars.

The first use of a strategic "nuclear" bomber, the B-52, was against suspected enemy troop areas in South Vietnam. The B-52D was modified to carry 500- to 1,000-pound high-explosive bombs. One aircraft could carry 150 tons of bombs. The early B-52 missions, called Arc Light, were controlled not from Saigon but from Strategic Air Command Headquarters in Omaha, Nebraska.

Escalation

President Johnson and his advisers had expected that Operation Rolling Thunder would pressure the North Vietnamese into negotiating a settlement and pulling back from their support of the civil war in South Vietnam. However, it was clear to many in combat that the U.S. show of force would be insufficient unless it was aimed at targets that would cripple the economy of the north. In June, 1965, there were seven known and occupied, but untargeted, SAM sites ringing Hanoi. By the end of 1966, North Vietnam had more than 150 SA-2 SAM sites. Although the first U.S. strikes against SA-2 sites were difficult and ineffective, the arrival of the modified two-seat F-105's allowed U.S. forces to reduce significantly the effectiveness of the SAMs.

In November, 1965, the end of the first period of F-105 involvement was marked by the arrival of more F-105's from the United States. Aircraft that had been on nuclear alert were moved to Southeast Asia, thus severely depleting the capability of the Fifth Air Force in Japan to counter any threats in that region.

In the first year of Rolling Thunder, an average of two large strikes per week would be authorized by the Joint Chiefs of Staff against targets in the Hanoi area. The need to hit industrial targets was recognized by the air war planners. Railroads in the north were added to the target list and a new target, oil storage, was finally approved in the spring of 1966. The first large-scale strike, on oil storage sites southeast of Hanoi on June 29, 1966, was a success. Eight F-105's from Korat and sixteen from Takhli were the Air Force strike package that day. A strike package of A-4's from the U.S. Navy also participated. Only one aircraft was lost and the pilot bailed out over Hanoi. Further raids against POL (oil) storage sites were flown. Soon the North Vietnamese were dispersing their oil in drums around the country.

Throughout 1965 and 1966, the U.S. forces refrained from bombing major enemy air bases. The appearance of enemy Mig-17's and Mig-21's was rare. American aircrews knew that if they were attacked from the air and had to jettison their heavy bomb loads, the enemy pilots would have accomplished their primary mission. All F-105 Mig kills were made with guns. F-105's shot down twenty-seven enemy fighters during the air campaigns. The F-4 was limited to air-to-air heat-seeking missiles (AIM-9's) and radar missiles (AIM-7's).

In 1966, the Joint Chiefs of Staff gained presidential approval to hit an additional eleven industrial targets. In the meantime, Secretary McNamara, losing faith in Rolling Thunder, issued directives that reduced the number of missions flown by any one squadron from twenty to sixteen per day. Flight leaders knew that their tactics might be negated by North Vietnamese countermeasures in the heavily defended Route Pack 6 region. Even with the incorporation of better SAM-warning devices and new QRC-160 jamming pods, the F-105 pilots faced difficulty in penetrating Hanoi's defenses.

Linebacker I and II

Historians have not fully accepted that by 1968 the ground war in South Vietnam was turning in favor of the allied forces. In February, 1968, the enemy mounted an offensive during the Tet holiday that shocked the American public and cast into doubt the U.S. strategy. Although the worst fighting centered on the South Vietnamese coastal town of Hue, VC and NVA units had sprung up throughout South Vietnam. It was not known until years later that this battle was a result of desperation on the part of the enemy. Their tactics failed, but their strategy worked: On March 31, 1968, Johnson announced that he would not run for another term in office, and on October 31, 1968, the last Rolling Thunder mission was flown. From November of that year through the winter of 1972, air combat operations in South Vietnam continued even as U.S. troop strengths were being reduced.

Finally, after years of fruitless negotiations and diplomatic moves, President Richard M. Nixon authorized resumed bombing over North Vietnam. By then, there were some newer weapons on hand. The Air Force attempted to fly F-105's over North Vietnam at night and in bad weather, but this mission, nicknamed "Ryan's Raiders," was a failure. The Navy and Marine Corps were more successful with the new A-6 Intruder, which could deliver bombs in limited visibility with its improved radar and computerized bomb systems. The question to be answered was how to bring the full power of the U.S. air arm to bear upon North Vietnam. That was done with a massive buildup of fighter-bombers and, later, B-52's.

Linebacker I was designed to hit North Vietnam's industrial sites. Hanoi and Haiphong were no longer off limits. The harbor of Haiphong was mined. In effect, the Joint Chiefs of Staff won its argument that the air war had been shackled to the concept of gradual escalation and that the United States had been unable to unleash the air power at its disposal.

The North Vietnamese government began to respond to this new phase of the air war. It was, however, an exhausting campaign for the pilots of fighter-bombers and supporting aircraft. After the Paris peace talks stalled in the fall of 1972, the U.S. government further escalated the bombing campaign. Under Linebacker II, B-52's began bombing the Hanoi area every night. At first, the bombers came over the area in trail and the SA-2 batteries discovered a break in the jamming through which they could target some of the bombers. Losses were high. It was not until the Strategic Air Command authorized the local commanders at U Ta Pao and Guam to work their own tactics that the North Vietnamese were defeated in their defenses.

This last bombing campaign lasted slightly more than two weeks, and by the end of December, 1972, agreement had been reached to release all prisoners of war and to bring a cease-fire to South Vietnam. It was the chance for the United States to pull out of the Vietnam debacle. No one trusted that the cease-fire would last, but there was

Image Not Available

hope that the South Vietnamese government was strong enough to defend itself.

During the air war over Vietnam, the United States learned many military lessons, some of which led to a complete revamping of both Air Force and Navy combat operations. New aircraft with much greater capabilities were developed and acquired, and new smart bombs were placed into the U.S. arsenal. However, the greatest lesson learned, which carried over into the development of weapons and tactics that were used nearly two decades later, was that seven years of escalation and bombing on a reduced level had been insufficient to end the Communist-driven civil war.

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See also: Air Force, U.S.; Bombing; Fighter pilots; Military flight; Missiles; Reconnaissance; Strategic Air Command; Stratofortress

Viking Program

Date: From August 20, 1975, to November 13, 1982

Definition: An uncrewed U.S. exploratory mission to Mars.

Significance: The Viking Program sent two uncrewed craft, Viking 1 and Viking 2, to Mars. These probes provided the first data from the surface of Mars and detailed images of the entire planet. The two landers were the first craft to land on and directly study the surface of Mars, greatly increasing the knowledge of Mars.

Predecessors to the Viking Program

Prior to the establishment of the Viking Program, four Mariner missions had been sent to Mars. The first, Mariner 4, was launched in 1964. It returned twenty-one images as it flew to within 10,000 kilometers of Mars. Five years later, Mariner 6 and Mariner 7 flew past Mars and sent back 201 pictures. Mariner 9 reached Mars in 1971. Because it was an orbiter rather than a flyby, Mariner 9 returned 7,300 images during its one-year lifetime. This mission discovered the volcanoes and Valles Marineris, which were explored in more detail by the Viking Program. In addition to the American Mariner probes, the Soviet Union launched four largely unsuccessful probes to Mars in 1973, including one that attempted to land on the surface.

Development of the Viking Program

Although plans to conduct uncrewed missions to Mars were initiated shortly after the National Aeronautics and Space Administration (NASA) was established in 1958, the Viking Program was not approved until 1968. Its primary scientific goal was to search for evidence of life on Mars. Other goals were to land on the surface of Mars and return scientific data about the planet. After the project's original launch date was delayed from 1973, the Vikings were finally launched in 1975 from Cape Canaveral, Florida, atop Titan III launch vehicles. They spent one year traveling to Mars and arrived in the summer of 1976.

Each Viking craft consisted of both an orbiter and a lander. Both Viking orbiters orbited the planet for a few years before being powered down. After 706 orbits, the Viking 2 orbiter was turned off first on July 25, 1978. The Viking 1 orbiter completed more than 1,400 orbits before being turned off on August 17, 1980. The two orbiters had different orbital inclinations, so that Viking 1 could study the lower latitudes, while Viking 2 could study the polar regions. Both orbiters returned what at the time were the highest-resolution images available of the entire Martian surface. They also made various atmospheric measurements. Each of the orbiters also flew near one of the two moons of Mars, returning close-up images.

Shortly after arrival at Mars, each lander separated from its orbiter to land on the surface of Mars. Viking 1 landed on the Chryse Planitia, or plain, at 22 degrees north latitude and 47 degrees west longitude on July 20, 1976. Viking 2 landed on the Utopia Planitia at 48 degrees north latitude and 226 degrees west longitude on September 3, 1976. Plains or relatively flat areas were chosen for both landing sites in order to minimize the risk of a crash landing. Despite this strategy, Viking 1 missed a large boulder by only 7.5 meters (25 feet). These two Viking landers were the first craft to successfully land on the surface of Mars. The Viking 2 lander continued to return data until the end of its mission on April 11, 1980. The Viking 1 lander continued to return data until the end of its mission on November 13, 1982. The data included detailed images of the surface, analysis of the soil and atmosphere, and a negative search for evidence of life.

Viking Experiments

Each Viking orbiter contained two cameras used to obtain detailed images of the entire Martian surface. The two Viking orbiters took a combined total of more than 46,000 photographs of the Martian surface. The average resolution was from 150 to 300 meters. In March, 1977, the Viking 1 orbit was adjusted so that its closest approach to Mars was 300 kilometers. Viking 2 followed on October 23, 1977. At this distance, the Viking orbiters could resolve surface features as small as 20 meters, although they did not map the entire surface with this resolution.

After performing their initial task of locating safe landing sites for the landers, the orbiter cameras revealed details of both previously known and previously undiscovered features, including global dust storms; the Olympus Mons and Tharsis Ridge volcanoes, the largest known volcanic mountains in the solar system; the Valles Marineris, a canyon that would stretch across the entire United States; and a number of arroyos, or dry river beds, and other features indicating the past presence of large amounts of liquid water. The orbiters also contained infrared spectrometers and radiometers to map Mars's atmospheric water vapor content and thermal properties. The Viking 1 orbiter took pictures of Phobos, the larger of Mars's two moons, from a closest approach of 90 kilometers. The Viking 2 orbiter photographed Deimos, the smaller of Mars's two moons, from a closest approach of 22 kilometers.

During the landers' descents, instruments on the landers performed analysis of the Martian atmospheric properties at various levels to determine the atmospheric structure. These properties included composition, pressure, and temperature. Scientists learned that the atmosphere of Mars is primarily (95 percent) carbon dioxide. At about 0.5 percent of Earth's surface atmospheric pressure, the surface pressure of Mars is too low for water to exist in a liquid state. Coupled with the evidence of large amounts of liquid water in the past, this information provided evidence for major global climate changes on Mars. After landing, these atmospheric instruments continued to provide data on the Martian weather and climate.

Each Viking lander contained two cameras to provide direct close-up images of the Martian surface. Over the course of the Viking mission, a total of more than 1,400 images were sent back from the Martian surface. They revealed a boulder-strewn reddish surface, which gives Mars the red color that inspired the ancients to name the planet for their god of war. Because Mars's atmosphere is too thin to scatter blue light the way Earth's atmosphere does and because the airborne dust particles are red in color, the images also show a pink sky. The images also show early morning surface frost and structures like sand dunes that result from the global dust storms.

To analyze the composition of this red surface, each lander was equipped with a scoop that could dig a few centimeters into the surface and place a surface sample into an X-ray fluorescence spectrometer. Analysis of these samples showed that the Martian surface contains a fairly large percentage of both iron and oxygen. The red color is iron oxide or rust.

Each lander also contained a seismometer to measure earthquake, or marsquake, activity. The Viking 1 seismometer failed, the only instrument to fail in the entire Viking mission. The other seismometer revealed that the few quakes that occurred were very weak.

Scientists integrated the results of these various experiments to deduce the geological and atmospheric history of Mars. They determined that whereas Mars had been geologically active early in its history, that geologic activity had ceased. Although the planet's volcanoes were no longer active, they had at one time released carbon dioxide, water vapor, and other gases. During this time, the thicker atmosphere had allowed water to exist in liquid form. As the atmosphere gradually escaped into space, water could no longer exist as a liquid and is now present as ice and vapor in thin clouds. Carbon dioxide is still present in the atmosphere. Solar ultraviolet rays split much of the water into hydrogen and oxygen. The lighter hydrogen escaped into space. The oxygen combined with the iron on the surface to produce the rust and the red color.

The Search for Life on Mars

Perhaps the most important experiments performed by the Viking landers were the three experiments designed to search for signs of life on Mars. Although cameras had already observed no obvious signs of large life forms, these experiments—the gas-exchange, labeled-release, and pyrolytic-release experiments—were designed to look for evidence of microscopic life.

The gas-exchange experiment involved placing a soil sample into an aqueous nutrient solution that was dubbed “chicken soup” by the experimenters. Any primitive life forms using the nutrients should release gas, which could be detected by looking for changes in the atmospheric composition of the test chamber. This experiment found no evidence of biological activity.

The labeled-release experiment used carbon-14, a radioactive isotope of carbon, in the nutrient solution. Primitive microscopic organisms absorbing the nutrient would eventually release gas containing the carbon-14, which could be detected by its radioactivity. The pyrolitic-release experiment also used carbon-14, but it used it in the atmosphere rather than in the nutrients. After an incubation period, the sample was analyzed to see if it had absorbed any of the carbon-14. The results of these experiments were somewhat ambiguous, but could be explained by chemical rather than biological reactions. Hence, the Viking mission, which was the first specific attempt to find evidence of life on another planet, found no solid evidence of life on Mars.

Prior to the inception of the U.S. space program, many people had believed that Mars might contain life. This idea resulted largely, but not entirely, from the efforts of Percival Lowell who, in the early twentieth century, had popularized the idea that Mars contained canals. Lowell made detailed maps of these alleged canals, asserting that they had been built by a race of Martians to transport water from the pole caps to the warmer equatorial regions on their dry world. Although most astronomers of the time disputed Lowell’s work, the idea of life on Mars had been firmly planted in the public imagination. In addition, other scientific studies of Mars had shown that although conditions there might be harsh, life on the planet was at least a possibility. After the Viking Program found no evidence of life on Mars, most scientists assumed that Mars was lifeless. However, the question was reopened two decades later by the announcement of possible evidence for primitive fossilized bacteria in a Martian meteorite that had been discovered in Antarctica.

After the Viking Program ended, there was relatively little exploration of Mars until the 1990’s, when exploration of Mars resumed. The next successful landing on Mars was that of the Pathfinder, which landed in July, 1996, twenty years after the Vikings had landed. For two decades, the Viking Program had provided humankind’s most detailed knowledge of the planet Mars.

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See also: National Aeronautics and Space Administration; Spaceflight; Uncrewed spaceflight

Virgin Atlantic

Definition: A successful airline based in England that has broken new ground in airline amenities.

Significance: Virgin Atlantic is one of the few airlines founded since 1978, when the deregulation of the airline industry drove competition to cutthroat levels, to remain in business and to carve a niche for itself. Virgin Atlantic’s success is largely based on its innovations in in-flight amenities and its projection of a hip, postmodern image.

Origins

Richard Branson is the founder of Virgin Atlantic. By the time he established the airway, Branson was already a successful entrepreneur with his Virgin Group, a conglomerate anchored by Virgin Records. In 1984, Branson followed up on a suggestion to found a new airline company operating a jumbojet passenger service between London and New York. On June 22, 1984, Virgin Atlantic made its first flight from London to Newark, New Jersey. Virgin Atlantic went on to become the second largest British long-haul international airline. It flies from London's Heathrow and Gatwick Airports to eighteen different cities throughout the world, including Shanghai, China, and the Caribbean.

Events in Virgin Atlantic History

1984: Virgin Music entrepreneur Richard Branson launches Virgin Atlantic airlines, with flights from London to New York.

1985: Virgin Atlantic inaugurates service to Miami, Florida, and introduces its Virgin Holidays and Virgin Cargo divisions.

1986: The airline initiates first-class sleeper service and incorporates its second Boeing 747 into its fleet.

1987: The airline carries its one-millionth passenger. Branson makes a record-breaking balloon flight across the Atlantic and subsequently launches the Virgin Airship and Balloon Company.

1988: Virgin Atlantic introduces service to Los Angeles, becoming the second-largest long-haul carrier in the United Kingdom.

1989: Virgin Atlantic begins flights to Tokyo and adds two more Boeing 747's to its fleet.

1990: The airline adds another 747 to its fleet and begins offering in-flight manicures and massages.

1991: Boston is added to Virgin Atlantic's route network, and the airline equips all seats with individual television sets for passengers' entertainment.

1992: Branson sells Virgin Music for $880 million and reinvests the money in Virgin Atlantic. The airline begins offering daily service to Orlando, Florida.

1994: Hong Kong and San Francisco are added to Virgin Atlantic's network of destinations.

1995: The airline adopts a nonsmoking policy on all transatlantic and Hong Kong-route flights.

1997: Virgin Atlantic adopts the new Airbus A340-600 aircraft.

1999: The airline redesigns its staff uniforms and aircraft livery and adds Chicago and Cape Town to its route network.

2000: Virgin begins offering the first-ever direct flights between London and Las Vegas.

Development of Virgin Atlantic

Branson decided to concentrate on the airline part of his business, selling Virgin Music in 1992 to Thorn EMI for $1 billion and reinvested the profits into Virgin Atlantic. Branson still had vast business interests, which fed into his airline interests. In December, 1999, Singapore Airlines purchased 49 percent of Virgin Atlantic.

Virgin Atlantic continued to expand into the jumbojet market. In May, 2001, Virgin Atlantic purchased six Airbus A380 superjumbos, with an option to buy six more, to be used on the North Atlantic routes. Additionally, Virgin modernized its operations and planned a move to Boeing's Mach 0.95 aircraft.

Operating Philosophy

Virgin Atlantic kept its offbeat image and edge in customer service through adherence to Branson's operating philosophy—namely, to operate a business that is "really focused on the customer and what the marketing proposition is."

In 2001, Virgin Atlantic had seventeen Boeing 747's, ten Airbuses, eight A340-600's, and six A380's on order. Virgin had expanded to Toronto, giving it an operation in the top-ten long haul markets from Heathrow. It also opened a route to Lagos, Nigeria, challenging British Airways. It was expanding to Dubai, Singapore, Australia, Osaka, and India.

Virgin has long been known for its in-flight amenities, such as a masseuse and personal entertainment centers. It announced plans to offer gyms and shops on the new A380's, and possibly bistro bars on the galley, as incentives to get passengers to move around on the plane. It is certain that Virgin will continue to maintain its "quirky" reputation for trying new things to keep passengers interested.

Virgin's advertising, for example, is on the cutting edge and eye-catching. Virgin ran a "sexy" campaign with models in thigh-high boots. The advertisements stressed the fun of its business-class service and mocked the increasing phenomenon of air rage by stressing that no one ever curses the air masseuses. Ads also poked fun at Queen Elizabeth and international travel itself.

Branson considered establishing an all-business-class airline, an area he believed has been neglected. The airline would fly not only to cities such as London and New York, but also to Nairobi and Seattle. On June 12, 2001, Branson announced that Virgin Atlantic was in talks with Bombardier, a Canadian regional aircraft manufacturer, about establishing an all-business-class carrier called Jetset Airlines. Branson explored the possibility of turning Bombardier's Global Express aircraft into a first-class sleeper configuration that would accomodate twenty passengers. However, he also looked into Airbus Industrie's A319 corporate jet and Boeing's business jet.

Branson had not forgotten the coach passenger, either, and moved to make these passengers comfortable with wider seats and more entertainment and food choices. Virgin became the first airline to have e-mail and World Wide Web access available for every passenger. Another aspect of that attention was Virgin Atlantic's campaign to update the look of flight attendants. In 1998, Virgin Atlantic hired Irish designer John Rocha to change the uniform of its flight attendants. Rocha gave them a sophisticated, red-suited look. Other airlines soon followed. British Airways hired designer Julien Macdonald to change their attendants' red, white, and blue garb. Air France employed designers Marithe and François Girbaud to update their crew's bland uniforms. JetBlue's attendants began their tenure with a chic, city-sleek, midnight blue ensemble.

Awards

As a result of Branson's innovative approach to airline management, Virgin Atlantic has won numerous awards for nearly every aspect of its service. In addition to awards for long-haul, business-class, coach, freight, and charter service, the airline has been awarded for its in-flight entertainment, in-flight magazine, food service, advertising, frequent-flier program, and even environmental awareness. In a highly competitive industry where airlines go out of business more often than they start up, Virgin Atlantic has made its mark by focusing on making the process of getting to the destination a pleasure rather than a chore.

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See also: Air carriers; Airline industry, U.S.; Richard Branson; Transatlantic flight

"Vomit Comet"

Also known as: KC-135A Reduced Gravity Flight Laboratory

Definition: A Boeing KC-135 aircraft equipped to conduct experiments simulating the zero-gravity environment of spaceflight.

Significance: Occupants of spacecraft in orbit around Earth feel no gravitational pull, a condition known as weightlessness. The KC-135A Reduced Gravity Flight Laboratory permits simulation of weightlessness for up to twenty-five seconds at a time, by flying through a controlled maneuver that simulates free fall and allows several types of experiments to be conducted in a simulated space environment.

Aircraft Particulars

The nickname "Vomit Comet" stems from the fact that many experimenters feel motion sickness during the maneuvers required to go in and out of the zero-gravity environment. A predecessor of the Boeing 707 airliner, the KC-135 Stratotanker was originally designed for refueling military aircraft in flight. Built in Seattle, the first KC-135A entered the U.S. Air Force fleet in 1957, and the last was delivered in 1965. About 550 of the 732 Stratotankers built remain in service.

The National Aeronautics and Space Administration's (NASA's) KC-135A Reduced Gravity Flight Laboratory is powered by four turbojet engines. It has a 60-foot-long, 10-foot-wide, 7-foot-high padded cargo bay, equipped with electrical power outlets, compressed gas sources, an overboard vent system, and photo lights with power receptacles and attachment points at which to mount experiments. Experimenters sit in the aft cabin during takeoffs and landings but move up into the padded area during the maneuvering parts of the flight.

The Vomit Comet is generally based at Ellington Field, near the Johnson Space Center in Houston, Texas. It also operates out of the NASA Glenn Research Center in Cleveland, Ohio, for several weeks each year to support the center's microgravity research.

Users of the KC-135A include astronauts training with experiment hardware prior to space shuttle missions, researchers conducting initial stages of experiments destined for space, and, since 1997, undergraduates and high school students who design and conduct experiments in reduced gravity. The current Vomit Comet is the third in a series of airplanes used for microgravity experiments.

Although the KC-135A has earned the "Vomit Comet" nickname through a long history of usage, other aircraft are also used for similar experiments. NASA Glenn Research Center, formerly called the Lewis Research Center, has operated a McDonnell-Douglas/Boeing DC-9 aircraft and a Learjet Model 25 for weightlessness research. Weightlessness experiments are also performed by the European Space Agency (ESA) and the Russian space agencies using other kinds of airplanes. ESA uses an Airbus A300 airplane. Russia uses an Ilyushin Il-76 aircraft, operated out of the Yuri Gagarin Cosmonaut Training Center in Star City.

Flight Profile

During a typical flight, the Vomit Comet flies out over the sea, climbing to around 26,000 feet above sea level and reaching 350 knots indicated airspeed. While the yaw and roll are controlled by autopilot, the pilot steadily pulls the craft's nose up to a 45- to 50-degree angle. The airspeed drops off, and the aircraft experiences a maximum acceleration of 1.8 times the acceleration of gravity (1.8 g), as the aircraft climbs steeply. The pilot then pushes the stick forward and reduces thrust, while using two of the engines to control the forward acceleration to zero. The aircraft executes a parabolic arc for about twenty-five seconds. At the top of the parabola, the aircraft reaches an altitude of 36,000 feet and a speed of about 160 knots. The pilot then pushes the stick forward to send the plane to a 45-degree, nose-down attitude and increases the thrust. When the speed again reaches 350 knots, the pilot pulls back on the stick, with the aircraft experiencing an acceleration of up to 1.8 g's.

This maneuver is typically repeated forty times during a two-hour flight, making up to one hundred parabolas on some flights. During the twenty-five-second segment in which the plane goes over the top of the parabola, the occupants experience weightlessness and begin conducting experiments, practicing chores, or executing maneuvers to test movement in weightless conditions.

The abbreviation "g" refers to the acceleration of gravity. Sitting still on Earth, one experiences an acceleration of 1 g, or a gravitational force of 1, the normal sensation of gravity. During periods of changing acceleration, such as a banking turn in an airplane, the so-called g-loading will change.

The duration of altered gravity depends on the types of conditions sought. Approximate values are as follows: Negative g (minus .1 g): fifteen seconds; 0 g: twenty-five seconds; lunar g (.16 g): approximately forty seconds; Martian g (.33 g): approximately thirty seconds. Atmospheric turbulence and other problems prevent the KC-135A from holding a truly zero-gravity level of acceleration for any length of time. The acceleration value is displayed inside the cabin on a large electronic display, which is updated three times per second and typically shows values between plus .03 g and minus .03 g, with the frequency of fluctuations depending on the atmospheric conditions. The target g-level is around .01 g on calm days.

Experiment Procedures

Those who fly experiments on the KC-135A must obtain a U.S. Air Force Class III medical certificate with NASA physiological training, which consists of an eight-hour training course and a high-altitude chamber run in which experimenters are trained to recognize symptoms of hypoxia, or oxygen deficiency, in case of a loss of aircraft pressure.

On the day before a flight in the KC-135A, a test readiness review is conducted, in which safety experts review the test documentation and discuss the experiment in detail with the experimenters. Approved experiments are mounted inside the padded cabin, fastened to strong points, and powered if necessary with the 120-volt AC power supply inside the cabin.

On the day of the flight, a preflight safety video reminds participants about safety equipment and procedures. The occupants wear flight suits and are given antinausea capsules and a cellophane bag to use in case of motion sickness.

Other Microgravity Experiments

Drop towers, facilities from which objects are dropped, fall freely, and are decelerated at the bottom using stacks of cushioning material, allow about two seconds of microgravity. Some drop towers have had the air evacuated from them in order to reduce air resistance and come closer to providing a true zero-gravity environment. The disadvantages of this type of microgravity environment are the short duration of free fall and the relatively sharp deceleration at the end.

Weightlessness experiments are also performed in water tanks with astronauts wearing suits that provide enough buoyancy to make them feel weightless. Although this method allows for a longer duration of weightlessness, water poses considerable resistance to movement.

Sounding rockets, which climb for several miles and then drop their payloads in free fall, offer up to eight minutes of microgravity, after which a parachute opens and brings the payload to Earth at a safe speed. However, this method of acheiving weightlessness is more expensive than are airplane experiments, and does not always allow the recovery of the payload.

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See also: Astronauts and cosmonauts; Crewed spaceflight; Forces of flight; Gravity; Microgravity; National Aeronautics and Space Administration; Spaceflight; Training and education

Voyager Program

Dates: Beginning on August 20, 1977

Definition: An uncrewed American exploratory mission to the outer solar system.

Significance: The Voyager Program probes executed the first "Grand Tour" in planetary exploration by successively encountering the outer planets: Jupiter, Saturn, Uranus, and Neptune. Such a tour, using the "planetary-gravity-assist" technique to travel from planet to planet, is possible only once every 175 years.

Introduction and Overview

The Voyager Program conducted the first planetary Grand Tour in history by sending two uncrewed spacecraft on a mission to explore the outer solar system. Preliminary design began in 1969. After obtaining official approval in May, 1972, Voyager 1 was launched on September 5, 1977. Voyager 2 was actually launched a few weeks earlier on August 20, 1977. Both were launched from Cape Canaveral, Florida, by Titan III-E/Centaur rockets. Voyager 1 encountered Jupiter in 1979 and Saturn in 1980, before flying out of the plane of the solar system. Voyager 2 encountered Jupiter in 1979, Saturn in 1981, Uranus in 1986, and Neptune in 1989. As of 2001, the two Voyager spacecraft are the most distant human-made objects from Earth and have provided humankind's most detailed views of the outer solar system.

The Voyager Program was originally approved as a mission to Jupiter and Saturn only. However, the mission scientists and engineers knew that during the 1970's, the configuration of the outer planets in the solar system provided a unique opportunity for a Grand Tour of the outer solar system. With this Grand Tour in mind, they designed the Voyager craft with the capability of extending the original mission should approval later be granted.

After Voyager's early success, the National Aeronautics and Space Administration (NASA) officially approved the extension of the mission. Voyager 1 turned to fly out of the plane of the solar system after its encounter with Saturn. Voyager 2 continued on to explore Uranus and Neptune. The only possible trajectory that would have allowed Voyager 2 to continue its mission to Pluto went directly through the interior of the planet Neptune.

During each planetary flyby, the Voyager craft used the gravity-assist technique, a sort of gravitational slingshot effect from the giant planets that propelled the spacecraft on to the next planet. The Voyager spacecraft trajectories were very carefully selected so that as the Voyager fell toward a planet, the craft would pick up speed. The planet also deflected the trajectory so that the craft was aimed in the right direction for the next planetary encounter. These gravitational boosts shortened the time required for Voyager 2 to reach Neptune by nearly two decades and significantly reduced the amount of fuel necessary to propel the craft from planet to planet.

Envoys Beyond the Solar System

On February 17, 1998, at a distance of 6.5 billion miles, Voyager 1 exceeded the distance from the Sun of the slower Pioneer 10 spacecraft (launched in 1972) to become the most distant human-made craft from Earth. As of January, 2001, the Voyager 1 and 2 craft remained functional and were located more than 7.4 billion and 5.8 billion miles from Earth, respectively. They have enough power to last until about 2020, when they will both be more than 10 billion miles from Earth. During this time, they may cross the heliopause, the boundary between the solar system and the surrounding universe, to become the first human-made objects to leave the solar system. Voyager 1 will pass near a faint star in the constellation Camelopardis in about 40,000 years. In 296,000 years Voyager 2 will pass near the brightest star in the night sky, Sirius.

As humankind's envoys beyond the solar system, both Voyager craft carry records containing pictures and sounds from Earth. The records are 12-inch copper disks plated with gold. The craft also contain needles for playing the records and illustrations of their use. More than one hundred pictures were included, twenty of which are in color. These pictures attempt to depict Earth and its rich variety of life, including human life and culture. The records contain spoken greetings in sixty different languages, natural and machine-made sounds of Earth, and a 90-minute selection of musical excerpts that represent a variety of cultures and forms.

Instrument Packages

Each Voyager craft, which is about the size and mass of a subcompact car, contains a suite of scientific instruments. The Voyager images were provided by two cameras on each craft. They have filter wheels to allow color images. The narrow-angle cameras, capable of resolving a newspaper headline from a distance of 1 kilometer, provided high-resolution images. The wide-angle cameras provided the global images at a lower resolution.

The Voyager crafts' infrared and ultraviolet spectrometers and photopolarimeters provided information about atmospheric and satellite compositions and structures. The planetary radio astronomy experiment measured the planetary radio emissions. The magnetometers measured and studied the planetary magnetic fields and their interactions with the solar magnetic field. Four experiments—the plasma-particles experiment, the plasma-waves experiment, the low-energy charged-particles experiment, and the cosmic-ray particles experiment—were designed to provide information about energetic charged particles at the planetary encounters and in interplanetary space.

Jupiter Encounter

Voyager 1 flew within 217,000 miles of Jupiter on March 5, 1979. Voyager 2 followed on July 9, 1979, flying within 449,000 miles. The detailed images and measurements taken during the Voyagers' encounter with Jupiter vastly exceeded what had been possible to accomplish from Earth or on previous Pioneer missions and revealed much new information about Jupiter and its system of moons. Pictures of Jupiter revealed beautiful detail in the striped zone-and-belt structure of the planet's cloud tops. The zones are the lighter-colored stripes, and the belts are the darker-colored stripes. The Voyagers showed that these zones and belts are manifestations of both east-west and up-down circulation patterns in the atmosphere. The high wind speeds are manifested by the obvious turbulence in the zone-belt interfaces. The previously known Great Red Spot is a centuries-old anticyclonic storm larger than Earth. It rotates fully counterclockwise within a period of four to six days. The Voyagers also measured a strong planetary magnetic field for Jupiter.

Surrounding Jupiter, the Voyager mission discovered a ring system, albeit much less extensive than that of Saturn, as well as three small, previously undiscovered moons. Both craft observed Jupiter's previously known moons in unprecedented detail, and Voyager 1 made the unexpected observation that Jupiter's closest major moon, Io, had nine active volcanoes at the time of the Voyager 1 encounter. The next major moon, Europa, has an icy crust covered with a large number of intersecting cracks, beneath which there may be a liquid ocean. Voyager found two distinct types of terrain, grooved and cratered, on Jupiter's next major moon, Ganymede. The final major moon, Callisto, has an ancient surface saturated with craters.

Saturn Encounter

On November 12, 1980, Voyager 1 flew to within 77,000 miles of Saturn, followed by the Voyager 2 on August 25, 1981, which flew to within 63,000 miles of Saturn. Both craft returned unprecedented data. Pictures of Saturn revealed a zone-and-belt structure to the cloud tops similar to that of Jupiter. However, Saturn's zones and belts did not have the richly detailed structure found on Jupiter, despite Saturn's higher measured wind speeds, which can exceed 1,000 miles per hour. Apparently, this zone-and-belt structure is slightly deeper on Saturn than on Jupiter and covered by a hazy layer that masks its detail. The Voyagers also measured Saturn's magnetic field and confirmed that it is the only planetary magnetic field almost perfectly aligned with the rotation axis.

Saturn's most beautiful feature is its extensive ring system, the only one that is directly visible from Earth. Voyager photographs revealed surprisingly detailed and completely unexpected structures. The major rings, called the A-, B-, and C-rings, consist of hundreds of smaller individual rings. They are apparently caused by the combined gravitational forces of Saturn's many moons on the individual ring particles orbiting Saturn. The faint outer F-ring was revealed to consist of apparently twisted strands. Dark spokes were found in the B-ring. Some of these spokes rotate with Saturn's magnetic field rather than at the orbital speed of ring particles.

The Voyager mission discovered six new moons of Saturn and studied the planet's previously known moons. Saturn's largest moon, Titan, was found to have a significant atmosphere, consisting primarily of nitrogen, like Earth's atmosphere, but much colder. Further studies may help scientists understand the chemistry of Earth's primitive atmosphere. With a diameter of only about 300 miles, Enceladus should be too small to be geologically active, yet it surprisingly proved to be the most geologically active of all Saturn's moons, except Titan. The source of this activity is poorly understood. The moon Mimas is slightly less than 250 miles in diameter, but it has a 6-mile deep impact crater that is 80 miles in diameter. This crater also has a central mountain comparable in size to Mount Everest. With this crater, Mimas resembles the Death Star of the motion picture *Star Wars*.

Uranus and Neptune Encounters

After the Saturn encounter, Voyager 1 exited the plane of the solar system. Voyager 2 continued on its Grand Tour to explore Uranus and Neptune. The challenges of the outer solar system necessitated extensive reprogramming during the four-year voyage from Saturn to Uranus. At a distance of nearly 2 billion miles from the Sun, it is much darker at Uranus. Hence, long time exposures are needed for the images. Because Voyager 2 was speeding by on its outward journey, it was not possible to mount the cameras on a steady tripod, as is usually done for timed exposures. In a difficult maneuver, called image-motion compensation, the craft rotated just the right amount to compensate for its motion. This technique worked to produce clear sharp images of Uranus and Neptune. In addition, with only a 23-watt radio transmitter the method used to transmit data back to Earth had to be revised, and the receiving antennaes on Earth had to be linked to pick up the distant signal.

On January 24, 1986, Voyager 2 flew to within 67,000 miles of Uranus, taking images that revealed a nearly featureless pale blue planet. With extensive computer processing, the images show a barely visible cloud structure on Uranus. Three years later, on August 24-25, 1989, Voyager 2 flew to within only 3,000 miles of Neptune's north pole. In contrast to Uranus, Neptune showed considerable atmospheric activity. There was a dark blue spot called the Great Dark Spot, similar to the Great Red Spot of Jupiter, and a few smaller dark spots. There were also white lenticular-shaped clouds above the Great Dark Spot.

Both Uranus and Neptune have fairly strong magnetic fields, with large tilts relative to their planetary spin axes. The source of these magnetic fields is poorly understood. The Voyager cameras also studied the thin ring systems around both planets. Voyager 2 studied the previously known moons around both planets and discovered ten new moons around Uranus and six around Neptune.

Context

On February 14, 1990, at a distance of 3.7 billion miles from Earth, Voyager 1 took a unique family portrait of the solar system. A series of 39 wide-angle images shows the Sun and all but the three smallest planets, Mercury, Mars, and Pluto. The narrow-angle camera also took images of the six visible planets. From this perspective, Earth is a faint dot.

The success of the Voyager mission far exceeded expectations. On their twelve-year mission to the outer solar system the Voyager craft sought out and explored many strange new worlds. Following the Pioneer 10 and 11 missions, the Voyagers were not the first missions to Jupiter and Saturn. However, the Voyager mission was the first to distant Uranus and Neptune. The Voyager mission provided the first detailed look at all these planets. These hardy craft will also be the first human-made objects to leave the solar system during the first two decades of the twenty-first century.

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See also: National Aeronautics and Space Administration; Spaceflight; Uncrewed spaceflight

W

Wake turbulence

Also known as: Wake vortex hazard, Kármán's vortex street

Definition: Disturbed fluid motion occurring in the region following an object moving through a fluid.

Significance: The different types of wake turbulence can disrupt the flow of air moving over an aircraft, posing flight hazards.

Types of Wake Turbulence

Two forms of wake turbulence are significant in flight. The first is the presence of vortices in the wake of aircraft. A vortex is defined as a region within a body of fluid in which the fluid elements have an angular velocity. Wake vortices are regions of spiraling or circulating fluid left behind in a medium after an object producing lift, or experiencing changes in lift, passes through the medium. Wake vortices created by aircraft pose hazards to following aircraft. This hazard of spiraling air limits the spacing between aircraft takeoffs or landings at many airports.

A second form of wake turbulence is the turbulence in the wake of mountains or tall buildings that is encountered by low-flying aircraft under windy conditions.

Wake Vortices

Every aircraft leaves behind a region of disturbed air, called its wake. The disturbances that are due to the flow accelerated by the propeller or jet engines are called propwash or thrust-stream turbulence. The largest disturbances are due to the effects of lift. When an aircraft generates lift on its wings, the pressure below the wings is lower than the pressure above. At the wingtips, the flow from below rolls up and over the wings. This rotation forms a vortex, which is a region resembling a long, thin tube, where the air moves in a spiral path. A vortex generally has a small core region of high rotation speed, surrounded by a much larger region of slower-moving fluid. Thus each aircraft typically leaves behind a pair of vortices, rotating in opposite directions and also moving downward at speeds of a few hundred feet per minute. The strength of these vortices is a function of the aircraft's weight, speed, wing shape and aspect ratio, and acceleration or deceleration. Peak tangential velocities encountered in a vortex can be in excess of 300 feet per second.

In addition to the strong wingtip vortices, there are several other vortices, and often a continuous sheet of vortices trailing behind aircraft. These vortices originate wherever there is a change in the distribution of lift across the aircraft. Leading-edge vortices are seen over swept wings and tails. Inboard vortex sheets are seen behind most wings and rotor blades. When lift changes suddenly, as during takeoff or a sharp maneuver, a starting vortex is left behind, with its core perpendicular to orientation of the trailing vortex. Sufficiently far behind the aircraft, all these vortices are swept up into the wingtip vortices.

Wake vortices originate when the aircraft rotates off the runway at takeoff and end when the aircraft touches down on the runway. The vortices generated near the runway can persist near the ground, generally spaced a little less than a wingspan apart and generally within a height of about one wingspan from the ground. They can then drift with the wind and cross over to adjacent runways.

An aircraft's wake vortices persist in the air for several minutes after the aircraft has passed. Because large airliners travel at nearly 600 miles per hour, persistence of vortices for three minutes means that strong vortices can be encountered as far as 30 miles behind the airliner in the upper atmosphere.

Helicopter rotors, whose tip speeds can exceed the speed of sound, also generate very strong vortices, which persist for substantial periods. Interaction of these vortices with the ground can kick up clouds of dust and small stones, posing hazards to people standing on unprepared surfaces when a helicopter hovers close to the ground. Pilot training manuals generally recommend that people remain at least three rotor diameters away from helicopter rotors to avoid this hazard.

Hazards

Aircraft encountering another aircraft's wake vortices are in danger of rolling out of control. Strong upward or downward air motion may be encountered as many as 50 feet from the central core of a vortex. The danger is greatest for small aircraft with short wings following a large, heavy aircraft with a clean configuration, that is, with a minimum of flaps and other controls deflected, flying at a slow speed. General guidance for avoiding the wake vortex hazard includes: flying above the flight path of the airplane ahead, touching down on the runway beyond the touchdown point of the previous aircraft, spacing takeoffs on the same runway by three minutes, maintaining a vertical separation of at least 1,000 feet between airplanes.

Because wake vortices limit the spacing between aircraft in flight, there is strong interest in the aviation community to find ways to alleviate their hazards. One method involves the alteration of wingtip shapes to generate several vortices that interfere with each other. Others include blowing air out of the wings near the tips and deflecting various small control surfaces. A phenomenon called the Crow instability has been observed, in which the counter-rotating pair of tip vortices left behind by an aircraft develop sudden bursts and dissipate shortly thereafter. Some research efforts attempt to accelerate the instability by suitably modifying the vortices. Other approaches to the alleviation of wake vortex hazards include the placement of sensing devices near airports that identify vortices drifting onto active runways and warn approaching aircraft. Researchers also attempt to place sensors on aircraft that sense such vortices in the aircraft's flight path.

Wake Turbulence Behind Bluff Bodies

Although aircraft are streamlined, mountains and buildings rarely are, and winds blowing across them cause large regions of turbulence downstream. Theodore von Kármán analyzed the flow patterns behind cylinders and described a phenomenon that became known as Kármán's vortex street, a series of vortices, of opposite directions, left behind alternately from each side of the cylinder. Such patterns can be observed in the clouds moving across islands and mountains. Aircraft flying into such conditions can encounter strong turbulence.

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See also: Aerodynamics; Airplanes; Runways; Safety issues; Tail designs; Weather conditions; Wing designs

Weather conditions

Definition: The changing physical conditions in the earth's atmosphere.

Significance: The amount and the location of heat, cold, wind, clouds, and precipitation affects the ability of all forms of flight to perform safely in the atmosphere.

Introduction to Weather

Weather is necessary to life on earth. The significant force that creates and drives weather is energy from the sun. The bulk of the world's water is contained in its oceans and seas. This water contains salt and is not potable for humans and other animals. The sun's heat energy warms this salty water, causing water vapor (in the form of a gas) to rise above the surface. When the water changes from a liquid to a gas, the salt is left behind. Wind blows this freshwater vapor over land, where it can condense and fall as rain.

Weather conditions are the processes and forces involved in causing this cycle of life-giving water to transfer from the sea to the sky and then to the ground. A key force in this process is the wind. Air movements and cloud formations are complex in nature, primarily due to uneven heating of land and water in different regions. Other factors are the rotation of the earth, the tilt of its axis, and its changing distance from the sun.

Both land and water start heating when the sun rises. The sun heats ocean surface water more slowly than it heats the land. This is partly due to the circulation of ocean water, whereby heat is transferred down to deeper layers, as opposed to the stability of solid land. Therefore, the ocean stores more heat energy than the land, and it gives up its heat energy more slowly than land. All land that is dark, including farmland, forests, and paved cities, readily absorbs heat energy from the sun. White regions of ice and snow mostly reflect the sun. When the sun goes down, land surfaces cool more quickly than water surfaces.

Because of gravity, the atmosphere is denser nearest the ground. Air molecules are more compacted at the surface of the globe and become less dense at higher altitudes. The density of the air at ground level, however, varies due to the uneven heating effects around the earth. This is very important, because air will flow from a high density (high-pressure) region to a low density (low-pressure) region. This pressure difference between any two areas causes an attempt to balance out the different air densities. The movement of this equalizing air is the wind, and the more the pressure differences, the stronger the wind.

The important mechanism that allows clouds to form involves the dew point. This is the temperature at which water vapor in the air will condense. The heat of the land that has received energy from the sun will warm moist air at ground level. When moist air rises, it expands due to the lesser pressure at higher altitudes. This expansion causes it to cool. Often it cools to the dew point and condenses. When a lot of water vapor condenses, clouds form. A huge number of tiny water particles float in the air, held up by air pressure and air movement. These miniature bits of water reflect light and give the cloud its appearance. These water particles can combine, forming larger water droplets. Eventually, they can become heavy enough to fall as rain (if the temperature is above freezing) or as snow or hail (if below freezing). Some clouds will form precipitation, and some will eventually dissipate as the water particles evaporate.

The two basic movements of wind are vertical and horizontal. Ground air that has warmed and expanded moves upward, traveling to areas of less pressure. This air rises vertically because the upward pushing force of denser air is greater than the downward pulling force of gravity. When this warm air also contains a large quantity of water vapor, it can condense when conditions are right. When condensing, it releases heat, which additionally warms the surrounding air, causing the upward rising process to continue.

An opposite effect occurs when liquid water particles in a cloud start evaporating. When the particles change from a liquid to a gas they absorb heat energy. This cools the surrounding air, causing it to become denser. This heavier air cannot be supported by the overall lighter pressure of thin air high up, and so it moves downward, pulled by gravity. These upward and downward vertical air movements can occur at the same time in different parts of a storm system.

Image Not Available

Two basic types of horizontal air movement are low winds affected by friction forces and higher winds moving without friction. Near the ground, air can be swirling and turbulent as it moves around obstacles such as buildings, trees, hills, and mountains. When moving horizontally, the forward portion of a warm or cold moving air mass is called a front.

Considering weather on a global scale, there is no place that repeatedly produces more violent weather than the United States. The continental United States is situated between a subpolar region that brings cold air into the country from the north (heading southward), and a tropical region that sends hot, humid air from the Gulf of Mexico northward. When these two air masses occur at the same time and collide, violent thunderstorms and hurricanes can result. The northern climate of Alaska and the southern climate of Hawaii add to the range of weather possibilities for the United States.

Weather Conditions Affecting Flight

Atmospheric conditions affect anything that flies, from birds to spacecraft. Prime weather conditions are clouds, precipitation, wind, lightning, heat, cold, and visibility. These are basic characteristics of weather that can combine to form events such as dust storms, thunderstorms, hurricanes, tornadoes, and blizzards.

Clouds. There are many cloud types and combinations. The range of possible air temperatures, pressures, air motion, and amount of moisture can combine in complex ways. The main cloud types of interest to pilots are cumulus and stratus. Cumulus clouds, created in unstable air, are typically fluffy and often rise to great heights. While they may originally develop in blue sky and look harmless, they can transform into dark thunderstorms. They tend to produce heavy precipitation.

Stratus clouds are created in stable air and produce smooth clouds that are layered and usually flat. They tend to produce steady, long-duration light rain over a widespread area. A pilot flying through stratus clouds will experience low ceilings, meaning the area near the ground can remain cloudy, with no visibility for navigating or landing.

Precipitation and Ice. The basic forms of precipitation are rain, snow, hail, and sleet. While all these conditions can cause problems of visibility for the pilot, the greatest hazard is freezing rain. Sleet (partly frozen rain) can form into ice when it falls on the metal surface of an aircraft that is at or below freezing temperature. This is called icing, and it is most hazardous to flying when it forms on wings and propeller blades and interferes with fuel systems and sensing devices. The icing condition can also occur when there is no precipitation—a light plane can experience carburetor icing when flying in cold, moist weather, for example. This is a serious condition, as it can cause engine malfunction.

Ice can build up very rapidly. When it covers a wing, the lifting ability decreases, drag friction increases, and the weight of the plane increases. Ice on wings or propeller blades will cause a decrease in power. There is an increase in stall speed, the minimum speed at which a plane will automatically drop one wing and proceed into an unwanted nose-down dive. In general, a deterioration of aircraft performance results when icing occurs. The solution to icing is to immediately increase thrust, activate anti-ice and deicing equipment, and leave the area producing the icing.

Wind and Turbulence. Conditions vary from no wind to extremely high wind. A headwind is the situation of flying directly into the wind, and a tailwind occurs when the flight is in the same direction as the wind. A crosswind is wind coming from an angle, between a headwind and a tailwind. Flying into a large low-pressure area allows easier altitude gain due to the rising air. When flying near a large high-pressure area, it is more difficult to gain altitude due to the downward-flowing air mass.

Turbulence is a general term for air movement that is characterized by irregular or violent motion, unlike a constant-speed wind staying in one direction. Turbulence can be exhibited between ground level and 70,000 feet (the altitude of a U-2 spy plane). Turbulence is strongly associated with thunderstorms, where its most dangerous form is a condition known as wind shear. This condition occurs when wind abruptly changes direction or speed or both over a very short distance. Wind shear can occur along the boundaries of thunderstorm activity, and in the downdraft under the storm cell. The most dangerous situation for aircraft is when wind shear occurs relatively near the ground (at an altitude of 200 feet, for example) while the plane is making a landing approach or a takeoff. The direction change can be 180 degrees; the speed change can be 50 miles per hour. That is extremely hazardous for an airplane at low altitude because it can place the craft in a position where there is no time for recovery from decreased lift and misaligned attitude before impact with the ground.

Another form of turbulence is wind that changes direction near ground level. This is due to the friction between moving air and ground objects. A pilot looking at a weather chart of winds aloft may observe the prevailing wind direction. This may be a headwind to a landing pilot, for example. However, at ground level, due to friction with ground objects such as buildings, fences, and control towers, the head wind can change into a crosswind. These changes affect the attitude and speed of a landing aircraft. Dust devils are another factor in landing or departing. These are small, whirling, circular air currents, normally seen at or near ground level by the dust they kick up.

A cruising aircraft can also encounter turbulence due to larger-scale objects. Any change in terrain elevation produces wind turbulence. This is due to air being pushed up over mountains and any type of rising land from gradual inclines to abrupt cliffs. On the downwind side of mountains, air mostly descends and can be choppy and rough.

Wind shear aloft can be caused by the same system that produces the near-ground-related wind shear problems. While dangerous and potentially lethal, it is not considered to be as hazardous as at ground level due to more time for corrective action before encountering the ground.

Jet streams are fast moving, high-altitude, narrow bands of air moving globally between cold arctic regions and hot tropic regions. These jet streams often travel in a serpentine manner, generally traveling from west to east, although direction varies. They range in location from about 60 degrees latitude in the summer, down to about 20 degrees latitude in winter, with travel excursions between these locations. Their speed varies, sometimes as high as 200 miles per hour, for example, at altitudes above 30,000 feet. Strong winds exist for hundreds of miles next to the jet streams. These winds interact with slower-speed wind to cause turbulence. Thunderstorms, tornadoes, hurricanes, and warm and cold air fronts all produce turbulence at varying altitudes.

Lightning. Lightning is caused by a difference in electrical charge between the ground and the sky, and even between clouds. It is most often generated when there is heavy cloud activity, as in thunderstorms. It can burn small holes in aircraft outer parts and affect sensitive instruments. However, it does not seem to strike people within a plane.

Heat. The temperature of air affects how dense it is—warmer air is less dense and cooler air is more dense. The denser the air, the better an aircraft will perform. Engines are more efficient, wings have more lift, and control surfaces provide more control. Much more runway is needed when taking off on a very hot day than is required on a very cold day.

Cold. Cold temperatures are primarily a problem for the pilot flying in freezing temperatures in areas of high moisture content. Even with the best anti-icing and deicing equipment, it is not always possible to prevent the effects of ice on an aircraft. Cold temperatures in the presence of moisture can also cause icy runways.

Visibility. Besides flying in clouds, precipitation, and darkness, other atmospheric conditions can cause visibility problems. Smog is a condition created when sunlight reacts with a combination of smoke and various gaseous pollutants and then combines with fog. Smog, smoke, dust, haze, fog, and sandstorms all describe conditions that are usually low-lying and can interfere with a pilot's visibility, especially when landing.

Thunderstorms. Thunderstorms can generate several adverse conditions for pilots of all types of craft. A thunderstorm is a cloud system containing very unstable air moving in all directions. Winds can batter and rock an aircraft, causing airsickness and aircraft attitude problems. Violent wind can also stress components of the craft, such as the wings and control surfaces. Wind can alter the course of an airplane, causing more fuel use. Strong turbulence in and around a thunderstorm may include ground-level wind shear that can make takeoffs and landings difficult or impossible. Hail can damage parts of the plane, and freezing rain can cause dangerous icing. Lightning discharges are usually frequent.

The extent of a thunderstorm depends on its type. Ordinary individual storms usually form rapidly, reach a peak of activity, and expire in about an hour. A line of thunderstorms is called a squall line. A supercell thunderstorm is one that can last for hours and travel more than three hundred miles. The supercell type can develop strong tornadoes as it travels. A tornado is a large, violent, swirling wind funnel that can easily destroy an airplane. The tops of thunderstorms range from about 33,000 feet to 80,000 feet. This means that small aircraft are not able to fly over the storm. Larger aircraft may not want to fly over the system, since rough air can extend far into the clear air above the main storm.

Pilot Aids Related to Weather Conditions

A weather map or chart is a drawing showing continuous lines indicating highs, lows, and fronts. The lines are called isobars, which are plot locations of similar air pressure.

A weather satellite photograph is an image printed from a picture taken by a television type of camera. The image, showing the land and tops of cloud formations, is transmitted from the satellite to the ground.

Radar in an aircraft sends out a beam that bounces off heavy moisture and rain particles, thus showing a pilot the location of the nearest intense storm cell activities.

Spherics in an aircraft is a system that detects and displays the electrical discharges of a thunderstorm. Lightning locations are shown as tiny dots of light on a screen.

Autopilot systems automatically control the aircraft's attitude, direction, and speed. This relieves the pilot of hands-on flying and allows more time for obtaining weather reports and communicating with air traffic controllers.

Ground-based wind shear detecting devices have been developed that aid in monitoring and predicting this activity in the vicinity of airports. In the 1990's, jet transports in the United States were required to be outfitted with wind shear detection devices. Accurate and timely predictions, while improving, are not yet an exact science in the year 2001. The storm system producing the wind shear can be more accurately monitored.

An instrument landing system (ILS) aids in organizing a landing through use of a ground radio beacon. The pilot uses cockpit instruments and a radio receiver to guide the plane to the runway.

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See also: Accident investigation; Icing; Pilots and copilots; Safety issues; Training and eduction; Wind shear

Whirly-Girls

Date: Founded in 1955

Definition: The popular name of the organization of International Women Helicopter Pilots. The term is also used to refer to a member of that organization or any female helicopter pilot.

Significance: The Whirly-Girls is the premiere organization representing female helicopter pilots and promoting helicopter aviation through scholarships and programs.

Anyone who has ever watched a hummingbird hover in midair near a flower or seen a maple seed twirl down to the ground has experienced the fascination of vertical flight. The Chinese wrote about the possibility in 320 C.E. and are credited with designing the first toy to display the principles of vertical flight, but it was not until the years right before World War II that inventors were able to create a machine capable of lifting a pilot vertically into the air and hovering. The first true vertical aircraft was flown by Hanna Reitsch of Germany in 1938. Reitsch became Whirly-Girl #1 in eyes of the organization that continues to encourage helicopter aviation to this day.

The Early Years

Jean Ross Howard-Phelan learned to fly airplanes in college, but she fell in love with helicopters in 1947 after her first flight. After receiving her helicopter rating in 1954, Howard-Phelan began her search for other women helicopter pilots. She identified twelve other women, whom she invited to Washington, D.C., in 1955. Six of these women met on the mezzanine of the Mayflower Hotel that year and formed the organization known as the Whirly-Girls. At first, the Whirly-Girls had no officers, no dues, and no record of their meetings, which they called "hoverings." They did, however, begin a tradition that continues to this day of giving each new member a number. The Whirly-Girls adopted as their logo a helicopter featured in 1950's ads for U.S. Army pilots. The female helicopter has long eyelashes and an expression resembling that of the cartoon character Betty Boop. Membership was open to all women who had received a certified helicopter rating from the U.S. Federal Aviation Administration (FAA) or its foreign equivalent. The goals of the organization were to promote helicopter aviation, encourage safety, and advance the opportunities of women in helicopter aviation. By 1961, there were forty-one members of the Whirly-Girls. That same year, twelve members of the Whirly-Girls met with President John F. Kennedy in the Rose Garden of the White House. The meeting had been arranged by Janey Hart, Whirly-Girl #25, who was the wife of then Senator Phillip Hart (D-Mich.).

The Organization Today

The Whirly-Girls now have over one thousand members from thirty countries. Their membership includes physicians, airline pilots, military pilots, law enforcement agents from dozens of state, local, and federal agencies, engineers, and homemakers. They sponsor three annual flight scholarships to encourage the further training of women interested in helicopter aviation. The first scholarship was created in 1966 in memory of Doris Mullen, who was fatally injured in an airplane crash that year. It is awarded to a Whirly-Girl interested in receiving advanced training in helicopter aviation. The second scholarship, established in memory of Gini Richardson, Whirly-Girl #64, is awarded to a woman airplane, balloon, or glider pilot for use toward obtaining her initial helicopter rating. The third scholarship fund was established in 1991 in honor of Major Marie Rossi, a helicopter pilot killed during the Gulf War. In addition to these activities, the Whirly-Girls also support a program to encourage the establishment of hospital heliports.

A Who's Who of Women in Aviation

Whirly-Girl #1 is often considered the greatest female pilot of the twentieth century. Hanna Reitsch was born in the Silesian town of Hirschberg in 1912. While studying medicine, she began taking flying lessons and soon received a license in both gliders and powered aircraft. In 1937, she became the first person to fly over the Alps in a glider. That same year she was appointed as flight captain in Germany for her work in the development of airplane "dive-breaks." She set another first in 1938 when she became the first women in the world to pilot a helicopter at the International Auto Show in Berlin. During World War II, Reitsch was one of Germany's leading test pilots, flying horizontal bombers, dive-bombers, fighter planes, a V-1 rocket, and the ME-163 rocket plane. In 1971, she became the first woman to win the World Helicopter Championships.

Dora Strother, Whirly-Girl #27, earned her pilot's license in 1940 and became the youngest member of the Women's Airforce Service Pilots (WASPs). Following World War II, Strother earned her doctorate in aerospace education and began work as a human-factors engineer specializing in cockpit design. In 1958, she went to work for Bell Helicopters, where she established distance and altitude records in a Bell 47G-3 and went on to help design the cockpit of the Army OH-58D, the first helicopter cockpit with computerized, digital avionics.

Other Whirly-Girl firsts include Commander Joellen Drag Osland, Whirly-Girl #179, the first female naval helicopter pilot in 1974; Sally Murphy, Whirly-Girl #181, the first woman aviator in the Army; Angelica Myles, Whirly-Girl #653, the first African American helicopter pilot on the West Coast; and Nancy Sherlock, Whirly-Girl #621, the first Whirly-Girl astronaut. Through the years, women like these have continued to pursue the dream of helicopter flight and to pass that dream onto a new generation of women.

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See also: Helicopters; Hanna Reitsch; Rotorcraft; Women and flight

Richard Whitcomb

Date: Born on February 21, 1921, in Evanston, Illinois

Definition: An aeronautical engineer who designed wing shapes for supersonic jets after World War II.

Significance: Whitcomb developed and built wind tunnels in which he could test various jet wing designs at speeds approaching the speed of sound. His experiments led to the discovery and application of the theory of area rule and the construction of a Coca-Cola-bottle-shaped fuselage for supersonic jets.

Richard Travis Whitcomb was fascinated from his childhood by model airplanes. He pursued his interest in aerodynamics at Worcester Polytechnical Institute in Worcester, Massachusetts, from which he received a bachelor of science degree in engineering in 1943. Immediately upon graduation, he joined the aerodynamic research center of the National Advisory Committee for Aeronautics (NACA) located in Langley, Virginia. Most of Whitcomb's professional life was spent at NACA and at its successor organization, the National Aeronautics and Space Administration (NASA).

Whitcomb's first project at NACA concerned the shape of the wings and fuselage attached to jets that were being built to fly at speeds greater than the speed of sound. Performing a series of increasingly complex experiments in specially constructed wind tunnels, Whitcomb and his team determined that the optimal shape of the fuselage for the Convair F-102, a potentially supersonic jet, should be like a Coca-Cola bottle, that is, slightly wider at both ends and narrower in the middle section. The Coca-Cola bottle-shaped fuselage would allow jets to fly faster while at the same time increasing stability while in flight. The general rule of aerodynamics that resulted from this discovery is known as Whitcomb's area rule.

Richard Whitcomb pioneered the design of supersonic aircraft. (NASA)

On December 21, 1954, an experimental Convair YF-102A utilizing Whitcomb's Coca-Cola-bottle-shaped fuselage design broke the sound barrier near Edwards Air Force Base, California. That same year, Whitcomb was awarded the prestigious Collier Trophy, an award given annually for the year's greatest achievement in American aviation, for his wind-tunnel experiments and fuselage designs.

After NACA was reorganized as NASA, Whitcomb joined NASA to continue his experiments on designs for supersonic jets. He is well known in aviation history for his design of the supercritical wing, a wing that is flat on the top and thicker at the front than the back, with a slight downward curve. In 1973, this wing type was tested on a Ling Temco Vought F-8A Crusader supersonic fighter. It resulted in higher jet speeds and a slower rate of fuel consumption, thus increasing the potential range of the supersonic fighter.

For his design and construction of the supercritical wing, Whitcomb was awarded a cash prize of $25,000 in May, 1974. During his long career with NACA and NASA, Whitcomb received numerous other awards, including the Distinguished Service Medal from NACA, the NASA Medal for Exceptional Service, and the Exceptional Service Medal from the United States Air Force, the highest award that can be awarded to a civilian.

Victoria Erhart

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See also: Aerospace industry, U.S.; Airplanes; Experimental aircraft; Jet engines; Military flight; National Aeronautics and Space Administration; National Committee for Aeronautics; Supersonic aircraft; Wind tunnels; Wing designs; World War II

Wind-powered flight

Definition: All manner of flight that is not powered by any mechanical or electrical source of energy. Wind-powered flight can be in an aerostat, which is a lighter-than-air aircraft such as a gas-filled balloon, or in an aerodyne, which is a heavier-than-air craft such as a glider.

Significance: All modern aircraft has its origins in wind-powered flight. Early aeronautical engineers studied, designed, constructed, and flew balloons and later gliders; many perished in the attempt. Wind-powered flight is now mainly for recreation and sport (ballooning, gliding, parasailing, and skydiving), for military purposes (troop and equipment parachute drops), and for scientific research (weather balloons).

Early History

Historians refer to several early attempts at wind-powered flight. In the ancient Greek myth, Icarus wore wings of feathers held together by wax; when he flew too close to the sun, the wax on his wings melted, and he plummeted to the sea. A Persian legend dating from 1500 B.C.E. relates the story of a king who used tethered eagles to fly him to China. In 850 B.C.E., a legendary English king made a pair of wings, attached them to his arms, and tried to fly, but he crashed and died.

For centuries, humans continued to pursue the concept of wearing artificial wings and attempting to fly like a bird. John Damian constructed wings from chicken feathers in early sixteenth century Scotland and tried to fly from the walls of Stirling Castle. A century later, a Frenchman made his wings out of wood and taffeta and tried to fly from a rooftop. Another Frenchman tried to fly with wings on his arms in 1712, and died in the attempt. Thirty years later, a man wearing wings on his hands and feet tried to fly across the Seine in Paris; he survived his fall. At about the same time in Germany, a man fastened large taffeta wings to his arms and tried to fly off a mountain.

Because of the failure to fly by attaching wings and jumping from great heights, early aeronautical engineers began investigating the idea of flying in lighter-than-air crafts. Roger Bacon, an English monk and scientist in thirteenth century England, wrote about lighter-than-air flight in *Secrets of Art and Nature*, a work that was not studied by aviation enthusiasts until the sixteenth century.

Aerostat Flight

Gas-Filled Balloons. A balloon is an aerostat in that it will lift in a static air mass and move horizontally with a moving air mass. Balloons work according to the buoyancy principle. The principle, attributed to Archimedes, states that the pressure in any stationary fluid, liquid or gas, increases with depth. A balloon is filled with a fluid, heated air, or a lighter-than-air gas, and the total weight of the balloon and its gas is less than the air that is surrounding the balloon. As a result, the balloon rises to that point of elevation at which the density of the air outside the balloon is the same as the density of the fluid inside the balloon; at this point the difference between the pressures at the top and bottom surfaces of the balloon is not longer great enough to propel the balloon upward. Because the density of atmospheric air reduces with elevation, a balloon filled with a gas that is lighter than air will rise to a point in the atmosphere where the gas in the balloon has the same density as the atmospheric air. To rise higher, the gas in the balloon must be heated further to reduce its density even more, or the pilot must jettison ballast, such as sand bags, to make the balloon lighter and thus able to ascend.

History of Balloon Flight. In 1670, Father Francesco Lana, an Italian priest, was the first person to apply scientific principles to the design of an aerostat. He sketched a figure that was basically a boat with large copper spheres; when emptied of air, de Lana theorized, the boat would rise and float in the air.

Almost forty years later, another priest, Father Bartholomeu de Gusmão, designed and built a model of a hot-air balloon that he demonstrated at the court of King John V in Lisbon, Portugal. De Gusmão's miniature aircraft contained a small fire to heat the air in the balloon; as the device rose, it collided with the curtains, crashed, and started a fire. Aviation chronicles credit de Gusmão with building the first aerostat in history.

The first successful passenger-carrying hot-air balloon was launched by the Montgolfier brothers in France in 1783. After observing that warm air in their fireplace caused paper to rise up the chimney, Joseph-Michel and Jacques-Étienne Montgolfier designed and built a hot-air balloon large enough to carry a human. They constructed it with a large linen bag and filled it with air that was heated beneath by small fire; their first passengers in the September 19, 1783, flight were a sheep, a rooster, and a duck. The animals traveled about two miles and then landed safely ten minutes later.

French physicist Jacques-Alexander-César Charles experimented with a hydrogen-filled balloon; he knew that the weight of hydrogen was about 7 percent of the weight of air, so he theorized that not only would a balloon filled with hydrogen ascend higher than one filled with heated air, but it would also be safer as no fire was required to heat the air. On August 27, 1783, Charles launched his uncrewed hydrogen balloon; it rose to a height of 3,000 feet and flew for about an hour.

The first crewed hot-air balloon flight occurred on October 15, 1783, when Jean-François Pilâtre de Rozier ascended in a tethered balloon. The following month, he and a fellow Frenchman made the first untethered crewed balloon flight. Their beautifully decorated balloon rose to a height of several hundred feet above Paris, drifted about 5 miles and landed safely almost thirty minutes later. They used a charcoal-burning brazier to heat the air for their balloon. De Rozier died in 1785 in an attempt to cross the English Channel in a hydrogen-filled balloon; a spark ignited the hydrogen and the balloon fell to the ground.

On December 1, 1783, Jacques-Alexander-César Charles made the first flight in a hydrogen-filled balloon. He and his passenger flew 27 miles and used sand bags to control their altitude. Charles then made a solo flight and reached an altitude of 10,000 feet; he was the first person to make a solo balloon flight. The next year the first woman to fly in an untethered balloon was Madame Elisabeth Thible. With his balloon flight on October 4, 1784, James Sadler became the first British aeronaut. On January 7, 1785, Jean-Pierre Blanchard and John Jeffries crossed the English Channel by balloon. The first crewed flight in a hydrogen balloon in the United States took place in January, 1793; President George Washington personally honored the pilot.

Balloons in the Military. By the end of the eighteenth century, balloon flight had been adapted for military use. In April, 1794, the world's first military air service was established in France. French troops used balloons to observe Austrian troop movements, and in the Franco-Prussian War of 1870-1871, the French interior minister escaped Paris in a balloon. Balloons were also used for observation by the North and South during the American Civil War. In 1883, the British Army established its balloon school, and the army's First Balloon Section left in 1899 to serve in the Boer War. Japan sent thousands of balloons filled with explosives across the Pacific and rigged them to descend and detonate on American cities; a few hundred did land but did little damage.

Scientific Balloons. Balloon flights specifically for meteorological research began in the nineteenth century. On September 5, 1862, English meteorologist James Glaisher and a colleague filled their balloon with scientific equipment and ascended to 30,000 feet, where both men lost consciousness; the balloon finally began its descent, and the men recovered and the balloon landed safely. A German meteorologist also ascended to 30,000 feet in his balloon in early 1894.

The main problem facing the aeronauts in their scientific expeditions was the low temperatures at such high altitudes. In 1930, Swiss balloonist Auguste Piccard designed an enclosed and pressurized compartment in which the scientists could conduct their research and still be protected from the cold air at elevations as high as 70,000 feet. Uncrewed balloons continued to be used for upper atmosphere research throughout the twentieth century and into the twenty-first century. These balloons, made of rubber or polyethylene and filled with hydrogen or helium, carry scientific equipment to measure the speed and direction of the wind and air temperature and pressure.

Recreational Balloons. Balloon flight in the late twentieth century developed into a popular recreational activity for sports enthusiasts and adventurers. Sport ballooning relies on hot-air balloons that utilize butane or propane burners or a combination of both hot air and lighter-than-air gases. Adventurers continue to use balloons to set altitude and distance records. In the late 1990's, several international teams attempted to circumnavigate the world in balloons that combined both a hot-air bag and a helium-filled bag, a method that allowed balloonists to reach higher altitudes. Bad weather, however, prevented the successful completion of their trips. In August, 2001, American adventurer Steve Fossett failed in his fifth attempt to travel around the world in a balloon.

Aerodyne Flight

Gliders. Gliders are heavier-than-air machines, meaning that they are heavier than the air that they displace. A glider's lift is due to the movement of air over the glider's surfaces that in turn causes lift.

Gliders are designed so as to increase lift and decrease drag. Lift is the force that is perpendicular to the direction of motion. Lift is created by the difference between the high pressure on the lower surface of the wing and the lower pressure above the wing. Drag is the force that is parallel but opposite to the direction of motion and thus resists the forward motion of the plane. Drag is created by the friction and pressure forces. The long wings of the glider increase its lift; the shape of the streamlined fuselage decreases the drag. Because it lacks a power source, a glider needs some method to launch it into flight. A powered vehicle, such as a truck or an engine-driven aircraft, can launch a glider; also, the pilot of the glider can take off by accelerating down a slope. Once aloft, the glider soars by riding rising warm air currents, or thermals, to higher altitudes; as the atmospheric air cools, the glider will descend unless it finds another thermal.

History of Gliders. The "Father of Aeronautics" is Sir George Cayley, the first person to understand and apply aerodynamic principles in the design of an aircraft. Cayley designed gliders with fixed wings for lift and a tail with horizontal and vertical surfaces for control; his wing and tail designs are remarkably similar to those of modern aircraft. The first crewed flight in a glider was in 1853, when a young boy flew in one of Cayley's fixed-wing gliders.

The greatest glider of the late nineteenth century was German Otto Lilienthal, an engineer and aviation pioneer. He experimented with fixed-wing gliders, and in 1891 made his first glider flight. By the time he died in a glider accident in 1896, Lilienthal had made more than two thousand glides in several different gliders he designed and built; they were elegant constructions that usually consisted of a willow and bamboo frame covered with waxed cotton. His method of flying was to race down a hill with his glider, and the momentum created lift over the curved wings. The air currents enabled him to sail hundreds of feet. He controlled the glider by gripping the framework bar and shifting his weight. He directed the glider by means of a harness around his forehead that was attached to the glider's moveable elevator. When Lilienthal lowered his head, the glider would aim upward; when he raised his head, the glider would go down. Lilienthal flew almost every day and kept meticulous records of the details of his flights; he was widely photographed in journals and newspapers. On August 9, 1896, his glider crashed 50 feet to Earth after a sudden shift of wind, and he died the next day.

American Octave Chanute, a civil engineer, followed Lilienthal and experimented with fixed-wing gliders. Chanute designed and flew several different models and wrote a detailed book about the history of human attempts to fly. He also gave technical advice to the Wright brothers, the two American men who made the most momentous contribution to aviation.

The Wright Brothers. Orville and Wilbur Wright followed a specific scientific approach in their early experimental flights with kites and gliders. To research flight, they contacted the Smithsonian Institution on June 2, 1899, and requested any information about the construction of a flying machine. They then read every publication from the Smithsonian, including Chanute's *Progress in Flying Machines*, and learned more about Lilienthal's work with gliders. Lilienthal had used elevators to regulate the pitch of his gliders and had used rudders for steering right or left. The Wright brothers discovered that Lilienthal had not known how to control yaw, or the side-to-side rolling, other than by simply shifting his weight as he flew. Wilbur Wright wanted to solve the problem of yaw; he studied buzzards as they flew and observed how they dropped one of their wings to maintain balance. He believed that the movement of the wing lifted the bird by increasing the air pressure under that wing. Wilbur and his brother tested this theory by building a biplane kite and manipulating the opposite wing tips with strings to turn either up or down, with the result that they were able to control the yaw of the kite.

In 1900, they built a glider and tested it near Kitty Hawk, North Carolina. It was a 52-pound biplane with a wingspan of about 17 feet; the pilot lay prone at center of the lower wing. The wings of the glider were made of fabric, and it was flown as a kite. They chose the beach in North Carolina because the Weather Service informed them that the strong winds at Kitty Hawk would be able to keep the glider up in the air. After a flight of ten minutes, the glider was able to make a soft landing on the sandy beach.

A year later they tested a second glider; this one was bigger in order to have more lift, but it was so big that it stalled dangerously in midair. In order to solve the problem, the Wright brothers tested wing profiles. They also designed and built a small wind tunnel in Dayton, Ohio, and carefully tested 150 different wing shapes to measure aerodynamic forces on wing sections and to solve lift and drag problems. They equipped their tethered gliders with mechanical instrumentation to measure the force of the wind upon the aircraft. Applying their findings, they designed a new glider that had longer and narrower wings and implemented a wing warping technique. In 1902, Wilbur and Orville flew almost one thousand times in their new glider. The next step was to add an engine, and their December 17, 1903, flight was the first heavier-than-air powered flight in history.

Recreational Gliding. Gliders, or sailplanes as they are also called, are now the mainstay of the international sport of gliding and soaring in which the pilot flies through the air using thermals, or rising currents of warm air, to maintain the desired altitude. Modern sailplanes are constructed of fiberglass with a wingspan between 15 and 20 meters (50 to 65 feet). They are launched most often by powered aircraft at a height of about 2,000 feet. Biannual competitions sponsored by the Fédération Aéronautique Internationale award the Lilienthal Medal to the winner.

Kites. A kite is a tethered device made of a lightweight frame covered with a thin layer of cloth or paper. Most probably invented by the Chinese more than two thousand years ago, kites were early wind-powered vehicles used frequently by scientists in the eighteenth century. In Scotland, Alexander Wilson used paper kites in 1749 to carry thermometers aloft to measure atmospheric temperatures at various altitudes. American Benjamin Franklin flew a kite in his famous experiment about the conduction of electricity in 1752. The British Army's balloon school set up a human-lifting kite section in 1894. In the same year, Australian Lawrence Hargrave invented the box kite; his design became the standard model for early airplanes, including the Wright brothers' planes. By the end of the century, Orville and Wilbur Wright tested their theory of wing warping on a biplane kite. In 1904, Samuel Cody crossed the English Channel in a boat pulled by a large kite.

The following year, the British Army's balloon factory hired a kiting instructor and planned to teach observation and signal transmission using kites. In 1907, a kite built by Alexander Graham Bell carried a man aloft to 168 feet for a seven-minute flight. By the late twentieth century, kites were popular in recreational and competitive sports throughout the world, and also as a method of signaling in rescue operations at sea.

Parachutes. Leonardo da Vinci's 1495 sketch was one of the earliest drawings of a parachute. He theorized that a human being could safely descend from any height provided he was wearing a tentlike apparatus. Parachutes were not made until the eighteenth century, however, when aeronauts realized that they needed a quick escape if their balloons caught on fire. Joseph-Michel Montgolfier and Jean-Pierre Blanchard, both famous eighteenth century French balloonists, are said to have jumped with a parachute from their balloons. Another Frenchman, André-Jacques Garnerin, made the first exhibition parachute jump over Paris in 1797. His jump was marred by severe oscillation, however, and Sir George Cayley then designed a cone-shaped chute that he believed would decrease the oscillation. This design was notable for causing the first fatality of a parachutist in 1837, when the chute collapsed and the jumper fell several thousand feet to his death. Subsequently, a small opening at the top of the parachute was added. With the increased popularity of ballooning in the nineteenth century, parachutes, too, became more widespread.

By the twentieth century, parachuting had evolved into an exhibition sport, extremely popular in the United States. Military forces around the world were reluctant to adopt the parachute for their pilots. Indeed, World War I pilots at first considered it cowardly to jump with a parachute from their burning aircraft. Balloonists who served in the war, however, did not hesitate to wear parachutes and thus escape their balloons if shot down. In 1916, an Austrian pilot parachuted safely from his burning airplane; soon afterward, all Austrian and German pilots were finally equipped with parachutes. Allied pilots, however, did not agree to use parachutes until World War II. By the end of that war, almost 100,000 people had parachuted to safety.

By the 1970's, parachuting had evolved into the recreational and competitive international sport of skydiving. Parachuters jump from an airplane at about 10,000 feet in solo jumps or in a group of several skydivers. They can travel at speeds as high as 150 miles per hour during their free fall, and can change their speed by maneuvering their bodies. Many perform rehearsed maneuvers during their free fall until they are at an altitude of approximately 4,000 feet, at which point they deploy their chute. Skydivers use controls to steer left or right, or to slow their descent.

Hang Gliders. Hang gliding is another type of wind-powered flight that, like skydiving, became popular in the 1970's; it relies on the same aeronautical principles first explained by Lilienthal and Chanute, who wrote about using air and gravity to fly and land lightweight aircraft.

Hang gliders have a frame and a kitelike sail; the person flying the hang glider wears a harness and is supported by holding on to the frame. The pilots self-launch the hang glider by running into an updraft; they control the aircraft by shifting their weight either forward or back, left or right. The primary designer and developer of the skysail or hang glider was Francis Rogallo, an aeronautical engineer. Working with his wife, Rogallo designed a successful paraglider with a flexible wing and received a patent for it in 1951. The Rogallo skysail is portable, inexpensive, and consists of two sails mounted on a frame.

Parasailing. The water sport of parasailing became popular in different countries in the late twentieth century. Parasailing developed from parascending, a method of training parachutists invented by Pierre Lemoigne in 1960. In parascending, the parachutist's harness lines were connected to a car, which then drove until the chutist was airborne. In 1961, a Connecticut company marketed the parachute as a "Parasail," and parasailing became adapted as a water sport with the parachutist being tethered to a boat in the water and being hoisted into the air by the moving boat. To land, the parasailer maneuvered the lines to return to the shore. The inventor and pioneer of the safe and popular sport of modern parasailing is Mark McCulloch, who in 1974 invented a launch and retrieval apparatus, known as a winchboat. He also designed and patented a single passenger device and a tandem passenger chair; the seating device remains tethered to the boat and is launched from and returns to a platform, also designed and patented by McCulloch, by means of a winch on a small boat.

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See also: Balloons; Buoyant aircraft; Sir George Cayley; Octave Chanute; Franco-Prussian War; Gliders; Hang gliding and paragliding; Heavier-than-air craft; Hot-air balloons; Human-powered flight; Kites; Leonardo da Vinci; Lighter-than-air craft; Otto Lilienthal; Military flight; Montgolfier brothers; Parachutes; Parasailing; Auguste Piccard; Reconnaissance; Skydiving; Jules Verne; World War I

Wind shear

Definition: A change in wind direction or speed, either vertically or horizontally, within a short distance in the atmosphere.

Significance: Wind shear is a concern in all phases of flight. Strong wind shear close to the ground can be especially hazardous to aircraft.

Wind shear is a gradient, which means it exhibits a specific change of wind velocity over a given distance. Wind shear can be horizontal, vertical, or both. If the wind direction changes as well as the wind speed, the actual wind shear will be greater than the wind speed shear alone. The most critical wind shears for pilots occur over horizontal distances of 1 mile or less and over vertical distances of 1,000 feet or less.

Low-Level Wind Shears

Wind shear that occurs below 2,000 feet above ground level, or along the aircraft's final approach or takeoff and climb path is called low-level wind shear (LLWS). Low-level wind shear is most hazardous when the wind shifts from a headwind to a tailwind. This shear will cause a decrease in airspeed equal to the decrease in wind velocity and can adversely affect the performance of the aircraft. These shears are considered significant when they cause airspeed changes of 15 knots or more. In recent years, an effective low-level wind shear alert system has been developed. These detectors are being installed at airports to warn pilots of the possibility of low-level wind shear in the vicinity. Three of the most common types of low-level wind shears are airmass wind shears, thunderstorm-associated wind shears, and topographical wind shears.

Airmass Wind Shears. Airmass wind shears commonly develop during calm, fair nights, during which the ground may become cooler than the overlying airmass, creating a surface temperature inversion. This nocturnal inversion is very stable and impedes mixing of the airmasses above and below the inversion. As a result, the surface air remains calm, while the winds aloft increase, because they are not slowed by surface friction. Vertical wind shear can be remarkably strong through the inversion. Wind shears should be expected whenever wind speeds at 2,000 to 4,000 feet above the surface are 25 knots or greater. After daybreak, the sunlight heats the ground, and the inversion and the wind shear dissipate. In cold-winter climates, however, when the ground is covered with snow and ice, inversions, with their accompanying wind shears, can persist throughout the day and night.

Thunderstorms and Microbursts. Thunderstorms produce strong updrafts and downdrafts throughout their lifecycles. The cumulus stage of thunderstorms is characterized by updrafts. Upon reaching the mature stage, the storm has both updrafts and downdrafts. Dissipating thunderstorms have mostly downdrafts. These updrafts and downdrafts can cause severe and even extreme turbulence that can cause an aircraft to experience structural damage.

The most severe form of wind shear produced by a thunderstorm is a microburst. A microburst is a core of cool, dense air that descends rapidly from the thunderstorm. When the column of air reaches the ground, it spreads out in all directions and rolls back over itself, forming a vortex ring. Microbursts usually do not last longer than fifteen minutes, although some can linger as long as thirty minutes. There is usually heavy rain in the microburst, although in drier climates, the rain can evaporate before reaching the ground, creating a dry microburst.

Microbursts pose a danger to aircraft because of their strong downdrafts and because the wind direction shifts 180 degrees across the center of the microburst. In a microburst with wind speeds of 45 knots, the shear across the microburst will be 90 knots. The wind shear created by the microburst can exceed the operating capabilities of even heavy transport jets. On February 8, 1985, a Delta Air Lines Lockheed L-1011 Tristar encountered a severe microburst while attempting to land in a thunderstorm at Dallas-Fort Worth, Texas. The aircraft crashed 6,300 feet short of the runway, broke up, and burst into flames, killing 134 of the 163 passengers and crew on board.

Topographical Wind Shear. Air moving across hills, mountains, and valleys can create wind shears. As air moves across the ridges of hills or mountains, the airstream is compressed and deflected upward. The compressed air speeds up. The change in direction and speed of the air creates wind shear on the tops of the hills and mountains. Higher mountains and faster winds produce stronger wind shears.

Air moving across a valley with gently sloping sides will produce downdrafts on one side and updrafts on the other side. These drafts can produce significant shears if the wind is strong. In canyons with steeply sloped sides, there may be sharp downdrafts on the leeward side of the canyon. In addition, wind may travel through the canyon at right angles to the airflow above it. Several aircraft have crashed in canyons due to the unpredictable wind shears they encountered.

High-Altitude Wind Shear

Wind shear can be associated with jet streams, high-level frontal activity, and the tropopause, the region at the top of the earth's troposphere, the lowest, densest part of the atmosphere. When high-level stable layers of air are displaced vertically, they produce atmospheric gravity waves. These waves can develop crests, much like ocean waves. The air is usually cloudless at these altitudes, so there are no visual clues to alert pilots to the presence of these shears, although if clouds are present, they will often reflect the wave pattern of the air. These wind shears are a common source of clear-air turbulence.

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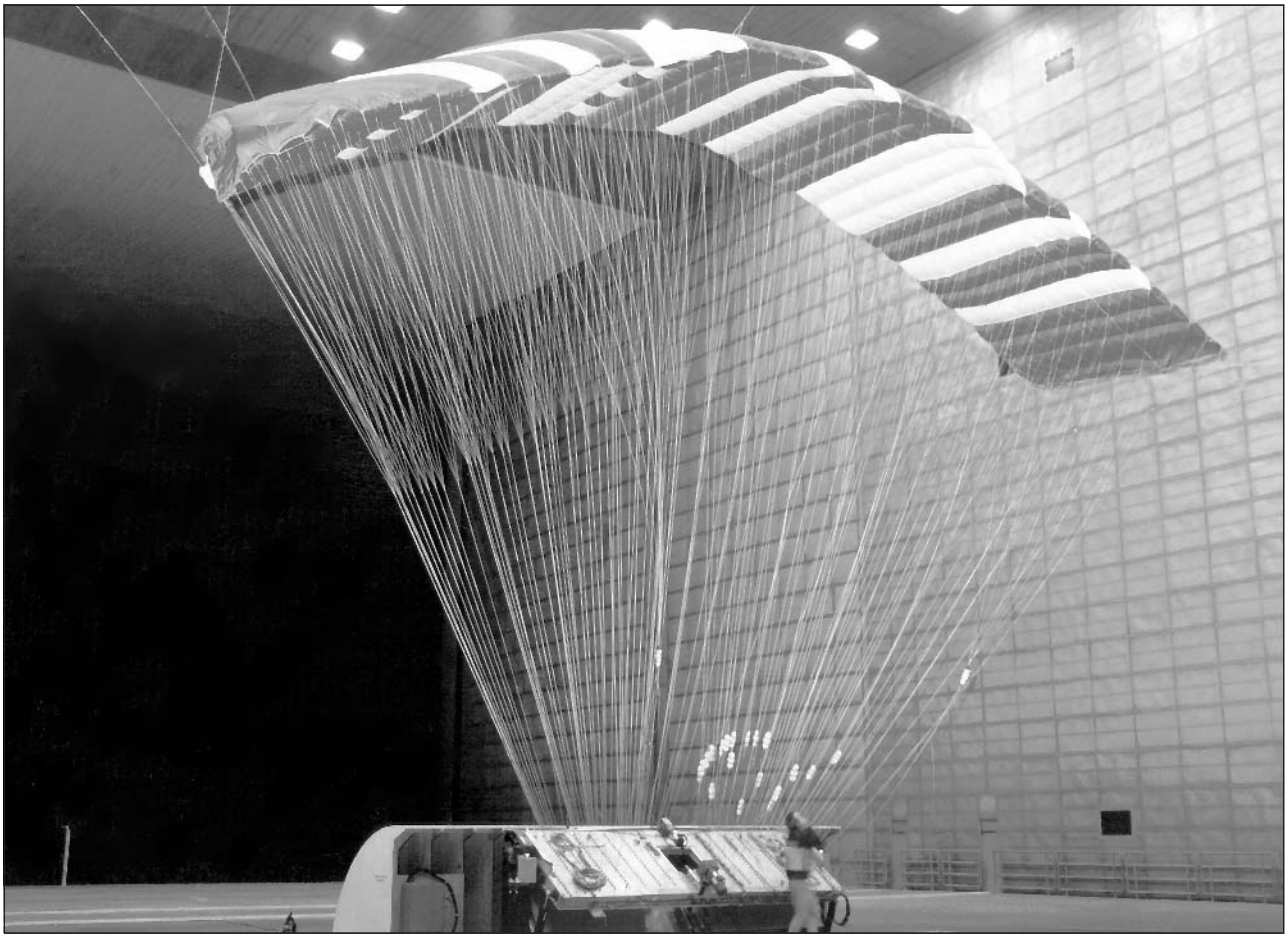
See also: High-altitude flight; Safety issues; Weather conditions

Wind tunnels

Definition: Flow channels through which air or another gas is passed over a model of an aircraft or other object to study the effects of the airflow on the forces acting on the aircraft model.

Significance: Wind tunnels are vital to the design and development of any aircraft. They permit the measurement of pressures and forces acting on a scale model of an aircraft to predict the flight characteristics of the aircraft even before it is built.



NASA operates a number of wind tunnels for testing the designs of experimental aircraft. The world's largest wind tunnel is located at NASA's Ames Research Center in Mountain View, California, where this parafoil is being tested. (NASA)

Principle of Operation

Wind tunnels are based on the principle of relative motion, which states that the forces acting on an aircraft or aircraft model are dependent only on the relative motion between the aircraft and the air. It does not matter whether the aircraft is moving at a certain velocity through still air, or whether the aircraft is fixed and the air is moving over it at an equal and opposite velocity to the aircraft speed.

Design

Although there are many types of wind tunnels, most of them share common characteristics. They all typically have an inlet section, which is a contracting passage called a venturi, or contraction cone, to speed up the flow of air. The air then enters the test section, where an aircraft model is mounted and where the effects of the air flowing over the model are measured. The most common measurements are of the forces acting on the model. The air then enters an expanding section called a diffuser, where it slows down again. One or more fans are located at the end of the diffuser to draw the air through the tunnel. At the entrance to the tunnel, flow straighteners are mounted to reduce the swirl imparted to the air by the fan, and to damp out most of the turbulence in the air. These flow straighteners consist of screens, or short sections of honeycomb material not unlike a cross section of cardboard box material. Tunnels of this design are called open-circuit, closed-test-section, or National Physical Laboratory (NPL) tunnels. The test section dimensions may vary in size, ranging from a few square inches to 80 feet by 120 feet.

Wind-Tunnel Models

Airplane models used in wind tunnels vary greatly in type and size, ranging from a few inches long to full-scale airplanes in the largest tunnels. Scales from one-twenty-fourth to one-third actual size are often used. Most commonly, a scale model of a complete airplane is tested in the wind tunnel. Sometimes components of the airplane, such as the wing, fuselage, or engine nacelles with scaled engines operating, are tested. Wind tunnels are also used by automotive engineers to test automobiles for their flow characteristics and by civil engineers to test wind effects on buildings and other structures. Numerous other things are tested in wind tunnels: parachute opening dynamics, effects of control surfaces on aircraft, helicopter rotor behavior, propellers, human ski jumpers, golf balls, and even the flight characteristics of birds and insects.

Measurements Made

The most common measurements made in a wind tunnel are of the forces and moments, or torques caused by forces that tend to rotate the model, acting on the model. The model is usually mounted from below on a strut-type mount or from behind on a sting mount. The strut or sting mounting is connected to a force measuring balance mounted outside the wind-tunnel test section, where the forces and moments are electronically or mechanically measured. The forces measured are usually relative to the airstream direction. The upward component of force is called the lift force; the rearward force, which must be overcome by the aircraft propulsion system, is called the drag force; and the sideward component of force is called the yaw force. The turning tendency, or torque, about the vertical axis through the aircraft's center of gravity is called the yawing moment; the torque about the lateral axis though the airplane wings is called the pitching moment; and the torque about the airplane's longitudinal axis, through the fuselage from front to rear, is called the rolling moment. All these forces and moments must be measured. The rolling, pitching, and yawing moments measured are important for predicting the airplane's response to deflections of its aerodynamic control surfaces.

In addition to forces and moments, other types of measurements are often made in wind tunnels. An important one is the pressure distribution across various sections of an airplane or other model. Measurements are also made for the local flow field in the vicinity of the model, in other words, the air velocity and direction along various portions of the model and very close to the model. These measurements are often made as part of a flow visualization study, where laser beams, injected smoke, or streamers or tufts are used to study local flow directions. Wind tunnels are also used for aeroelastic studies, where control surface flutter may be examined or aeroelastic twisting or bending of helicopter rotor blades may be investigated. The list of variables that can be studied is endless. For this reason, when a new aircraft is being designed, it is not unusual for several different types of models to be built and tested in different tunnels to determine all the necessary characteristics of the airplane's aerodynamic and structural response.

Problems with Testing

There are a number of problems that occur with wind tunnel testing, which engineers must constantly strive to overcome. One of these is the scale effect, which occurs because the model is usually smaller than the full-scale prototype. The difference in size causes some important differences in flow between the model and the prototype. These flow differences must be accounted for using various techniques at the engineer's disposal, before the model data can be used to predict the prototype behavior. The air temperature, pressure, and velocity used in the tunnel test may have to be somewhat different from actual flight conditions. Again, there are ways to compensate for this, but they must be carefully evaluated.

Another reason for differences that occur between measurements made on a wind-tunnel model and what may occur in flight is due to tunnel wall effect. An airplane flies through open air that is free to move out of the way as the airplane passes through it. Such is not usually the case with a wind-tunnel model. The walls of a wind tunnel provide a partial constraint to the motion of the air as it passes over the model, somewhat altering the forces that would occur in free flight. This effect is especially important in transonic and supersonic aircraft that are generating shock waves. In actual flight, shock waves are free to extend from an actual aircraft as far as necessary. In a wind tunnel model test, these shock waves will strike the tunnel walls and be reflected in complicated patterns that reach the aircraft model or model support system. These interactions are accounted for by complex techniques that ensure the validity of the data measured.

Other Types of Wind Tunnels

The most common variation to the open-circuit tunnel is the closed-circuit design, which has a return flow path that recirculates the air from behind the fan back around to the inlet section. Thus the same air continually recirculates through the tunnel. This type of tunnel is called a Prandtl- or Göttingen-type tunnel. The main advantage of this design is a reduction in the power required for a given test-section velocity, because the air is not wasted as it leaves the diffuser, but much of its kinetic energy is recovered by recirculating it back to the inlet. Other advantages are lowered noise, due to elimination of the open exhaust, and the ability to control tunnel test-section conditions better by heating, cooling, or pressurizing the air. In a closed-circuit, closed-test-section tunnel, it is even possible to change the test gas from air to some other gas to simulate certain conditions. For example, extremely low-temperature nitrogen is sometimes used to simulate high-density air, and helium or Freon have been used for other kinds of simulations.

Sometimes, open-test-section tunnels are used to eliminate the tunnel wall effects. This can only be done in tunnels using air. Other types of tunnels are especially designed for testing aircraft in supersonic or hypersonic flight where aerodynamic heating effects may be important. Free flight tunnels are sometimes used to check aircraft response to control surface inputs or recovery characteristics from unusual attitudes. Propulsion tunnels are used to study airframe-engine integration. These tunnels may use actual operating jet or rocket engines, or devices designed to simulate the intake or exhaust flow of a propulsion system.

Finally, civil engineers often do studies in what is known as a boundary-layer wind tunnel. This type of tunnel usually has a test section that is very long, compared to its width and height. The long test section is used to simulate the growth of the earth's atmospheric boundary layer, the region near the ground where wind velocity increases with height. Boundary-layer wind tunnels are used to study wind effects around buildings or skyscrapers, the dispersion of smoke plumes from smokestacks, and the interaction of smoke with buildings located downwind.

Examples of Wind Tunnels

Wind tunnels are usually operated by research organizations such as universities, aerospace companies, or government research laboratories. Prominent university wind tunnels include those of the Georgia Institute of Technology, which operates a test-section tunnel, and the Massachusetts Institute of Technology, which operates the Wright Brothers Wind Tunnel with an elliptically shaped test section. Other noteworthy wind tunnels are located at the Texas A&M University, the University of Michigan, and the University of Washington.

Well-known company wind tunnels include the Boeing Research Wind Tunnel, with a 5-foot-wide-by-8-foot-high test section, the McDonnell Douglas 8-foot-by-12-foot tunnel, and the General Motors Automotive Wind Tunnel with an 18-foot-by-34-foot test section.

The U.S. government operates wind tunnels at many of the National Aeronautics and Space Administration (NASA) facilities, predominately the NASA Langley Research Center in Hampton, Virginia, and the NASA Ames Research Center in Mountain View, California. Much of the airframe-engine integration testing is done in propulsion wind tunnels located at the United States Air Force Arnold Engineering and Development Center (AEDC) in Tullahoma, Tennessee.

One of the most famous wind tunnels in the world is the 80-foot-by-120-foot cross-section wind tunnel located at the NASA-Ames Research Center. The largest wind tunnel in the world, it was originally built as a closed-return wind tunnel with a 40-foot-by-80-foot oval cross section capable of a test speed of 230 miles per hour. In the early 1980's, the tunnel was modified also to include an 80-foot-high-by-120-foot-wide test section operating as an open-circuit tunnel. In this mode, the maximum speed drops down to 115 miles per hour, but the test section is large enough to fit a full-size Boeing 737 airliner inside it. The six fans that drive the tunnel are powered by electric motors totaling 135,000 horsepower. With this power, the original 40-foot-by-80-foot test section can now operate at 345 miles per hour. Virtually every fighter plane and transport plane produced in the United States since the 1970's has had one of its models tested in the NASA-Ames 40-foot-by-80-foot tunnel.

Another unique wind tunnel facility is the National Transonic Facility (NTF) located at the NASA-Langley Research Center. This is a cryogenic wind tunnel that uses very low temperature nitrogen gas at -253 degrees Fahrenheit. This tunnel can simulate flight speeds as much as 20 percent greater than the speed of sound, which is 760 miles per hour at sea level. The use of the high density nitrogen gas in the tunnel's 8-foot-by-8-foot cross section makes it possible to simulate flight conditions very close to those encountered by full-scale craft with a relatively low power requirement compared to other tunnels.

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See also: Aerodynamics; Aerospace industry, U.S.; Airplanes; Forces of flight; Helicopters; Manufacturers; Testing

Wing designs

Definition: Any of a variety of wing shapes, which provide the lift needed for an airplane to fly and ensure optimum performance in the designated mission of a particular aircraft.

Significance: The most significant part of an airplane, wings generate the lift an airplane needs to overcome its weight and maneuver in flight. Wings can be long and thin or short and stubby. They can be angled or straight. The design of the wing must suit the purpose of the airplane: long-distance flight, aerobatic flight, high- or low-speed flight, or even space flight.

Background

Wings and the concept of flight go hand-in-hand. From the beginning of time, humans have watched birds and insects fly and dreamed of somehow making their own wings and soaring into the skies. Early designs for flying machines, from those of Leonardo da Vinci to those of Otto Lilienthal, copied the wing shapes of birds and bats for the simple reason that these were proven designs. However, the first successful powered aircraft had wings that were nearly rectangular in shape and stacked one above the other, nothing like the designs of nature. Modern airplane wings take almost any shape imaginable, from the long, slender wings of sailplanes to the sleek, highly swept wings of the Concorde.

Many things define the shape or design of a wing, including its span, sweep, taper, dihedral, twist, and its airfoil section or sections. All of these elements can be varied to provide an optimal design for a particular type of airplane. In designing wings, engineers must look first at the mission of the aircraft and determine whether it is to be designed for low-speed, high-speed, subsonic, supersonic, or even hypersonic flight. They must know whether the aircraft will travel long distances or remain close to home. They must know whether it will be used for stunt flying or aerial combat or for slow and comfortable flight movements. They must determine the aircraft's aerodynamic constraints, structural constraints, and even simpler limitations, such as the width of hangar doors.

Sweep

The sweep of a wing is the angle at which the wing curves. One can define several different sweep angles for a wing, including those for the wing's leading and trailing edges. This angle is defined as the angle between the relevant part of the wing and the free-stream or oncoming airflow. To an aerodynamicist or a wing designer, the important definition of the sweep is that of the quarter-chord line, a line that would run along the span from the wing root, or centerline, to the wingtip, one-fourth of the way back between the wing's leading and trailing edges. In other words, a straight or unswept wing would have a quarter-chord line that is perpendicular to the free-stream flow, whereas a swept wing would have its quarter-chord line at an angle other than 90 degrees to the flow. By this definition, a tapered, unswept wing, one with its chord at the tip different from the chord at the center or root, would still have some sweep of its leading or trailing edges.

Wings may be swept for several reasons, but the usual reason is to reduce the drag rise that occurs when a wing nears the speed of sound. Because the airflow accelerates over the top of a wing as an airplane approaches the speed of sound, a region of supersonic flow appears above the wing before the plane actually reaches Mach 1. As that flow moves further back over the wing's upper surface, it must decelerate back toward the free-stream air speed. However, supersonic flow has a strong tendency suddenly to decelerate through a shock wave. This small shock wave, which often occurs over the wing of an airplane flying at speeds just below the speed of sound, causes a sudden pressure change in the flow over the wing and can result in the flow breaking away from the wing at the shock location. The shock wave itself and the resulting separation of the flow over the wing cause an increase in drag, known as the transonic drag rise, which may double or triple the drag of a wing from its subsonic value.

The onset and magnitude of this drag rise are functions of the Mach number of the flow normal, or perpendicular, to the quarter-chord line of the wing. If this line is swept, the normal component of the Mach number will be lower than the free-stream Mach number. Sweeping the wing will therefore delay and reduce the transonic drag rise, allowing an airplane to fly closer to the speed of sound with less engine thrust or to accelerate past Mach 1 and fly at supersonic speeds with smaller engines. Hence, supersonic aircraft, such as fighters and supersonic transports, have highly swept wings with sweep angles of 45 degrees or more and high-speed, subsonic transports, such those made by Boeing and Airbus, have sweep angles of around 30 degrees to allow them to fly economically at Mach speeds of 0.8 or higher.

Although rearward and forward sweep will provide this drag benefit, aft sweep is usually the design choice, because forward sweep introduces a unique structural problem. The wingtip of a forward-swept wing tends to twist to a higher angle of attack than the rest of the wing, and this can lead to structural failure if the wing is not designed to resist the resulting forces. Thus, the forward-swept wing is often heavier and more expensive to produce than its aft-swept counterpart.

Some airplanes have wing sweep for other reasons such as to have the lift of the wing centered at some point behind or ahead of where the wing root attaches to the fuselage. The Douglas Aircraft DC-3, the world's first commercial airliner, which cruised below 200 miles per hour, had swept wings. The designers needed to move the wing's lift a little aft from their original design and wanted to do this without changing the place where the wing mated with the fuselage.

Aspect Ratio

The ratio of a wing's average chord to its span is known as the aspect ratio. Aerodynamic theory says that a wing with a high aspect ratio will have a very good lift-to-drag ratio, which will, in turn, make it very efficient for both long-range cruising and gliding. The aerodynamic cause of the aspect ratio effect is the flow around the tip of the wing from the higher-pressure area on the lower surface into the region of lower pressure on top. This has the effect of reducing the wing's lift and increasing its drag. If two wings have the same area, but one has a larger span and smaller chord, these losses near the tip will not affect as much of the wing area on the wing with the higher aspect ratio. Therefore, the wing with the higher aspect ratio will have a higher lift and lower drag than will a lower aspect-ratio wing with the same area and angle of attack. In contrast, a wing with a high aspect ratio will require a stronger structure than one with low aspect ratio and will make the airplane more sluggish in roll. This leads to tradeoffs in the design of aircraft.

Wing designs with a very high aspect ratio, such as 15 to 20, are used for sailplanes that depend solely on glide for flight. In these planes, the added structural weight is more than offset by the improved gliding ability, and there is no need for fast roll rates.

Commercial and military transports and general aviation airplanes designed for longer flights have wings with aspect ratios on the order of 6 to 10. This ratio is sufficient to give excellent long-range cruise capability, a lightweight structure with room for fuel in the wing, and the moderate roll rates needed for comfortable and controllable flight.

Aerobatic and fighter aircraft have wings with smaller aspect ratios of 5 or less, because their ability to roll and do other maneuvers at high rates is more important than efficient, long-range flight. Later variations of the famous Spitfire airplane used by the British in World War II had the span of their efficiently designed wings clipped, or shortened, in order to improve the planes' roll capability in combat with enemy aircraft.

Twist

Many wings are twisted to make the angle of attack near the wingtip lower than it is at the base. Although wings may be twisted for several reasons, such as to obtain the most efficient aerodynamic loading along the wing's span or to create effective structural loading, they are often twisted to make sure the inboard part of the wing stalls before the wingtips do.

It is important that the pilot be able to control the roll of an aircraft after the wing begins to stall. Otherwise, the stall can easily turn into a dangerous spin. Because the ailerons, near the wingtips, are the devices that provide roll control, the wing should be designed such that stall will begin on the inboard portion of the wing and progress outward, allowing the pilot to feel the stall while the ailerons are still effective. Although an untwisted wing will have some tendency to stall in this desired manner on its own, due to the three-dimensional flow around the tips, twist is often added to provide an extra degree of certainty of control during a stall.

Dihedral

When looking at an airplane from the front or rear, one may see that the wings are not horizontal but are rather swept slightly upward or even sometimes downward. This angle is called the dihedral, and it is used to improve the roll stability of the airplane.

Two factors in the design of a wing will influence the airplane's stability in roll. One is the vertical placement of the wing on the fuselage, and the other is its dihedral. Stability in roll means that if the airplane were disturbed from its wings-level position, it would automatically tend to roll back to level. For most aircraft, this stability is achieved by the use of dihedral. In a slight roll, the wing that moves downward toward a level position generates more lift than the opposite wing. The added lift then automatically helps restore the aircraft to equilibrium.

If the aircraft has a high wing placed above the fuselage, the fuselage's weight hanging below the wing will cause a pendulum-like effect, giving the craft some roll stability. Therefore, less wing dihedral will be needed than for a low-wing design. In fact, if the high-wing plane is a heavy transport, the wing may need to be built with negative dihedral, or anhedral, to ensure that the aircraft is not too stable in roll. Excessive stability would make the airplane resist the roll required during turns or other maneuvers.

Planform

The shape of a wing when viewed from above is known as its planform shape. The area inside this shape, the planform area, is used as a reference area when calculating wing lift, drag, and pitching moment coefficients.

An examination of airplane designs since the beginning of flight will reveal almost every planform shape imaginable. Planform shapes include simple rectangles, basic trapezoids, smooth curves, bird- or bat-wing contours, triangles, and wings with swept leading edges and sawtooth trailing edges.

The simplest wing planform to build is probably the rectangular shape, and sometimes this is the designer's choice when the cost of construction is more important than other factors. From a structural-efficiency perspective, a wing that is tapered to give a smaller chord at the tip than at the root is a good choice. The tapered planform can give a reasonable aspect ratio while placing the major portion of the lift on the wing's inboard sections where it is less likely to bend the wing-support spar.

Aerodynamic theory holds that, in addition to the benefits of high aspect ratio, the drag on a wing can be further minimized by optimizing the way that lift acts along the wingspan. The best low-drag lift distribution over the wingspan is an elliptical one, in which the lift tapers from a base value at the center, or root, of the wing to zero at the wingtip in a shape like an ellipse. One way to try to achieve such a lift distribution is to actually vary the chord of the wing elliptically along its span, and many airplane wings have been designed this way. Such designs were particularly prevalent in World War II-era fighter aircraft, with the best-known example being the British Spitfire.

Elliptically shaped wing planforms are, however, more expensive to build than straight tapered wings, and the wing designer must compare the cost of a purely elliptical wing shape to that of a tapered wing that may approximate the same aerodynamic efficiency. Because it is the wing's lift distribution and not actually its shape that should be elliptical, there are other alternatives available to the designer. One can design a wing with the right combination of taper, twist, and sweep to give an elliptical load distribution. Another alternative is to employ variations of airfoil section along the wingspan to tailor the lift distribution. In fact, a calculation of the lift distribution on the B-2 flying wing stealth bomber, with its swept wing and unusual sawtooth trailing edge, will reveal a near-elliptical lift distribution.

Wingtip Designs

Over the years, wing designs have included some interesting variations in wingtip shape. Many of these have been accompanied by claims of improved performance due to the reduction or elimination of the drag-producing flow around the wingtip. Although some wingtip shape variations may be capable of slightly altering the structure of the swirling vortex that trails behind a wing, none have ever demonstrated any significant effect. The trailing vortex is a consequence of the lift on a wing, and the only way to reduce or eliminate it is to lower or eliminate the lift on the wing.

The winglet is, however, a wingtip device that is designed to use rather than alter the developing wingtip vortex to produce a thrust. It has been used successfully to improve the performance of many aircraft. Some wing shapes have beneficially altered the wing dihedral at the tip to enhance stability or handling or, as add-on devices, to slightly increase the wing's aspect ratio and, thus, its aerodynamic performance.

Combinations and Other Variations

Sometimes there is a strong desire to optimize the performance of a wing in seemingly conflicting ways or to design a wing for good flight performance while meeting a nonflying requirement. Variable sweep wings have been used on several fighter and bomber designs to take advantage of the properties of an unswept, high aspect ratio wing and of a swept wing with lower aspect ratio on the same airplane. This increases the cost of manufacturing and maintenance, as well as the weight of the aircraft, factors that must be weighed carefully against the aerodynamic and other performance gains. Over the history of aviation, several designs have employed wings that folded in various ways or extended and retracted either in flight or on the ground in order to optimize wing area or aspect ratio in the air or to fit into tight spaces on the ground.

There have also been designs with interesting combinations of sweep. The scissor-wing concept has a single wing that rotates on an axis, with one side of the wing rotating to a forward sweep and the other moving aft. This design provides a simple but somewhat strange-looking way to achieve variable sweep. The joined wing, with fuselage-mounted aft-swept wing joined at its tips to a forward-swept wing mounted on the vertical tail, claims structural and aerodynamic benefits.

Biplanes, with their wires and struts, are usually considered World War I-era designs. However, modern aerobatic biplanes provide plenty of wing area and lift with a short span for ease of roll. Tandem-wing designs place one wing in front of the other, and at least one past design proposed including a sliding section to fill the space between the tandem wings for added area on takeoff. The channel-wing design wraps part of the wing around the lower half of a propeller supposedly to enhance both wing and propeller performance. Radar reflectivity or stealth considerations may also lead to strange shapes for both the planform and the airfoil sections. Flexible or inflatable wings are often used for "flyable" parachutes and hang gliders and in military applications where wings need to be stored in small places for deployment on demand.

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See also: Airplanes; Biplanes; Flying Wing; Forces of flight; Leonardo da Vinci; Otto Lilienthal; Manufacturers; Monoplanes; Stealth bomber; Triplanes; Wind tunnels

Wing-walking

Also known as: Daredevils, stunt fliers, air circus

Date: The 1920's

Definition: A feature attraction in early air shows, in which a performer stepped out of an airplane's cockpit and onto its wing while the airplane was in flight.

Significance: Like the barnstormers, wing-walkers and other aviation daredevils helped popularize airplanes and the concept of air travel. As competition for audiences grew, wing-walking and other stunts became more extreme, including gymnastics, plane-changing, and in-air skits.

After World War I, veteran pilots became the first barnstormers, itinerant fliers who traveled throughout the rural United States selling rides and demonstrating their flying abilities in surplus Curtiss JN-4D biplanes, also known as Jennys. Because planes were inexpensive and federal regulations were nonexistent, anyone with the urge to fly and the freedom to travel could do so.

As the novelty of air travel and airplane rides began to wear off, however, barnstormers had to find new ways to attract audiences for their annual visits. Stunt-flying became the next step, with pilots performing elaborate in-air maneuvers, seeming to cheat death at every turn.

Many early pilots disdained parachutes, but seeing a person jump from an airplane also proved to be quite a draw, and stunt jumpers were added to the performance. Before the invention of the ripcord, parachutes were often stored in boxes attached to the wing of the airplane. To prepare for the jump, the performer had to step out of the cockpit and onto the wing, taking care to stand in the proper place so as not to tear the fabric. The parachute was deployed either by releasing it from the box and letting it pull the jumper off the plane or by letting the jumper's weight release it jumping.

For some, wing-walking evolved from the suspense-building delay leading up to the jump. It did not take long for daredevils to realize that the sight of a person standing on the wing of an aircraft in flight was remarkable in itself. Many early stunt fliers were the barnstormers themselves; even famed aviator Charles A. Lindbergh performed as a wing-walker while traveling with barnstormer Erold Bahl.

Image Not Available

Others started out as circus performers, making the transition from the trapeze and the high wire to the wing of a biplane. Although these early performers worked without harnesses or special equipment, the structure of Jennys flown by the barnstormers allowed for many gripping points.

One of the most famous daredevils was Ormer Locklear, known as the "man who walked on wings," who had "more guts than brains." Locklear began his wing-walking career in the military, when he climbed down onto the landing-gear spread bar of his Jenny trainer in order to read a message flashed to him from the ground below. After that experience, he took seemingly every opportunity to step out of the cockpit and was soon doing handstands on the upper wing, riding the tail, and dangling upside-down from the landing gear. Rather than discipline him, his superiors instead used his stunts to generate publicity for the armed forces.

After leaving the military, Locklear continued his daredevil stunts as a featured performer in air shows around the country. He is reputed to be the first man to climb from one plane to another while both were in midair. At the height of his popularity, Locklear received up to one thousand dollars a day for what amounted to a half-hour's work. Unfortunately, his civilian career lasted only sixteen months, after which he was killed during a wing-walking stunt for a motion picture.

Unlike most careers in the early twentieth century, wing-walking was not a male-only occupation. The first woman to change planes was Ethel Dare, originally a trapeze artist with the Barnum and Bailey Circus. She was known as "the Flying Witch," the "Queen of the Air," and the "1920 Aerial Sensation." In one of her most popular stunts, Dare would appear to fall from the wing, only to be caught by a line attached to her harness. She would then climb up the rope and resume her position on the wing. Her specialty was the "iron-jaw spin," in which she would clasp a mouthpiece between her teeth, step off the wing, and spin behind the plane in the wake of the propeller.

Eventually, wing-walking became insufficient to amuse audiences. Dances, table tennis games, card games, and even shootouts were staged on specially-built platforms on the upper wings of biplanes. Daredevils would perform maintenance, tire changes, and refueling operations in midair. In one of its most notable stunts, the Hollywood-based stunt-flying group Thirteen Black Cats would fake an accident during a plane change in which the stuntperson would free-fall for about 400 feet before opening a parachute.

As the years passed, the stunts grew increasingly more dangerous. It was no longer enough for daredevils to transfer from plane to plane, and daredevils used locomotives, automobiles, boats, and even horses for their changes. When parachutes, which had once been part of the demonstrations, were perceived to lessen the apparent danger, air circuses began advertising that their performers worked without them.

The federal Air Commerce Act of 1926 put an end to many of the more dangerous stunts, especially those performed in front of a large audience. The art of wing-walking gradually faded away along with the barnstormers and the air circuses and remains to be seen only as a part of nostalgia acts in smaller air shows around the United States.

P. S. Ramsey

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See also: Aerobatics; Air shows; Barnstorming; Biplanes; Jennys; Charles A. Lindbergh; Safety issues; Women and flight

Winglets

Definition: Small, winglike devices mounted at the tips of wings.

Significance: Winglets are used to increase the aerodynamic efficiency of a wing by using the flow around the wingtip to create a thrust. They can improve airplane performance by as much as 10 to 15 percent.

Winglets, sometimes known as Whitcomb winglets, after their developer, Richard Whitcomb of the National Aeronautics and Space Administration (NASA), are placed at the tips of the wings of many airline, commuter, and business class aircraft. They look like small wings and are usually attached to the main wingtip at an angle that tilts them slightly outward from vertical. In some cases, a winglet will include elements extending both above and below the wingtip, although many extend only upward from the wing.

Many people believe that the primary purpose of a winglet is to reduce or eliminate the swirling flow, or trailing vortex, beginning at an airplane's wingtip as air moves around the tip to the low-pressure region above the wing, but this is not the winglet's primary purpose. Although a winglet may somewhat alter this tornado-like vortex that flows from the wingtip of every airplane, its main purpose is to use that flow to create a thrust.

A properly designed winglet is mounted on a wingtip at a slight angle to the oncoming airflow, and the combination of the swirling flow around an aircraft's wingtip with the oncoming flow causes a "lift" on the winglet, which is directed both inward along the wing and forward. This forward force is essentially a thrust that counteracts some of the normal drag of the airplane, improving its lift-to-drag ratio and giving it better range in flight.

A similar improvement in a wing's lift-to-drag ratio could also be obtained by using a wing of greater span that gives a higher aspect ratio. The aircraft designer who wishes to make such an improvement may choose either to extend the wingspan or to use winglets. The latter choice may depend on factors such as the ability of the airplane to fit through hangar doors and between allowable airport gate widths.

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See also: Aerodynamics; Airplanes; Forces of flight; National Aeronautics and Space Administration; Wake turbulence; Richard Whitcomb; Wing designs

Winnie Mae

Definition: The name of the record-setting Lockheed Vega airplane that was flown by Wiley Post from 1930 to 1935.

Significance: Piloted by Post, the *Winnie Mae*, the most aerodynamically advanced aircraft of its time, made two record breaking around-the-world flights and pioneered stratospheric flight. The *Winnie Mae* now resides in the National Air and Space Museum in Washington, D.C.

In 1928, Oklahoma oilman F. C. Hall bought a Vega airplane from Lockheed Aircraft Company so that his company pilot, one-eyed Wiley Post, could fly him to important business meetings. Hall named the plane after his daughter, Winnie Mae. When the stock market crashed in 1929, Hall sold the plane back to Lockheed and had them remove the name from the aircraft, but just the next year, in June, 1930, he decided he needed another Vega, which he also named *Winnie Mae.* It was this *Winnie Mae* that Wiley Post used to make all his famous flights, thereby making it one of the best known of all aircraft.

The Lockheed Vega was a beautifully streamlined high-wing aircraft, with an internally supported wing and tail, in an era when other aircraft were enormously draggy biplanes or at least had exposed wing struts and wires and draggy landing gear. The Vega fuselage was built by first gluing together very smooth shell halves of laminated plywood that had been shaped in a concrete mold; the fuselage thereby gained most of its structural strength from its outer skin, known as a semi-monocoque construction. The efficient, fabric-covered wood wing used an 18 percent thick Clark Y airfoil at its root, tapering to 9.5 percent thickness at the wingtip. Both *Winnie Mae* Vegas were delivered with 9-cylinder, 420-horsepower Pratt & Whitney Wasp radial engines.

As delivered, the first seven-place Vegas had wingspans of 41 feet, an empty weight of 2,361 pounds and a useful load of 1,672 pounds. The early Vegas cruised at about 140 miles per hour and, under sea level conditions, climbed at 1,300 feet per minute and landed at 54 miles per hour. Their 96 gallons of fuel and 10 gallons of oil gave a range of 725 miles.

The Hall's second Lockheed Vega 5B cost him $22,000. Already interested in flights that furthered aviation developments, he agreed to let Post prepare the new *Winnie Mae* for the Los Angeles-to-Chicago race in August that was part of the 1930 National Air Races. Additional fuel tanks were added in the passenger compartment, bringing capacity to 500 gallons, the oil capacity was increased to 25 gallons, and a high-ratio supercharger was fitted that brought the horsepower up to 500 for takeoff. The incidence angle of the wing was decreased to lower fuselage drag and increase the cruising speed by about 10 miles per hour, but this modification also increased the landing speed to about 80 miles per hour. Despite the loss of his magnetic compass, which cost him an extra 40 minutes, Post still won the first place prize of $7,500 by averaging 192 miles per hour over the 1,760-mile course. (Art Goebel, flying the first *Winnie Mae,* was second.)

By early 1931, Post had decided that he wished to demonstrate the advances in aviation by flying around the world, and Hall was willing to provide the necessary financial backing. Realizing that navigation would be critical, Post enlisted as a second crew member the navigation expert Harold Gatty, who had helped him prepare for the Los Angeles to Chicago race. Post, profiting from Jimmy Doolittle's pioneering flights with "blind flying" instruments, installed rate-of-climb and gyroscopic instruments, a turn-and-bank indicator and an artificial horizon, in a cluster that made it easy to scan them while flying in clouds, realizing that the ability to fly solely by reference to instruments would be critical to their survival as well as their success.

A favorable "weather window" finally came on June 23, 1931, and Post and Gatty took off from New York for the nearly seven-hour flight to Harbour Grace, Newfoundland, then the sixteen-hour transatlantic flight to England, followed by stops in Germany, Russia, Siberia, Alaska, Canada, and Cleveland. Finally they were back at Roosevelt Field in New York, to be met by a crowd ten thousand strong. A ticker-tape parade, a visit with President Herbert Hoover in Washington, D.C., gala celebrations in Oklahoma, and a tour of the country followed.

Post and Gatty's official flight time was 8 days, 15 hours, and 51 minutes. They had eclipsed the flight times of the previous three around-the-world flights (two U.S. Army Douglas World Cruisers in 1924 and the *Graf Zeppelin* in 1929). The *Winnie Mae* had performed faultlessly, proving the thoroughness of Post's preparation, the aerodynamic efficiency of the Vega, the necessity for blind flying instruments, and the reliability of the Pratt & Whitney Wasp engine.

Wiley Post and the *Winnie Mae* were not through yet. Post decided that he could take advantage of emerging technological advances—an air-driven autopilot, a radio compass that would point toward any transmitting radio station, and an adjustable-pitch propeller that he could optimize for takeoff or cruise—to make a solo flight around the world. A little over a year later, on July 15, 1933, Post and the *Winnie Mae* lifted off from Floyd Bennett Field in New York (now JFK International Airport). Berlin, Germany, was his first stop, establishing yet another transatlantic record. Fuel stops were made in Russia, Siberia, Alaska, Canada, and then it was nonstop to New York. Post and the *Winnie Mae* had broken the previous year's record by more than 21 hours, becoming the first person and the first airplane to fly around the world twice, and the first to do it solo.

Another ticker-tape parade down Broadway, another presidential visit, major aviation awards, and joint appearances with the *Winnie Mae* in Rockefeller Center in New York and in other cities followed. Post realized, however, that further advances in around-the-world flight required the ability to fly above the weather and he began to plan for *Winnie Mae*'s last great adventure: stratospheric flight (about 36,000 feet above Earth's surface, where the air temperature becomes constant).

Winnie Mae received an external supercharger that compressed the air before it reached the carburetor, augmenting the internal supercharger (boosted to a 13:1 compression ratio) which compressed the fuel-air mixture after the carburetor, allowing *Winnie Mae*'s Wasp engine to develop its rated power of 450 horsepower at 35,000 feet and have the ability to climb as high as 50,000 feet. The airplane's ignition magnetos had to be pressurized to prevent sparking between high voltage sections in the thin air. The landing gear was replaced with droppable gear and the airplane was designed to be landed on a belly skid. Post also expended a great deal of effort developing a completely enclosed pressure suit for himself, finally achieving a suit that included pure oxygen from a liquid oxygen container while still allowing him to fly the airplane. By late 1934, Post had reached an unofficial 50,000-foot altitude and had confirmed the existence of the jet stream by measuring 200-mile-per-hour winds there. In March, 1935, his quest for a nonstop, high-altitude, transcontinental flight brought him and the *Winnie Mae* one hundred miles past Cleveland before his oxygen supply was exhausted; he had experienced 100-mile-per-hour tailwinds. An engine failure on the fourth attempt, in June, convinced Post that the *Winnie Mae* and her original engine were getting tired, and he agreed to sell her to the Smithsonian Institution for $25,000.

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Women and flight

Definition: A brief history of women's struggles and accomplishments in the world of aviation.

Significance: The contributions made by women in flight have been extensive, from aviation to the space program.

In the early days of aviation, women faced many more obstacles than just finding a way to fly. The original notions of flight and flying always involved the image of men. "Those magnificent men in their flying machines" became a lofty image of bigger-than-life male pilots. The public believed that the world of flying belonged to an elite group of men, a band of adventurers bonded by the magic, fears, and challenges of conquering this new realm.

Women constantly had to prove themselves worthy of a chance to enter the cockpit. In the early 1900's, when airplane flight had its birth, women were expected to be in the home as mothers and wives. To dare to dream outside of that realm caused extreme problems for women. Women needed permission from families, husbands, and even society itself. The traits that were envied in male pilots were found to be unattractive, unnatural, and unacceptable in women. Women not only had public image problems with flying but acceptance problems with male pilots. These pilots believed that men and only men qualified to be the true pioneers of the skies.

Even when given permission to try flying, many early women applicants were unable to find a flight school or an instructor that would accept a woman student. The parents of famed aviator Amelia Earhart made her find a woman instructor. They did not like the idea of their unmarried daughter spending so much unchaperoned time alone with men. Earhart was lucky to find the first woman to operate her own aviation business, Anita “Neta” Snook.

Flight, the Ultimate Adventure

In early accounts of flying, it is rarely mentioned that there were, indeed, women who not only had dreams of being airborne, but were actually a part of the very beginning of aviation. It is a little-known fact that six months before the Wright brothers’ historic 1903 flight, Aida De Costa had already flown solo in a Dumont dirigible with a three-horsepower engine. De Costa’s astounding accomplishment was not reported in the press because her parents were afraid that it would make her unmarriageable. There are thousands of stories of pioneer women pilots who seldom, if ever, got into print.

Women were piloting aircraft as early as 1798, when Jeanne Labrosse made a solo balloon flight over France. Margaret Graham of England dedicated a thirty-year career to the sport of balloon flying by charging a fee for carrying passengers for a ride, most likely becoming the first woman charter pilot. Mary Myers set altitude records in balloons, including one to 21,000 feet over Pennsylvania in 1886. She accomplished this feat without the aid of oxygen.

In 1911, Germany’s first aviatrix, Melli Besse, found that her male colleagues had tampered with her plane’s steering mechanism and drained gas from the fuel tank. The sabotage efforts were finally uncovered and eventually Besse was able to fly without interference.

From the 1920’s to the 1940’s, women aviators faced the same problems as other women wishing to enter male-dominated careers or hobbies. The question of the day was whether a “real lady” would fly around in an airplane.

Women in Early Competition

It was not unusual in the late 1920’s for women pilots to go into business for themselves. Women established passenger-carrying operations in several cities, but these ventures did little to promote women in the field of aviation. If they were to receive national recognition, they would have to compete, as male pilots were already doing, in the record-breaking arenas of distance, altitude, and speed.

Viola Gentry is credited with one of the first attempts by a woman to set an endurance record. On December 20, 1928, she stayed aloft for 8 hours, 6 minutes. Two weeks later, her record was broken by Bobbi Trout, who managed to stay in flight for more than 12 hours. The following spring, Elinor Smith astounded fliers everywhere by staying in the air for 26 hours. Women still had a long way to go, however, because the men’s record at that time was 60 hours.

In 1929, the first National Women’s Air Derby was held. The race began in Santa Monica, California, and ended in Cleveland, Ohio. The winner was Louise Thaden.

When World War II began, it looked as though American women pilots would be grounded or forced to fly only in civilian capacities. Thanks to people such as Jacqueline Cochran, women did have an opportunity to fly and help with the war effort. Many went to England to join the Air Transport Auxiliary to ferry airplanes to the fighting men. These women flew with great valor, facing many obstacles.

In 1942, a similar group of women pilots was formed in the United States, known as the Women’s Auxiliary Ferrying Squadron (WAFS). Indeed, throughout World War II, groups of women defied convention en masse to fly for their countries. The Women’s Airforce Service Pilots (WASPs) in the United States, the Women’s Section of the Air Transport Auxiliary (ATA) in England, and the 586th Bomber Regiment of the Soviet Union were composed of women who gladly utilized their skills as pilots to help the Allies win the war. Many of these pioneer women pilots enlisted in war efforts against the wishes of their husbands and families.

Breaking into a Man’s Field

Flying today is totally different than it was in the early days of flight. In the first aircraft, it was pilot judgement and skill as well as the aircraft that made for a successful flight. The sky was all but free from other aircraft; rules and regulations were just about nonexistent. There were only a few types of aircraft available. Famed pilot Dorothy Stenzel would often recount that it was a delight to fly in 1927: “Everything looked so neat from up there and you feel so free. You were your own boss and you could get up there alone.”

Dorothy Stenzel started to fly in 1927, one day after her seventeenth birthday. She found a place where she could go for an airplane ride; she spent her birthday money and her adventure began. The biplane was a Waco 9 with a Curtiss OX-S engine. She sat in an open cockpit and felt the rush of air sweep over her when the engine started. "When we lifted off the ground, my heart swelled and I felt like I was in heaven. It was the most wonderful feeling I had ever had, and I decided right then that I had found my calling." After landing, she spoke to Tex Rankin, who owned the Rankin School of Flying. She asked if he would teach her to fly. Tex Rankin agreed, even though she was not a boy. The only problem was obtaining the $250 she needed to pay for the ground course, a large sum at the time. Rankin mentioned that if she were male, she could earn the money parachute jumping in his air shows. Indignant at the implication that women could not parachute merely because of their gender, she convinced Rankin through forcible argument to break the established barrier of men-only in the air.

Stenzel's determination has become legendary, and she became the first woman in Oregon to parachute during an aerial show. She got $100 per jump, and she earned her pilot's license and flew. Dorothy Stenzel also held the world's inverted snap roll record for more than half a century. On May 15, 1931, with twenty thousand people looking skyward from Omaha, Nebraska, Stenzel performed sixty-nine consecutive outside loops, tracing them again and again for more than two hours.

Image Not Available

Many factors have changed over the years, as the airplane itself has changed. In the first days of woman pilots, women were considered good if they could fly like men. It meant that they had the physical strength to manhandle the airplane. As the airplanes improved, so did the chances for woman pilots, as it became no longer necessary to muscle an airplane around.

Groundbreakers and Pioneers

Knowing that the life of the early woman pilot came with so many burdens, one must wonder why so many have worked so hard to gain a place in the skies. Nonetheless, the record of women in flight is long and impressive.

Beryl Markham, born in 1902, was a famous adventurer and bush pilot who is most widely known for her record-breaking solo flight from east to west across the Atlantic in 1936, and for her best-selling memoir *West with the Night* (1942).

Markham was possibly the best pilot to fly out of Kenya, and certainly the boldest. Some likened her courage to that of a lion. In April, 1932, with only 127 hours of flying time, she set off alone from Kenya in a single-engine Avro Avian headed for England. She first headed for Lake Victoria, then over Uganda and down the Nile, crossing the seemingly endless expanses of marsh and swamp known as the Sudd. She then crossed the Mediterranean Sea and Europe and arrived in England. Markham repeated this trip several times in the early 1930's. While in Kenya, she worked as a bush pilot, transporting people and supplies. She worked for safari companies and even became a flying elephant-herd spotter. All of her daring escapades culminated in one flight that topped them all. On September 4, 1936, she began a 22-hour flight, mostly at night and mostly on instruments, headed across the Atlantic, west with the night. Beryl Markham was an inspiration for millions as a true woman flying pioneer. She died in 1986.

Markham was not the only woman aviation pioneer of her era. Ruth Law was the first woman to fly at night, in 1912. She was also the first to loop-the-loop. She made a living by taking Florida tourists on joyrides for $50. Law was renowned as an inventor as well as for her solution to the problem of keeping a map readily accessible. She cut the map of her route into eight-inch-wide strips and affixed them to cloth, creating a cloth map that she could tie to her knee during the flight and roll out one section at a time, thus keeping her hands free to operate the controls. In 1917, after breaking the cross-country record, Law commanded a salary of nearly $9,000 a week for her exhibitions. Even earlier, Matilde Moisant, born in 1886, was the second licensed woman pilot in the United States and the first woman to fly to an altitude of 1,200 feet. Moisant qualified for her license after only thirty-two minutes of in-flight instruction. In so doing, she established the record for the shortest time spent learning to fly, a record that has never been broken. The first American woman to earn a pilot's license was Harriet Quimby in 1911, who started her plane manually by turning the propeller.

Amelia Earhart was the best-known woman flier of the early twentieth century, flying across the Atlantic with two companions in June, 1928, and becoming the first woman to make a solo crossing in 1932. She piloted a Lockheed Vega on the west-east solo flight from Honolulu to California on January 11-12, 1935. Earhart was lost in an attempt to fly around the world with pioneer aerial navigator Fred Noonan.

Florence Lowe, also known as "Pancho Barnes," was a record-breaking stunt pilot who eventually headed the Women's Air Reserve in 1931 and the first woman to fly into Mexico. Fran Bera held the record of most wins for the Women's Air Derby. She learned to fly at sixteen, got her commercial license, taught aviation, and worked for the Federal Aviation Administration issuing licenses to pilots. The Women's Air Derby, however, gained her the greatest fame, winning five second-place trophies and seven first-place trophies. In June, 1966, Bera set a new world altitude record for flying to a height of 40,194 feet over Long Beach, California. Anne Morrow Lindbergh, wife of Charles A. Lindbergh, was the first American woman to earn a glider pilot's license. She served as her husband's navigator when he set a transcontinental speed record in 1930, at which time she was seven months pregnant. She was also a best-selling author.

In 1964, Geraldine "Jerrie" Frederitz Mock became the first woman to fly around the world, twenty-seven years after Amelia Earhart's disappearance in 1937. Joan Merriam Smith was flying with the same goal in mind at the same time and completed her trip successfully, but Mock had registered first with the FAA and therefore won the title. Her plane was named *Spirit of Columbus*. Katrina Mumaw was the first child, male or female, to pilot a plane through the sound barrier. Federal Aviation Administration regulations do not allow anyone under the age of seventeen to be issued a pilot certificate, but training can begin at any age. She fell in love with aviation at the age of three. She took her first plane ride at the age of five and began training with a flight instructor when she was eight. In 1994, Mumaw broke the sound barrier at the age of eleven. At thirteen, she was both competing and speaking at air meets and aviation events around the state.

Women Aviators in the Military and in Space

The fight to be allowed into the military has been a long and hard struggle for women. Their first toehold came during World War II, when the need to use all qualified male pilots in battle opened opportunities for woman pilots in noncombatant roles. Nancy Harkness Love, already a commercial airline pilot, was one of the first women to head a military unit of female pilots, the Women's Auxiliary Ferrying Squadron, which ferried military planes from manufacturing sites to air force bases. Cornelia Fort, a flight instructor who was the first Tennessee woman to qualify for her commercial pilot's license, was the second woman to volunteer for the WAFS. She was in the air when the Japanese bombed Pearl Harbor in December 7, 1941. Fort and her student landed safely, but Fort died in a 1943 midair collision while ferrying a plane. She was the first woman to die in U.S. military duty.

Mildred McAfee was the first director of the Women Appointed for Volunteer Emergency Service (WAVES). On July 30, 1942, the WAVES were created by an act of Congress. When she was appointed to lead them, McAfee became the first woman ever commissioned as an officer in the U.S. Navy. She retired from the WAVES as a full captain in December, 1946. For her service she received the Distinguished Service Medal.

In the years since World War II, many women have broken gender barriers to become successful military pilots. Trish Beckman was one of the first women trained to be a United States Navy test pilot. Sarah Deal was the first woman aviator in the U.S. Marine Corps. Troy Devine was the first woman captain in the U.S. Air Force U-2 program. Kelly Flinn was the first woman to pilot a B-52 bomber for the U.S. Air Force. Patricia Fornes was first woman to lead a U.S. Air Force ICBM Unit. On June, 1993, Fornes took command of the 740th Missile Squadron at Minot Air Force Base, North Dakota. She also became the first woman to take over the command of a squadron once commanded by her own father. Colleen Nevius was the U.S.

Navy's first woman test pilot and the first woman to graduate from the Naval Test Pilot School in Patuxent River, Maryland.

In space aviation, Sally K. Ride was the first American woman in space, launching in the space shuttle *Challenger* on June 18, 1983. She was also the youngest American astronaut to orbit the earth. Judith Arlien Resnik was the second American woman to go into space and the first Jewish astronaut. Linda M. Godwin performed the first spacewalk while docked to an orbiting space station. Shannon W. Lucid has logged more continuous time in space than any other American astronaut, male or female. Lucid spent seven months on the Mir Space Station in 1996. She was also the first American woman to go into space five times.

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See also: Astronauts and cosmonauts; Jacqueline Auriol; Jacqueline Cochran; Bessie Coleman; Crewed spaceflight; Amelia Earhart; Amy Johnson; Beryl Markham; Navy pilots, U.S.; Ninety-nines; Hanna Reitsch; Sally Ride; Space shuttle; Spaceflight; Valentina Tereshkova; Test pilots; Whirly-Girls; Women's Airforce Service Pilots

Women's Airforce Service Pilots

Also known as: WASPs

Date: From August, 1943, to December, 1944

Definition: Women pilots who flew training missions and ferried aircraft for the United States Army during World War II.

Significance: WASPs demonstrated the military potential of women pilots. They also compiled an outstanding record of service and flight safety, and became a symbol of the entrenched sexism which kept women pilots out of the armed forced during the Second World War and denied WASPs veterans benefits and military recognition until 1977.

The origin of the WASPs dates to 1941, when famed pilot Jacqueline Cochran recruited American women to fly for the Air Transport Auxiliary of the Royal Air Force. A veteran pilot holding numerous distance and speed records in a wide variety of aircraft, Cochran hoped to assist the British in their fight against Germany while also creating the foundation for a contingent of women military pilots in the United States. She led her first group of pilots to the United Kingdom in 1942, hoping to command any similar contingent which formed in the U.S.

At the same time, Nancy Harkness Love persuaded Major General Harold L. George, commander of the U.S. Army's Air Transport Command, to use female pilots in his Ferry Division. First Lady Eleanor Roosevelt publicly endorsed the idea, and in September, 1942, Love took over the Women's Auxiliary Ferrying Squadron (WAFS) at Love Field (named after her millionaire husband, Colonel Bob Love, who was George's Chief of Staff) in Dallas, Texas.

Cochran was devastated. Lieutenant General Henry Harley "Hap" Arnold, who commanded the United States Army Air Force (USAAF), responded by placing her in charge of training women pilots for the Army Air Force (AAF). Cochran's Women's Flying Training Detachment (WFTD) set up shop at Howard Hughes Airfield outside Houston, Texas, in 1942, then moved to Avenger Field in Sweetwater, Texas, the following year.

Formation of the WASPs

The move to Sweetwater coincided with the Army's decision to combine the WAFS and the WFTD to form the Women's Airforce Service Pilots (WASPs) under Cochran's command in August, 1943. The move eliminated confusion and duplication of effort in the training of women pilots, and gave Cochran a free hand to set the highest standards for training. She demanded that each female pilot trainee have a minimum of thirty-five hours of flight time prior to acceptance into the WASP program (male pilot trainees in the Army did not have to have any prior flight time), and accepted only 2,000 applicants from a pool of more than 25,000.

Interestingly, Cochran's pilots became civilian employees of the War Department (earning 20 percent less than men in the same grade) rather than members of the armed forces. Army Chief of Staff George Marshall wanted to commission the women as officers in the Women's Army Corps (WAC), but Cochran refused to give up control over her pilots to the WAC commander, Colonel Oveta Culp Hobby, and the issue faded away. It came back to haunt the WASPs later.

Successes

Despite their nonmilitary status, Cochran's pilots trained to AAF standards during a twenty-three week course which included cross-country, aerobatic, instrument, and night flying in a number of different aircraft, and many hours of classroom work and simulator training. More than 50 percent of the trainees washed out, while the 1,074 who eventually graduated moved on to fly training missions and ferry aircraft for the Army. By the end of the war, WASPs had flown every airplane in the AAF inventory, from nimble P-51 Mustangs to B-17 and B-29 heavy bombers, and compiled an amazing record of safety. Only three WASPs were lost in fatal accidents in the course of delivering 12,652 planes, while another thirty-four were killed in training accidents. This record proved far superior to that of male pilots, who had a higher rate of discipline problems and were more reluctant to perform mundane training missions. In contrast, WASPs enthusiastically pulled target sleeves for aerial gunnery practice, simulated bombing runs on antiaircraft positions to train gunners, ferried aircraft across the United States and even overseas, and served as instructors for male pilots learning to bomb and strafe ground targets.

Setbacks

The success of the Women's Airforce Service Pilots seemed to promise a greater role for women pilots in the armed forces. Instead, the shortage of pilots that had driven the creation of military programs for women pilots eased by mid-1944, and male civilian pilots began to push for an end to the WASP program. They resented competing with women for military duty as pilots, and argued that the impending Allied victory made additional women pilots unnecessary. Cochran and Arnold tried to save the WASPs by supporting legislation integrating them into the AAF, but after intense lobbying the bill they supported proved to be nineteen votes shy of passing in June, 1944. Afterward, it seemed clear the WASPs were doomed, and in December, 1944, the last class of pilots graduated from Avenger Field.

Those women already flying for the Army served until the end of the war in 1945, then found themselves mustered out. Ironically, their greatest battle was yet to come, for they soon found themselves denied status and benefits as veterans because they had officially served in the Army as civilians. It took thirty-three years of lobbying for the United States to finally recognize WASPs for their military service, a step which Congress took in 1977.

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See also: Bombers; Jacqueline Cochran; Flying Fortress; Military flight; Royal Air Force; Superfortress; Women and flight; World War II

World War I

Date: From July 28, 1914, to November 11, 1918

Definition: An international conflict, resulting from growing tensions within Europe and increasing German dominance over the region.

Significance: World War I, the first truly global conflict, was also the first war in which rapidly developing aviation technology allowed for the widespread use of fighter planes and bombers in support of ground troops.

Airplanes in World War I

At the start of World War I, often known as the Great War, airplanes were little more than ten years old. The Blériot XI type airplane, only five years old, had first gone to war in 1911 with Italian forces in North Africa. At the outbreak of World War I, the British Royal Flying Corps (RFC) brought twenty-three Blériot XI's to France with its expeditionary force. These planes served as reconnaissance aircraft with six RFC squadrons. The French Air Service also furnished Blériots to eight of their escadrilles, or air squadrons, and Italy went into action with its own previously acquired Blériot XI's in six squadrons.

The first airplanes were looked upon not as weapons of destruction but rather as scouts. Even at the end of the war, fighters such as the Sopwith Snipe and the Fokker D-VIII were still classified as scouts. At the start of the war, planes were unarmed, and pilots from opposing sides would wave as they flew by each other, in a sort of "camaraderie of the sky." This arrangement did not last.

Armed Aircraft

On the night of June 17, 1915, in a Morane Saulnier L, Lieutenant R. A. J. Warneford of the Royal Naval Air Force (RNAF) was flying toward Evere, Belgium, to bomb zeppelin bases. Warneford spotted the *LZ-37*, a German zeppelin, 521 feet long, kept aloft by 935,000 cubic feet of dangerously flammable hydrogen gas and armed with four machine guns.

Warneford's single-seater carried only a few bombs and a carbine. The zeppelin crew fired at Warneford as it dumped ballast and rapidly rose higher into the sky. On through the night and early into the morning, Warneford pursued the zeppelin, which eventually began to lose altitude. Warneford pushed his Morane to higher altitudes until he was above the zeppelin, at which point Warneford released his bombs. The bombs made contact with the zeppelin, resulting in a tremendous explosion. The dirigible, engulfed in flames, plummeted to the earth. Lieutenant Warneford was the first Allied flier to bring down a zeppelin.

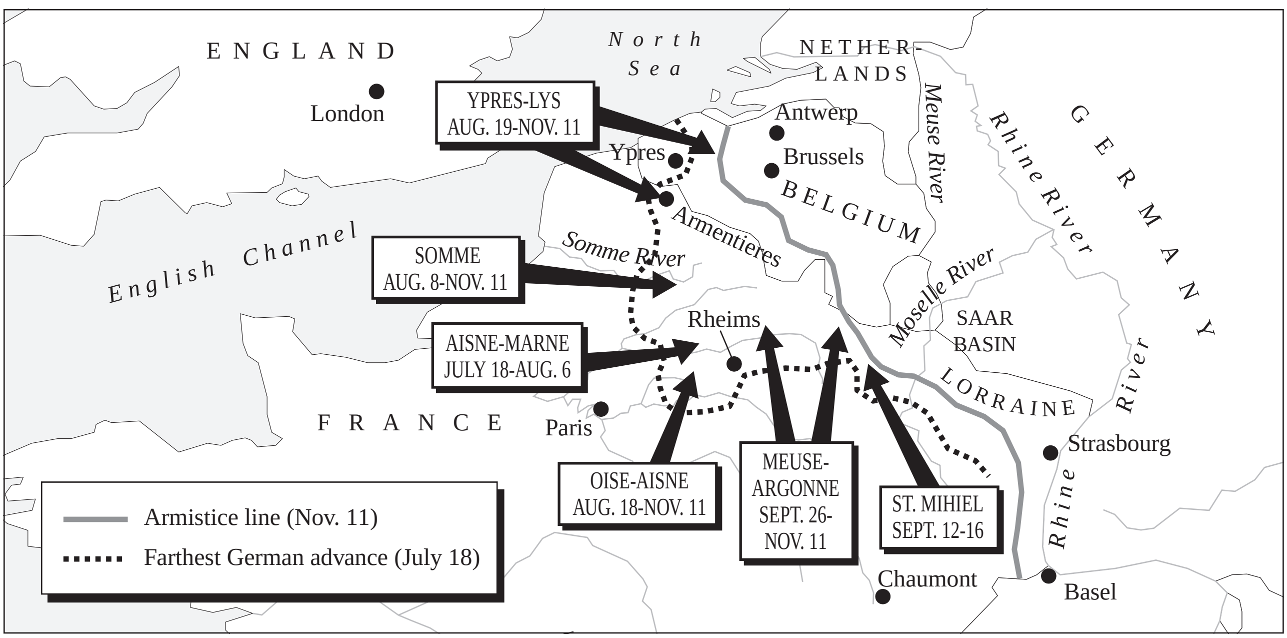
Air fighting began as the exchange of shots from small arms between enemy airmen meeting one another in the course of reconnoitering. Fighter aircraft armed with machine guns, however, made their first appearance in 1915. Tactical bombing and the bombing of enemy air bases were also gradually introduced at this time. Contact patrolling, with aircraft giving immediate support to infantry, was developed in 1916.

Fighter Group Organization

On the German side of the western front, aviation units in the field were at first divided into thirty-four flying sections, or flights, known as *Feldfliegerabteilungen*. Each flight had six aircraft for reconnaissance, photographic duties, and artillery target-spotting. Two additional aircraft were later added for escort work. When, in 1915, the need for more specialized duties was clear, units for reconnaissance and fighting only were formed, known as *Kampf und Feldfliegerabteilungen*.

The British established the Air Battalion of the Royal Engineers in 1911. In April, 1912, the RFC was estab-

World War I: Offensives on the Western Front, 1918



lished and the Military Wing of the RFC absorbed the Air Battalion. The Military Wing initially had seven squadrons of planes with twelve aircraft to a squadron, an aircraft for each squadron commander, and one airship and manned kite balloon squadron. The RFC was still attached, however, to the army. The Royal Air Force (RAF), the world's first separate air military service, was brought into active existence by a series of measures taken between October, 1917, and June, 1918.

The French Air Service had a structure similar to those of the British and the Germans. The French had a unit of American volunteers that was created in April, 1916, and renamed the Lafayette Escadrille in December, 1916. The Lafayette Escadrille saw much frontline action and suffered heavy casualties. In January, 1918, the Lafayette Escadrille was reorganized in the U.S. Army as the 103d Pursuit Squadron.

Image Not Available

Development of Fighter Planes

After a few months into the war, pilots were unanimous in their desire for fixed machine guns. Pusher aircraft presented no problem in this matter, because their propellers were placed behind the cockpit compartment. Thus, a machine gun could be mounted in front of the pilot with a clear line of fire. In contrast, a tractor aircraft, with the propeller at the front of the plane's fuselage, had no clear line of fire ahead of the pilot. A machine gun mounted along the line of the fuselage would have shot off the propeller blades.

During the month before the outbreak of the war, French engineer Raymond Saulnier had been working on an interrupter gear that would allow a machine gun to be fired through the propeller arc. He had grown impatient with hang-fire failures, so he attached steel deflection plates on the propeller where the bullets passed through the arc. The famous sporting pilot and friend of Saulnier, Lieutenant Roland Garros, asked Saulnier to attach steel deflector plates to his propeller blades and to mount a fixed machine gun in front of the cockpit. Garros relied upon the steel plates to ward off the bullets that hit the airscrew. Shortly thereafter, Garros shot down five German planes and was awarded the French Legion of Honor.

The problem of perfecting a machine gun that would synchronize its firing with the rotation of the propellers was the assignment given to the Dutch engineer Anthony Fokker. In 1915, Fokker considerably improved upon Garros's innovation. Fokker Eindecker E-I's armed with synchronized Spandau machine guns roamed the skies virtually unopposed. German aces such as Lieutenant Max Immelmann and Captain Oswald Boelcke led a reign of terror in the skies, known as the "Fokker Scourge." However, the Allies soon came up with a synchronized gun designed by Georges Constantinesco.

Early Losses

British losses in the air in 1915 were serious. The British workhorse aircraft was the BE.2 of pre-1914 Geoffrey De Havilland design. The BE.2, under mass production in a way not accorded to any other British machine, was used on all fronts for all types of work. By 1915, improvements to the BE.2's original design had been made, but the Fokker Eindecker E-I, with its interrupter-geared, forward-firing machine gun, still outmatched the BE.2. Any effective British response to the Fokker scourge was often hampered by the difference in the tactics of the British and the Germans. British tactics were to cover as much of the war theater as possible while the Germans would concentrate their strength at key areas where it was felt that an effort was needed. The latter approach proved the more effective.

From the winter of 1914-1915, the practice of British squadrons in France was to have one or two single-seat scouts with some form of armament that enabled them to act as fighters, not merely as faster reconnaissance aircraft. The successful RFC single-seat fighter was the Airco DH.2 pusher biplane. RFC Squadron Twenty-four, equipped with these planes, went to France in February, 1916, and momentarily overcame the Fokker monoplane and the German two-seaters in the struggle for aerial supremacy.

The Fighter Planes

Of the German fighter planes, the D-types were single-seat, single-engine biplanes, which usually had two fixed Maxim (Spandau) machine guns. The Dr-types were single-seat, single-engine, armed triplanes, such as that used by the "Red Baron," Manfred von Richthofen. The Dr's had the same armament as the D-types. The E-types were single-seat, occasionally two-seat, single-engine, armed monoplanes. The Fokker E-IV was equipped with three synchronized machine guns.

The Airco D.H.2 finally put an end to the Fokker scourge in 1916, but was soon outclassed by faster and more agile German fighters. With the Albatros D.II, the Germans reclaimed the skies in early 1916. The Fokker Dr.I, the triplane made famous by the Red Baron, was not as fast as many other aircraft of the time, but it could outmaneuver them. The Fokker D-VII was the best fighter aircraft that Germany had. The D-VII could "hang on its prop," or, point straight up, and shoot the underside of an enemy aircraft.

Next to the Sopwith Camel, the S.E. 5 was one of Britain's most successful fighters during World War I. The S.E. 5 was designed by Royal Aircraft and used the 150-horsepower Hispano-Suiza engine. It was introduced in 1916 and modified first with a 200-horsepower engine, then later with a Wolselev W.4a Viper engine. The latter engine proved very successful. Large numbers of this aircraft did not reach the front until early 1918. British fighter pilots, such as J. B. McCudden, William A. Bishop, and Edward Mannock, had a lot of success flying this plane. The S.E. 5 was one of the fastest fighters of the war and was also used for sneaking up under the enemy and shooting into its belly.

Of the French planes, the Spad S. VIII was a very good climber and was favored by many pilots, such as Captain Eddie Rickenbacker of the United States. The main problem with the plane was that when the engine power or speed was reduced, the plane would drop like a dead weight.

Bombing

Strategic bombing was initiated very early in the war. British aircraft from Dunkirk bombed Cologne, Dusseldorf, and Friedrichshafen in the autumn of 1914. Their main objective was the sheds of the German dirigible airships or zeppelins. Raids by German planes or seaplanes on English towns in December, 1914, heralded a great zeppelin offensive sustained with increasing intensity from January, 1915, to September, 1916. London was first bombed in the night of May 31 to June 1, 1915. In October, 1916, the British, in turn, began a more systematic offensive from eastern France against industrial targets in southwestern Germany.

While the British directed much of their new bombing strength to attacks on the bases of German U-boats, the Germans used theirs largely to continue the offensive against the towns of southeastern England. On June 13, 1917, in daylight, fourteen German bombers dropped 118 high-explosive bombs on London and returned home safely.

Many World War I bombers, such as the Blackburn Kangaroo, were converted passenger planes that returned to passenger service after the war. The Breguet Br-14B2, probably one of the best French-made bombers, was produced until 1926. The Caudron R-11 was the last bomber the French built during the war.

Aces and Bloody April

The honorific title of "ace" was given to any pilot who had downed five or more aircraft, including balloons, unarmed observation planes, and machine gun-armed fighter planes. The dark side of being a fighter pilot was that the vast majority of pilots flew until the war ended or they were killed. It often was only a matter of time until the odds went against individual pilots. This was true of the Red Baron, who was killed on April 21, 1918, as well as of many others, such as Boelcke and Immelman of the Fokker scourge. The top aces who survived the war were truly lucky.

The British often referred to April, 1917, as "Bloody April." During this month, the British listed 316 RFC pilots and observers as killed or missing and 224 RFC aircraft as having been destroyed. Credit for the losses was given to the inadequate training of new British pilots and to the superiority of the German fighter planes, principally the Albatros D.III, the effect of their shrewdly concentrated organization, aerial tactics, and the skill of the German pilots.

Major Fighter Planes of World War I

Name	*Date*	*Country*	*Speed (miles per hour)*	*Range (hours)*	*Ceiling (feet)*	*Number of Machine Guns*	*Wingspan (feet)*	Weight (pounds)
Airco D.H.2	1916	Britain	93	3	14,000	1	28.25	1,441
Albatross D.II	1916	Germany	109	1.5	17,060	2	27.83	1,954
Albatross D.III	1917	Germany	109	2	18,044	2	29.66	1,949
Aviatil D.1	1917	Austria-Hungary	115	2.5	20,177	2	22.75	1,475
Bristol Scout D	1915	Britain	100	2	16,000	1	24.58	1,250
Bristol F.2B	1917	Britain	123	3	21,500	3	39.25	2,779
Fokker E.II Eindecker	1917	Germany	87	1.5	11,843	2	30.83	1,342
Fokker Dr.1	1917	Germany	103	1.5	19,685	2	23.58	1,289
Fokker D.VII	1918	Germany	124	1.5	19,685	2	29.25	1,870
Hanriot HD.1	1917	France	115	2.5	20,670	1	28.50	1,334
Hansa-Brandenburg D.I	1916	Austria-Hungary	116	2.5	16,045	1	27.92	1,478
Nieuport 11	1915	France	97	2.5	15,090	1	24.75	1,060
Nieuport 17	1915	France	110	2	17,390	1	26.83	1,246
Phönix D.I	1917	Austria-Hungary	112	2	19,685	2	21.58	1,411
R.A.F.E. 2b	1915	Britain	91	2.5	11,000	2	47.75	1,289
S.E. 5	1916	Britain	138	2.5	19,500	1	26.58	1,988
Sopwith Camel F.1	1917	Britain	115	2.5	19,000	2	28.00	1,453
Spad S.VII	1916	France	119	2.25	18,000	1	25.50	1,555
Spad S.VIII	1917	France	119	2	18,000	2	26.92	1,801

Other Theaters of the War

The RFC was active in northern Italy, Egypt, Palestine, Macedonia (northern Greece), Mesopotamia (Iraq), northern Persia, the Dardanelles and the Aegean Sea, and East Africa. The RFC's efforts in most of those theaters were in support of ground troops. However, on the Austro-Italian front in northern Italy, the RFC had a strong presence. Great Britain sent seasoned fighter units to northern Italy because the Austro-Hungarian Air Service was very experienced and supported by German fighter and bomber forces. By May, 1918, the British squadrons had shot down eighty-three enemy aircraft on the Austro-Italian front.

In Egypt and Palestine, the RFC aided the breakout of the British Expeditionary Force from the Suez Canal area of Egypt into Palestine. In Macedonia, the RFC primarily was engaged in patrolling over the Bulgarian positions using kite balloons. In the Dardanelles and the Aegean Sea area, the RFC primarily scouted and bombed Turkish positions. The British rarely encountered significant aerial opposition in those diverse areas, with the notable exception of Macedonia.

In the areas of Macedonia, in northern Greece, and Bulgaria, a German ace, Rudolf von Eschwege, had twenty victories, three of which were against kite balloons. Von Eschwege's Bulgarian allies called him "The Eagle of the Aegean." In October and November, 1917, von Eschwege proved to be a serious threat to the Seventeenth Balloon Section of the Royal Flying Corps (RFC) at Orljak in Macedonia. On November 21, 1917, the Allies prepared a decoy balloon with a dummy observer and 500 pounds of explosives. When von Eschwege made his expected attack, the explosive was electronically detonated from the ground. The destructive radius of the blast was sufficient to cripple von Eschwege's aircraft, and the plane crashed, killing its pilot.

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See also: Balloons; Biplanes; Bombers; Dirigibles; Dogfights; Fighter pilots; Fokker aircraft; Roland Garros; Military flight; Monoplanes; Reconnaissance; Manfred von Richthofen; Eddie Rickenbacker; Royal Air Force; Triplanes

World War II

Date: From 1939 to 1945

Definition: Military operations that included transportation of troops, supplies, and equipment; support of land and naval forces by bombardment and aerial observation; direct combat between fighter planes; and bombing of strategic communication, factories, and population centers including the atomic bombs that ended the war.

Significance: The outbreak of World War II marked the beginning of a new era in aerial warfare, speeding up development of piston-engine-driven aircraft leading to the inauguration of the first jet to fly a combat mission, the German Messerschmitt Me-262. Following World War II, fighting jets often determined the outcome of contemporary military confrontations as their speed, maneuverability, and destructive capability rapidly escalated.

Background

World War II began with the 1939 German bombing of major cities in Poland and the rapid destruction of the Polish air fleet by the Nazi air force, called the Luftwaffe. The 1940 German victories over Denmark, Norway, Holland, Belgium, and France were greatly assisted by air support. The Battle of Britain in August and September of 1940 dramatically ended with the Royal Air Force

(RAF) Fighter Command's defeat of the Luftwaffe. Later German strategic air bombing efforts, designed to destroy factories and civilian morale, were curtailed from completing their objectives by technically advanced Allied warcraft.

As the European front of the war developed, U.S. president Franklin D. Roosevelt repeatedly proclaimed the neutrality of the United States, thus satisfying the public opinion of the majority of Americans. U.S. neutrality laws forbidding arms sales to warring nations were quickly changed by Congress to assist the aerial warfare efforts of Britain and France.

The U.S. entry into World War II began with the Japanese carrier-borne aircraft attacks on Pearl Harbor, on the island of Oahu, Hawaii, which quickly destroyed or disabled many U.S. land-based combat aircraft in the Pacific. At the time of the December 7, 1941, Pearl Harbor bombing, the U.S. Army Air Force possessed only 1,100 combat-ready planes. Historians of aviation often note that no motivating force speeds up aircraft development and technology more rapidly than war. By 1944, the U.S. Army Air Force had nearly 80,000 planes in sixteen separate air forces stationed around the world.

World War II: The European Theater

Aircraft Development

On August 27, 1939, four days before the outbreak of World War II, the Heinkel He-178 took off from Germany's Marienhe Airport. The monumental first successful flight of this slender research turbojet aircraft began a new era in aerial warfare and is generally credited to two men: Hans von Ohain of Germany and Sir Frank Whittle of Great Britain. Desperate to curtail Allied bombing offensives, Germany then rapidly developed the Messerschmitt Me-262 jet, considered a "Nazi wonder-weapon." Following its maiden flight in July, 1942, the Me-262 was regularly utilized by German engineers as a flying laboratory for the testing of new weapons. Among the more successful weapons utilized on the Me-262 were 550-pound bombs installed on the aircraft's wing racks and a row of twelve R4M rockets fitted directly upon each wing. These attached rockets were able to fire in rapid succession and could saturate a target the size of a B-17. In their rush to enhance the capabilities of the Me-262, German scientists initially attempted to attach a 50-millimeter nose cannon, which produced a flash that blinded the pilot when fired. Engineers also experimented with attaching a 2,200-pound bomb in tow, which made the plane functionally unstable during flight.

Allied bomber crews flying over Germany during the summer of 1944 were stunned by their encounters with the Messerschmitt Me-163 Komet, a jet fighter much faster than the jet-propelled Me-262. The Komet carried a revolutionary 3,750-pound thrust rocket motor, which enabled travel at nearly 600 miles per hour. Called the "powdered egg" by Luftwaffe test pilots, the Komet had a limited radius of action of only 25 miles. It would exhaust its 437-gallon fuel supply within seven minutes of takeoff. The Komet's great effectiveness was due to its ability to climb vertically at 11,810 feet per minute, thus rising quickly above Allied planes. The Komet could then nose over and dive-attack Allied bomber formations and efficiently utilize its twin 30-millimeter cannons. After the war, historians noted that only a handful of the 279 Komets manufactured during the war actually saw combat, but the fact that the Komets claimed nine monumental victories over Allied forces should not be minimized. The most serious flaw of the Komet was its required fuel mixture of methyl alcohol and concentrated hydrogen peroxide, which proved so volatile that several prototypes exploded on the runway during takeoff. Some Komets suffered engine failures that rapidly filled the cockpit with acrid fumes, literally blinding the crew and dousing them with corrosive chemicals from ruptured fuel lines that rapidly dissolved any exposed flesh. Military analysts later reflected that the Komet was probably ten years ahead of its time. Despite the flaws consequent to its escalated development, the Komet remained known as the most dangerous warplane in the sky during World War II.

In the summer of 1944, Germany first flew the Blitz, a twin-engine Arado 234B bomber capable of a maximum speed of 461 miles per hour and an elevation of 33,000 feet. Other features attempted on the Blitz included a dramatically reduced weight and drag, a trolley that was jettisoned after takeoff, skids that allowed grass landings, rocket boosters enabling takeoffs from short runways, a pressurized cabin, four engines, and one of the first crew ejection seats. Although the Blitz was considerably more advanced than any Allied bomber, its implementation came too late to significantly assist Third Reich bombardment strategy.

Major Wolfgang Schenk, a top Luftwaffe pilot, established the Edelweiss Bomber Group of Me-262's, which were originally designed as fighters but later manufactured as fighter-bombers by a late change in orders directly from Adolf Hitler. Schenk's unit of fifteen planes, stationed in Orléans, France, however, was too small to deter significantly the advancing Allies and was pulled back to Germany for the final unsuccessful Nazi defense.

Frantically trying to rapidly manufacture a miracle jet that might turn the tide late in the war, Nazi engineers designed three revolutionary planes later considered to be amazingly ahead of their time. The German Gotha 229 Flying Wing, originally designed as a glider, was modified as a high-speed fighter by the attachment of turbojets to its drag-resistant body. One experimental Gotha was clocked at 497 miles per hour while still in its development stage as the war ended.

The German Junkers Ju-287 was designed with forward-swept wings mounted over swept-back wings to delay the onset of air compressibility and establish stability at low speeds. The first Junkers was built in 1944 from sections of other planes, including the nose wheels of a downed U.S. Consolidated B-24. The Junkers made seventeen test flights before it was captured in 1945 by Soviet troops, who experimented extensively with the plane themselves for three years before moving to later designs. Soviet engineers attached tufts of wool to the fuselage and forward-swept wings of the Junkers to study its airflow. The planned design of the first jet attempted with variable-sweep wings, the Messerschmitt P-1101, was probably never flown, but the swing-wing design was later developed on the U.S. F-14 and F-111 fighters of the 1970's, the B-1 bomber of the 1980's, and an entire generation of Soviet fighters.

The first fighting jets had only minimal influence on the outcome of World War II, but they clearly set the stage for the rapid, future evolution of jet warplanes. Great Britain, the United States, and Japan rapidly followed Germany by developing and flying jet fighters before the conclusion of the war. Britain's first jet fighters consisted of seven Gloster Meteors, which joined the RAF in July, 1944, after four years of development. With an airspeed of 490 miles per hour, the Gloster Meteors were effective in intercepting German bombers that were daily attacking London at speeds of 400 miles per hour. However, they proved ineffective at downing enemy planes due to faulty guns. The first combat victory for an Allied jet occurred on August 4, 1944, when pilot T. D. Dean's gun failed as he maneuvered alongside the attached missile of a German bomber. Dean then slid beside a wingtip beneath a bomb wing before banking sharply to unbalance and crash the German aircraft.

Other Technological Developments

British air-defense systems were greatly assisted by the development of radar. The development of German night-fighter systems was not prompted until after British night bombers began large-scale raids on Germany, most notably the one-thousand-plane raid over Cologne in May, 1942. Radar enhanced the ability of U.S. bombers to avoid detection and simultaneously to carry out early morning attacks on prominent Nazi industrial and military targets. These Combined Bomber Offensives notably included the Ploesti, Romania, mission of August 1, 1943. The Ploesti raid utilized B-24's of the U.S. Fifteenth Air Force, originally based in Italy but launched from Africa, to bomb the Romanian oil refineries that were Germany's largest supplier of fuel. This costly mission, known as the "graveyard of the Fifteenth," was quickly followed by the Regensburg-Schweinfurt mission of August 17, the first large-scale U.S. attack on Germany launched from English bases. American losses in these offensives were considerable until 1944, when long-range P-47 and P-51 escort fighters enabled the attack of strategic sites deep within German-occupied territories with relative safety. The Allies were then able to establish clear air superiority and hit considerably more German planes and aircraft facilities. A notable example of this timely Allied air supremacy was D day, June 6, 1944, when Allied air forces restricted Germany to only a few Luftwaffe sorties against land invasion forces.

Newer designs of wings and other structural improvements greatly increased the speed and maneuverability of combat jets. By the end of the war, one of the most advanced fighters was the British Spitfire, which achieved a top airspeed of 350 miles per hour and an elevation of 40,000 feet. The United States and Soviet Union both developed jet bombers that could fly nonstop from their homelands deep into enemy territory anywhere in the world in only a few hours.

Surfaces that deflected radar beams and materials that absorb radar energy and made planes much more difficult to detect, later known as stealth technology, were initially developed during World War II. Modern supersonic wings, which are thinner and flatter for increased speed and range, began to be made with heat-resistant materials. Materials such as titanium later began replacing aluminum, which melts at high speeds, using ideas initiated during World War II.

Other notable German aerial warfare developments included the V-1 buzz bomb, a pilotless jet-propelled plane carrying 2,000 pounds of explosives, which flew against England in June, 1944. The V-2, a true guided missile capable of carrying 1,650 pounds of explosives over 200 miles, was launched in September, 1944. These technologies arrived too late to have an impact on the final outcome of the war, but their designs set the stage for future military warcraft.

Notable Battles and Flying Groups

Air battles in the Pacific most notably included the June, 1942, Battle of Midway, a crucial victory for the U.S. carrier-based navy. Battles for the Gilbert Islands, the Marshall Islands, and the Mariana Islands were also monumental, as they later provided bases for air attacks upon Japan. Because Japan failed to develop a strong home air defense, the Boeing B-29 Superfortress caught the nation unprepared in late 1944 to detect bombers and coordinate army and navy maneuvers. On March 9, 1945, a massive raid on Tokyo, Japan, torched approximately 25 percent of the city's buildings. On August 6, 1945, the U.S. B-29 *Enola Gay* dropped the first atomic bomb on the city of Hiroshima, three days later a second atomic bomb was dropped on the city of Nagasaki, after which Japan surrendered.

The skills of the Flying Tigers, a United States Volunteer Group, were displayed in the China-Burma-India theater, following the Japanese conquest of Burma, later known as Myanmar. Supply flights from India to China over the Himalayas became as critical as combat flights, with bases in China later used to launch critical bombing operations against Japan.

Casualties and Costs

Advances in air warfare strongly contributed to making World War II the costliest military conflict in history, in

World War II: The Pacific Theater

terms of both human casualties and resources. An estimated 15 million to 20 million military personnel were killed in action, along with approximately 25 million civilians. Military deaths for the Axis powers have been estimated at 3.5 million Germans, 1.5 million Japanese, and 200,000 Italians. Of the Allies, the Soviets lost an estimated 7.5 million military personnel, and China lost an estimated 2.2 million combatants from July, 1937, until the war's end. Britain lost 300,000; the United States lost 292,000; and France lost 210,000. In terms of civilian casualties, the Soviet Union lost 10 million; China 6 million; France 400,000; Britain 65,000; and the United States 6,000. Of the Axis powers, Germany lost 500,000 civilians; Japan lost 600,000; and Italy lost 145,000. Approximately 6 million Jews, most from Eastern Europe, died in Nazi death camps. Total expenditures for war materials is estimated at $1.154 trillion, with the United States spending $300 billion and Germany $231 billion.

Long-Term Effects

The Japanese surrender in 1945, which did not require a land invasion, indicated to many that future military en-

The Japanese air attack on Pearl Harbor, December 7, 1941, caused the United States to enter World War II. Air power was particularly important in the Pacific theater, which largely encompassed widely separated islands that were most easily reached by plane. (Digital Stock)

counters would ultimately be determined by the combatant that controlled the battlefield in the air. The tactical use of fighting aircraft continued to escalate immediately following World War II, with essentially all world governments developing military planes by the early 1950's in response to the Cold War. Military air force strategies have since displayed disturbing trends, from the use of aircraft to prevent enemy movements and destroy enemy communications and supply lines to the doctrine of massive retaliation, whereby a country would not necessarily confine air strikes to local hostilities but would consider bombardment of civilian centers within enemy homelands.

Notable battles in which the ultimate victor was determined by warcraft technology begun during World War II included those of the Korean War, in which American propeller-equipped planes were initially very effective. Later Korean air combats employing the F-80 and F-86 against the Russian-built MiG-15 were notably the first aerial combats between opposing modern jet fighters. After spending the Korean War dodging the best in Soviet fighter technology in what became known as "MiG Alley," the United States developed the world's first supersonic fighting jet, the F-100 Super Sabre, in 1953.

Another example was the 1967 Six-Day War between Israeli and Palestinian forces, which was essentially decided within the first three hours when Arab forces lost 452 aircraft. Ground warfare was also transformed forever by World War II aircraft developments. The widespread use of helicopters mounted with jet engines enabled enhanced speed and lift capacity to transport troops and supplies efficiently.

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See also: Air Force, U.S.; Aircraft carriers; Battle of Britain; Black Sheep Squadron; Bombers; Jimmy Doolittle; *Enola Gay*; Fighter pilots; Flying Tigers; Gulf War; Korean War; Luftwaffe; Marine pilots, U.S.; Messerschmitt aircraft; Military flight; Billy Mitchell; Navy pilots, U.S.; Pearl Harbor, Hawaii, bombing; Radar; Hanna Reitsch; Eddie Rickenbacker; Rockets; Royal Air Force; Superfortress; Vietnam War

Wright brothers

Wilbur Wright

Date: Born on April 16, 1867, near Millville, Indiana; died on May 30, 1912, in Dayton, Ohio

Orville Wright

Date: Born on August 19, 1871, in Dayton, Ohio; died on January 30, 1948, in Dayton, Ohio

Definition: Aviation pioneers who made the first piloted flight in a powered heavier-than-air plane on December 17, 1903.

Significance: The Wright brothers discovered the principles of human flight and opened the era of aviation by inventing, building, and flying the first heavier-than-air craft.

Early Lives

Bishop Milton Wright and Susan Catherine Wright had four sons, Reuchlin, Lorin, Wilbur, and Orville, and one daughter, Katherine. Wilbur, the third son, was born on a small farm near Millville, Indiana, on April 16, 1867. Orville, the fourth child, was born in Dayton, Ohio, at 7 Hawthorn Street. Bishop Wright, a Methodist minister, moved frequently from one small congregation to another in Indiana and Ohio. Neither Wilbur nor Orville graduated from high school. In 1892, the two brothers opened a bicycle repair shop in Dayton, and three years later, they began making their own bicycles. In the early 1890's, they became interested in Otto Lilienthal's experiments with gliders, but they did not begin flying until after Lilienthal died in a glider accident in 1896.

In 1900, the Wright brothers built their first airplane, a two-person glider, and began experimenting in Kitty Hawk, North Carolina. They chose this site because it was remote and they could conduct their experiments out of public view. There also was plenty of sand for soft landings and strong winds to make takeoffs easy. Wilbur and Orville first visited Kitty Hawk in September, 1900, and pitched a tent close to the landing field. They began gliding in October, and their longest glides were between 300 and 400 feet in length.

The Wright brothers returned to Kitty Hawk in July, 1901, with a bigger glider, the wings of which were 22 feet wide and 7 feet deep. However, they still could not produce adequate lift, and their longest flight covered only 389 feet. The discouraging results depressed the brothers, and Wilbur predicted in a letter "men would sometime fly, but that it would not be within our lifetime."

In October, 1902, the Wright brothers began to build a powered aircraft. During their experiments, they developed a system of aileron control, the basic stabilizing mechanism in modern planes, which maintained the plane's equilibrium, or balance, by shifting the angles of the wings and other parts to balance outside air pressure. In 1903, the Wrights built a larger version of their 1902 glider, added a power plant, and made the first self-powered flight.

Success

Building a power plant required an understanding of how propellers work. The Wright brothers tried to buy an engine to drive the propeller, but could not find one that met their specifications. With the assistance of their colleague, Charles Taylor, they built their own four-cylinder model and then returned to their wind tunnel in Dayton to test propeller shapes. By the time they headed to Kitty Hawk, they had tested the engine, which had just enough horsepower to provide thrust for the propeller. They knew the wings they had constructed would provide adequate lift. Thus, before they returned to North Carolina, they knew they had built an effective airplane.

On December 17, 1903, at Kitty Hawk, Orville made the first piloted flight in a powered heavier-than-air plane, remaining aloft for twelve seconds and covering a distance of about 120 feet. They made three more flights that day, the longest of which was Wilbur's flight of fifty-nine seconds over a distance of 852 feet. In 1905, they flew a plane for thirty-eight minutes covering 24 miles at Huffinan Field in Dayton, Ohio.

Unhappy Ending

On September 9, 1908, the Wrights demonstrated their plane for the United States Army at Fort Meyer, Virginia. The War Department awarded the brothers a contract to build airplanes capable of flying at 40 miles per hour, a speed achieved in 1909. That year the Wright Company was incorporated in Dayton, with Wilbur as president. However, trouble was soon to follow.

During the next several years, ugly lawsuits erupted in Europe and the United States over aircraft patents, as the Wrights managed to build improved flying machines. The Wrights sued aircraft designer Glenn H. Curtiss for selling airplanes with the European-invented aileron control, protesting that any wing-warping device owed credit to themselves. Curtiss received help from Albert Zahn, the director of the Smithsonian Institution in Washington, D.C. Zahn argued that Samuel Pierpont Langley, a former director of the Smithsonian who had spent much of the Institution's money on developing heavier-than-air craft, had actually invented the airplane. Although Langley's craft had never been airworthy, the Smithsonian refused to give any credit to the Wright brothers. Only after a long fight did its view change.

Wilbur, exhausted and worn out from the legal battles, died from a mild case of food poisoning in 1912. The courts finally sided with the Wright brothers' claim, and Orville received some money for their patent. He received nothing from the Europeans. In 1915, Orville sold his patent rights and retired from the airplane business to devote the rest of his life to experimentation and research. He died in 1948 in Dayton.

Leslie V. Tischauser

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See also: Airplanes; Biplanes; Glenn H. Curtiss; Heavier-than-air craft; History of human flight; Samuel Pierpont Langley; Wing designs; Wright *Flyer*

Wright *Flyer*

Also known as: *Flyer* 1, *Aerostat*, the *Flying Machine*
Date: From 1899 to 1903
Definition: The first heavier-than-air plane flown under its own power by a human being in controlled flight.
Significance: The Wright *Flyer*, the most honored airplane in history, revolutionized modern aviation. Through their scientific and engineering research, Orville and Wilbur Wright solved the problems of lift, propulsion, and control that had defeated other aviation pioneers.

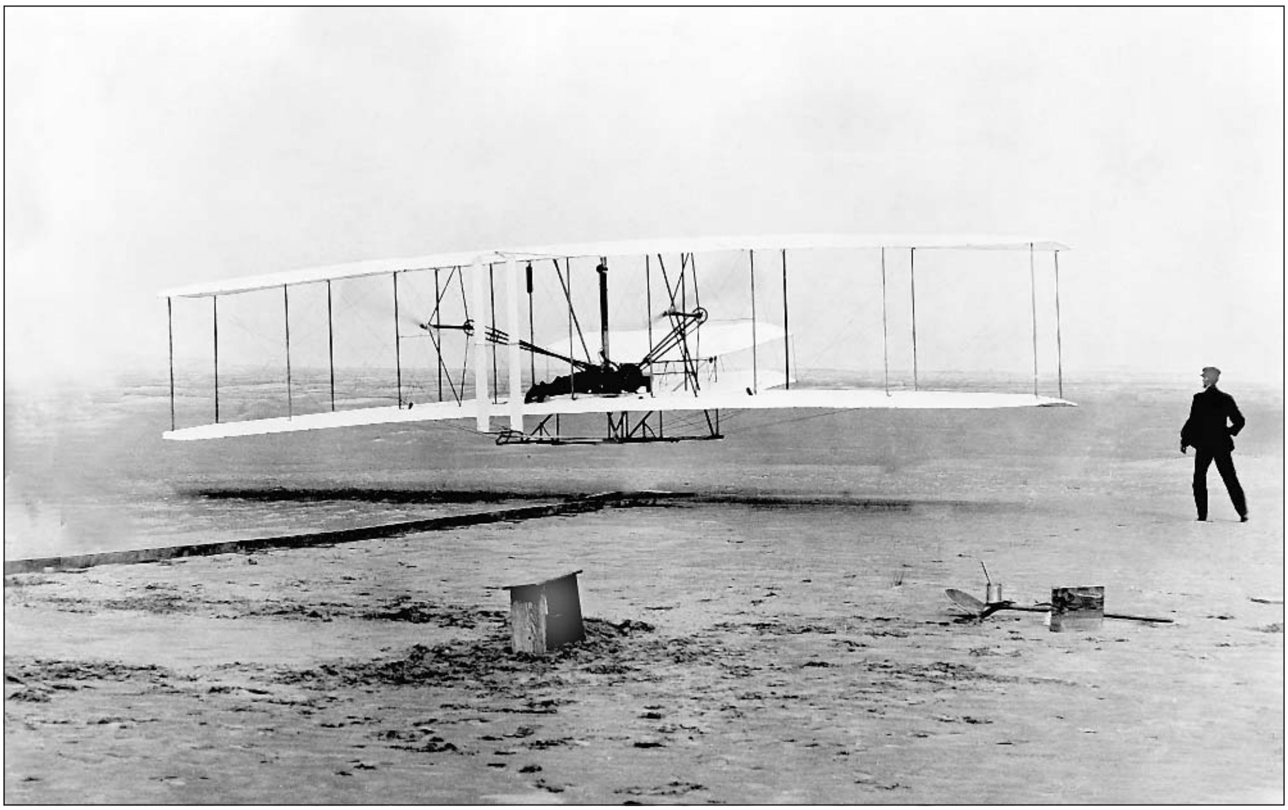
Evolution of the *Flyer*

Long treated as tinkerers who were lucky to invent the airplane, Orville and Wilbur Wright are now seen as highly creative scientists who helped found aeronautical engineering by designing, constructing, and test-flying a series of increasingly sophisticated aircraft, from kites and gliders to the Wright *Flyer*. Modern scholars are amazed by the Wrights' collaboration, versatility, and ability to master the many fields involved in controlled flight. Without formal scientific or technical training, the Wright brothers were able to design movable wings, rudders, and elevators; a light and powerful motor; and a proper propeller. Because of these accomplishments, they came to embody an ideal as heroic American inventors.

The brothers, Wilbur, elder by four years, and Orville, became interested in flight when their father gave them a gift of a toy helicopter. As young men, they established the Wright Cycle Company in Dayton, Ohio, where they not only repaired and sold bicycles but also manufactured their own models. The death of German aviator Otto Lilienthal in an 1896 glider accident rekindled the brothers' interest in flight. Based on information they received from the Smithsonian Institution, they built a double-winged kite whose movements could be manipulated by using tethers to alter the angles of its wings. According to Wilbur, he and his brother discovered this wing-twisting mechanism by observing the flights of birds.

The Wrights then moved from kites to human-carrying gliders. To test their gliders, they needed a place with consistently high winds, and the Weather Bureau informed them that Kitty Hawk, North Carolina, was one of the windiest locations in the country. Furthermore, at Kill Devil Hill, near Kitty Hawk, there were long, wide beaches. Beginning in 1900 and continuing in 1901 and 1902, the Wright brothers tested their gliders from this spot. They discovered that their human-carrying glider could be controlled with their wing-warping apparatus, but that their aircraft had less lift and more drag than they had expected. They realized that they needed scientific data on the lift pressures of various wing structures.

Back in Dayton, they built wind tunnels in which to determine the angles at which differently shaped wings would cause lift. With the data generated by these tests, the Wrights made a double-winged glider with a vertical tail. However, in their 1902 tests at Kill Devil Hill, they found



The Wright Flyer*, with Orville Wright at the controls and Wilbur Wright looking on, makes its first flight, 120 feet in distance, on December 17, 1903.* (Library of Congress) that their glider behaved erratically in high winds. They solved this problem by making the aircraft's tail movable. They also installed a movable panel, known as an elevator, to the front of the glider to control its ascent and descent. This movable elevator and tail rudder, along with their wing-warping mechanism, gave the Wrights' glider a three-dimensional system of control.

The Wright *Flyer*

Having created a controllable glider, the Wright brothers realized that their next step should be to equip it with a motor and propeller to achieve powered flight. Because commercial motors did not suit their needs, they designed a powerful, lightweight engine that was built by Charlie Taylor, a worker in their bicycle shop. This 4-cylinder, 12-horsepower water-cooled, fuel-injected engine was constructed of cast aluminum and steel. Because this motor would add weight and cause vibrations, the brothers lengthened the glider's wings and added stay wires to strengthen the glider's structure. This new system of control restricted the warpability of the 40-foot wings to the wingtips, but it worked well nonetheless. To provide thrust for their new machine, which they dubbed "the *Flyer*," they used propellers, designed in the shape of a twisted wing, which spun at 350 revolutions per minute.

In the fall of 1903, the Wrights returned to Kitty Hawk, where they reassembled their *Flyer*, installed its motor, and waited for good weather. On December 17, Orville took off from the beach in the *Flyer*, rose to a height of about 10 feet, and flew a distance of more than 100 feet in 12 seconds. The age of human flight had begun. For the rest of the day, the brothers alternated runs, the longest of which was flown by Wilbur, who remained in the air for nearly one minute and covered a distance of 852 feet.

The Wright *Flyer* After Kitty Hawk

Upon returning to Dayton, the Wright brothers decided to abandon their bicycle business and devote all their time to improving the *Flyer*. Over the next three years, they transformed their experimental aircraft into the world's first practical airplane. Because they no longer needed the winds of Kitty Hawk, they were able to test their flyers near Dayton. In 1904, the *Flyer* made its first complete circle, and by 1905, Wilbur stayed aloft for 38 minutes and traveled 24 miles. On May 22, 1906, the brothers were granted U.S. patent 821,393 for their flying machine. They continued to increase the reliability, meaneuverability, and range of their planes by constant technical improvements. Although they formed a company to manufacture aircraft, Wilbur, who died in 1912, did not live to experience the full glory of the airplane's evolution.

One of Orville's chief concerns after his brother's death was securing the *Flyer*'s place in the history of aeronautics. For many years, the Smithsonian Institution refused to acknowledge the Wright *Flyer*'s role in initiating the age of aviation, and Orville kept the *Flyer* on display in England until the Smithsonian finally conceded that the 1903 *Flyer* was indeed the world's first genuine airplane. However, the Wright *Flyer* was installed in the Smithsonian eleven months after Orville had died.

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See also: Airplanes; Biplanes; Octave Chanute; Glenn H. Curtiss; History of human flight; Samuel Pierpont Langley; Otto Lilienthal; Wing designs; Wright brothers

X

X planes

Definition: Experimental aircraft intended to test new configurations or unexplored aerodynamics.

Significance: The U.S. X planes were the first to fly faster than the speed of sound, the first to test a variable-sweep wing in flight, the first to fly at altitudes greater than 100,000 feet, and the first to fly three to six times the speed of sound. Lessons learned from these research aircraft have been applied to all the high-speed aircraft and spacecraft that followed them.

In the United States, the federal government, under the direction of the National Advisory Committee for Aeronautics (NACA), its successor, the National Aeronautics and Space Administration (NASA), the U.S. Air Force, or the U.S. Navy, has sponsored a number of dedicated research aircraft, starting with the X-1 in 1944. As of 2001, the most recent X plane in progress was the X-43. Many of these aircraft were initially top secret. Additionally, new fighter and bomber prototypes are often initially given an "X" designation (for example, the XP-59 and XB-70) in the United States as well as in other countries.

Bell X-1 and X-2

The X-1 program was initiated in response to difficulties World War II fighter aircraft were experiencing as they approached the speed of sound in dives. These included especially Lockheed's P-38 Lightning fighter and Republic's P-47 Thunderbolt fighter planes. Even at flight speeds of about 75 percent of the speed of sound (that is, at a Mach number of 0.75), regions around the fuselage and around the thickest part of wing were experiencing supersonic flow and causing shock waves to form there. The consequences were a pitch-down trim which tended to increase the airspeed even more, separated flow behind the shock waves which caused control surface buffet and ineffectiveness, and a great increase in drag. Recovery, if possible, often relied on a reduction in Mach number produced by an increase in the speed of sound as the air temperature increased at lower altitudes. A specialized research aircraft seemed to be the only available approach because it was not known at that time how to build a wind tunnel with a supersonic test section.

Since its rocket engine had fuel for only 2.5 minutes, the only option was to attach the X-1 to the bomb bay of a B-29 bomber and release it at the maximum altitude and speed, and then glide to a landing on Muroc Dry Lake in California (now Edwards Air Force Base). The X-1 made its first powered flight in August, 1947, and in October, with test pilot Chuck Yeager, made the world's first supersonic flight. In the following year, Yeager reached Mach 1.45. He also flew the second series X-1A; in 1953 he achieved Mach 2.44 in it but nearly lost the plane and himself when it tumbled out of control due to what was later recognized as inertia coupling. (Roll or inertia coupling occurs when a rolling motion creates a pitch moment because the aerodynamic axis is not aligned with the inertial axis. It caused the X-1 to tumble out of control on one flight and later caused the loss of an X-2. A solution to inertia coupling was found with the X-3 in time to solve the similar problem with the F-100 Super Sabre.

Starting from its first powered flight in 1955, the X-2 used a two-chamber rocket engine and, in 1956, set a new world speed record of 1,900 miles per hour and a new altitude record of 126,200 feet.

Supersonic Experimentation

Throughout the 1950's and 1960's, one of the main focuses of X plane research was the exploration of supersonic flight. The Douglas X-3 Stilleto was designed to explore the transonic speed range, where mixed subsonic and supersonic flow exits around a plane in the range from about Mach 0.8 to about Mach 1.2, using two afterburner-equipped jet engines. (An afterburner uses raw fuel in the exhaust, after the compressor and combustor and turbine that powers the compressor.) Its first flight was in 1952.

The Northrop X-4 Bantam, a small piloted research aircraft, was a test of the semitailless configuration (that is, it had no horizontal tail surface). Its first flight was in 1948. A porpoising instability was found to limit flight speeds to less than Mach 1. Beginning in 1951, the Bell X-5 tested in-flight variable sweep of the wing, from 20 degrees to 60 degrees. (The later Navy F-14 Tomcat uses variable wing sweep.) For the Convair X-6, two standard ten-engine B-36 bombers were to be modified to carry a nuclear-powered turbojet, which was expected to yield almost indefinite range. However, only the modified aircraft which tested the shield of the nuclear reactor ever flew.

Six Lockheed X-7's made 130 flights from 1951 to 1960, and many speed (Mach 4.3) and altitude (106,000 ft) records were set. The knowledge obtained was applied to the Lockheed F-104 Starfighter aircraft. The Aerojet General X-8 Aerobee was an uncrewed aircraft, recovered via parachute, designed to measure properties of the air above the atmosphere. With flights that began in 1947, it eventually reached Mach 5.96 and an altitude of 360,000 feet above Earth's surface.

Missile, Rockets, and Other Research

Many X planes were designed to perfect their missile capabilities. Beginning in 1950, the uncrewed Bell X-9 Shrike provided valuable information relevant to the guidance and control of an air-launched air-to-ground missile. The uncrewed North American X-10, with a first flight in 1953, provided needed information for the design of supersonic cruise missiles. A canard surface was shown to be useful. The uncrewed Convair X-11demonstrated the successful use of vectored thrust to control the trajectory of rocket-powered ballistic missiles. First flight was in 1948. The X-12, a follow-on to the X-11, became the prototype for the B-65 Atlas intercontinental ballistic missile (ICBM). First flight was in 1957.

The Ryan X-13 Vertijet was a tail-sitting, delta-winged, jet-powered vertical takeoff and landing (VTOL) aircraft. It made its first full transition from vertical takeoff to fully horizontal flight and back in 1957. The complexity of the system reduced payload, but jet-powered VTOL was shown to be possible.

The Bell X-14 was a VTOL aircraft that took off and landed in a horizontal attitude by diverting the jet thrust downward and then reducing the deflection in stages to transition to horizontal flight. Starting with preliminary tests in 1954, it ended up making research flights for nearly twenty-five years.

The North American X-15 was perhaps the most valuable high performance research aircraft of the X planes. The rocket-powered X-15 used a bullet-shaped fuselage with dorsal and ventral fins along with an all-moving slab-type horizontal tail. First flying in 1959, it eventually reached Mach 6.33 (considered to be hypersonic flight since it was greater than Mach 5) and 354,200 feet above Earth's surface. The full pressure suit worn by the pilots was the basis for later astronaut pressure suits.

The Bell X-16 was intended to be a long-range, subsonic reconnaissance aircraft flying at or above 70,000 feet. The "X" designation was a cover-up. The project was canceled before the first flight could take place.

Beginning in 1955, twenty-six Lockheed X-17 multistage rockets were used to test the reentry requirements of long-range missiles. It showed that a blunt nose-cone shape reduced aerodynamic heating upon reentry because it forced the shock wave to form well in front of the nose.

Bell Aerospace Textron X-22 explored VTOL using four turboprop engines utilizing ducted fans (that is, there was a channel or duct around each of the four propellers). It was able to demonstrate sustained hover at over 8,000 feet. First flight was in 1966. A complex transmission system insured that an engine failure would only result in a reduction in total power without any tendency to roll.

Making its first flight in 1966, the uncrewed Martin Marietta X-23A proved the feasibility of a hypersonic lifting body for an orbiting, reentering space vehicle, playing a key role in the design of the space shuttle. (A lifting body is a fuselage that is broadened enough to generate a sufficiently large lift-to-drag ratio that it can be landed safely after a steep glide through the atmosphere.)

The single Martin Marietta X-24A was a Mach 2, rocket-powered, air-launched aircraft that was designed to explore the low-speed characteristics of a maneuverable lifting body; its first flight was in 1969. The X-24B was a modified X-24A with a new nose and a different tail configuration and made its first flight in 1973.

The X-26 aircraft, based on a Schweizer sailplane, were intended to perform ultraquiet reconnaissance over enemy territory. The X-26A was made by Schweizer and the X-26B by Lockheed. A low radar cross section was also part of the design. One aircraft was used in the Vietnam War. Two aircraft were used by the Navy to train pilots in inertia, or roll, coupling.

Forward wing sweep had been recognized for many years as conveying the same benefits as rearward wing sweep, as well as potentially better low-speed and maneuverability characteristics because the stall begins at the root and progresses to the wingtips, leaving the ailerons effective as long as possible. The problem with forward sweep is aeroelastic divergence: When the forward swept wing is loaded, it will try to bend so as to increase the angle of attack, which causes more loading, and this can quickly lead to structural failure. Advanced composite materials in which stiffness and strength can be tailored for the directions in which it is needed were used to overcome this problem in the Grumman X-29A.

X Planes at the Turn of the Millennium

The Rockwell/MBB X-31 was a multinational enhanced fighter maneuverability test aircraft that used vanes on the exhaust to direct the thrust over a wide range of angles. It was able to demonstrate a 180-degree turn from a deep stall at an angle of attack of 70 degrees after a dynamic entry (the Herbst maneuver). Its first flight was in 1990. The first of two X-31's was lost on its two hundred ninety-second flight in 1995 when the airspeed probe iced up, but the pilot ejected safely.

Boeing X-32 was designed as a joint strike fighter (JSF) concept demonstrator aircraft, rather than as a pure research or experimental vehicle. It was in competition with the Lockheed Martin X-35 to become a successor (as the F-24) to the early models of the F-16 for the United States Air Force, replace early models of the F-18 for the Navy, and (in its short takeoff and vertical land, or STOVL, version) replace the Harrier and the F-18 for the U.S. Marine Corps and the British Royal Navy and Air Force. Its first flight was in September, 2000. The STOVL version first flew in March, 2001. The first flight of Lockheed Martin's non-V/STOL version was in October, 2000.

Lockheed Martin X-33, a liquid hydrogen/oxygen-powered space launcher using a new aerospike engine, was designed to test a particular single-stage-to-orbit configuration as part of a future reusable launch vehicle (RLV). Payload was projected at 25,000 pounds or more, and hypersonic speeds of greater than Mach 15 were anticipated. Its lifting-body design was expected to yield touchdowns at 190 miles per hour (about 60 miles per hour slower than the space shuttle). Lockheed Martin's contract with NASA expired on March 31, 2001. Assembly continued, but the future of the vehicle was placed in doubt.

The uncrewed Orbital Sciences X-34 was intended to provide design information for next-generation spacecraft. A powered version was expected to reach Mach 8. By 2001, three had been built.

McDonnell Douglas/Boeing X-36, a 28-percent-scale prototype jet, was designed to test the agility of future fighter aircraft that lack the traditional tail surfaces. A forward canard, split ailerons, and thrust-vectoring were used for directional control. Designed to be unstable in both pitch and yaw, it used a fly-by-wire (computer-controlled) control system. Thirty-one flights were made in 1997.

The Orbital Sciences X-37 was expected to validate new propulsion, thermal protection materials, and lightweight structures that would eventually lead to less expensive access to space. The Boeing X-40A was an 85-percent-scale version of the X-37. Its first flight was on August 11, 1998.

Three lifting-body, uncrewed Scaled Composites X-38's, intended to provide a rescue vehicle for astronauts, had been built. The first flight of an X-38 was in 1998. A parafoil deployed to slow the final descent to Earth.

Micro Craft X-43, an uncrewed scramjet-powered hypersonic research vehicle, also known as Hyper-X, was intended to reach Mach 10, becoming the first air-breathing (jet-powered) aircraft to achieve hypersonic speeds (above Mach 5). The first flight attempt in 2001 ended in the loss of the first X-43 because of a launch vehicle failure.

The two Boeing X-45's that had been built by 2001 were intended to acquire data leading to future uncrewed combat air vehicles (UCAVs), building on the success of uninhabited aerial vehicles (UAVs) for reconnaissance.

Impractical Experiments

A number of X planes proved impractical for a number of reasons—they were too expensive, they were good ideas that could not be translated into realistic designs, or they simply fell afoul of congressional funding agendas. For instance, the Hiller X-18, a test bed for a vertical/short take-off and landing (V/STOL) large cargo transport, made twenty flights, starting in 1959, before a failed prop control caused an unrecoverable spin. The whole wing, along with the turboprop engines, tilted from horizontal to vertical.

Curtiss-Wright X-19 was a tandem-winged aircraft with fully tilting turboprops at each of its four wingtips. However, on its only flight, the aircraft and its crew were lost when a propeller separated from the aircraft. The project was terminated in 1965.

Boeing X-20 Dyna-Soar (for "dynamic soaring") was intended to be a prototype of a piloted, maneuverable hypersonic research aircraft that would go into orbit and then glide in for landing, much as the space shuttle does now. However, the success of the Mercury and Gemini suborbital and orbital missions caused this project to be terminated in 1963.

Designed to explore the feasibility of producing extensive laminar flow on a large aircraft by using suction through tiny holes in the wing surface, the Northrup X-21 demonstrated the ability to obtain close to 75 percent laminar flow over the wings, with a potential increase of perhaps 50 percent in its range. However, maintenance costs (keeping the holes free of water and dust and insects) and production costs made it appear to be too expensive to be practical. The X-21's first flight was in 1963.

Three versions of the Benson X-25 autogyro were built and tested. It was intended as a stowable emergency flight vehicle for pilots who were forced to abandon their aircraft behind enemy lines. (An autogyro, or autogiro, obtains lift from rotating blades rather than from a wing, and the rotor blades can be folded to minimize the space required.) The concept proved to be feasible but not practical. The first flight of the X-25A was in 1968.

The Lockheed X-27 Lancer was intended as a low-cost, advanced lightweight fighter that would appeal to countries using the company's F-104 Starfighter, but it was never funded.

The Pereira X-28A Osprey I was a homebuilt design, a low-cost, single-place seaplane that the government thought could be usefully employed in Southeast Asia for civil police patrols. It was successfully tested in 1971, but no production contract resulted.

The X-30 Spaceplane, announced by President Ronald Reagan in 1986 as the "Orient Express," was intended to be a crewed, single-stage-to-orbit vehicle that could take off and land on conventional runways. It was expected to use turbojets at low speeds, ramjets at the lower supersonic speeds, scramjets (supersonic combustion ramjets) above Mach 4, and rocket engines while in orbit. The program was canceled in 1995 with no planes built.

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See also: Air Force, U.S.; Airplanes; Experimental aircraft; Hypersonic flight; Military flight; National Advisory Committee for Aeronautics; National Aeronautics and Space Administration; Ramjets; Scramjets; Space shuttle; Supersonic aircraft; Tail designs; Uncrewed spaceflight; Uninhabited aerial vehicles; Wing designs

Y

Chuck Yeager

Date: Born on February 13, 1923, in Myra, West Virginia

Definition: World War II ace, test pilot, and pioneer in aviation endurance and speed records.

Significance: Yeager was the first person to break the sound barrier, as the speed of sound was perceived in the 1940's.

Pilot and Ace

Charles Elwood "Chuck" Yeager was born in 1923 in Myra, West Virginia. After graduating from high school, he enlisted in the Army Air Corps in September, 1941, to be a mechanic, a job at which he had had previous experience. After his induction, he was further trained for work on airplanes. He became a crew chief, servicing airplanes and overhauling their engines. He eventually decided to try to become a pilot. On December 4, 1941, he took a physical and was called up for training six months later.

Yeager first rode in an airplane in the spring of 1942. He was commissioned as a reserve flight officer on March 10, 1943, at Luke Field, Arizona. His first assignment was as a P-39 pilot with the 363d Fighter Squadron in Tonopah, Nevada. He trained at various bases in the United States before being sent overseas to England in November, 1943.

Yeager eventually served as a fighter pilot in the fighter command of the Eighth Air Force stationed in England. Based at Leiston, Suffolk, England, he flew P-51's in combat against Germany. He shot down an Me-109 and an He-111K before being shot down on his eighth combat mission over German-occupied France on March 5, 1944. Although he was wounded, he managed to parachute safely to the ground. With the help of a French farmer and the French Resistance, known as the Marquis, Yeager made his way to Spain and eventually back to England to rejoin his fighter unit. At first he was told that he could no longer fly missions over Europe because, if shot down again and captured by the Germans, he might be tortured by the Gestapo into giving away secrets of the French Marquis and then shot. Yeager pleaded his case to General Dwight D. Eisenhower. Shortly thereafter, the Marquis began openly fighting the Germans, so General Eisenhower decided in Yeager's favor. On October 12, 1944, Yeager shot down five enemy aircraft in one day, became an ace, and subsequently received the Silver Star. Between July and October, 1944, he was promoted from second lieutenant to captain.

Yeager flew a total of sixty-four missions over Europe and shot down thirteen German planes. In February, 1945, he returned to the United States, and on February 26, 1945, he married Glennis Faye Dickhouse, whom he had met in California, in his parents' home in Hamlin, West Virginia. He subsequently went to Edwards Air Force Base in California and became a test pilot.

A Ride into History

On October 14, 1947, over California's Rogers Dry Lake, Yeager became the first person to break the sound barrier, riding the Bell X-1 airplane, attached to the belly of a B-29 bomber, to an altitude of 25,000 feet. He released the aircraft from the B-29 and rocketed to an altitude of 40,000 feet, safely taking the X-1 to a speed of Mach 1.07, or 670 miles per hour, faster than the speed of sound at the altitude of 40,000 feet. No one had known whether a pilot could successfully control a plane under the battering effects of the shock waves produced as a plane's speed neared Mach 1. After keeping Yeager's record a secret for eight months, the Air Force finally announced it in June, 1948.

Test Pilot and General

During the next two years, Yeager flew the X-1 thirty-three times, reaching a maximum speed of 957 miles per hour, or Mach 1.45, and an altitude of 70,000 feet. He was the first and only American to make a ground takeoff in a rocket-powered X-plane. In December, 1953, Yeager flew the Bell X-1A at a speed of 1,650 miles per hour, or Mach 2.44, a record that still stands for straight-winged aircraft.

Yeager continued to make test flights for the Air Force. On December 12, 1953, in an X-1A rocket plane, he set a world speed record of 1,650 miles per hour. In 1954, after nine years at Edwards Air Force Base, Yeager left his post as assistant chief of test-flight operations at Edwards to join the staff of the Twelfth Air Force in what was then West Germany, becoming an F-86 squadron commander.

Image Not Available

In 1962 Yeager returned to Edwards Air Force Base as a colonel to command the Aerospace Research Pilot School. During this time he trained to break the world speed record again, in an NF-104 fighter-interceptor. In a practice flight, Yeager's plane went into a spin and fell from an altitude of more than 100,000 feet. He survived only by ejecting, and, despite safely parachuting into the desert, he was badly burned. It was his last attempt to break the speed record.

In 1968, Yeager took command of the Fourth Tactical Fighter Wing. He retired from the Air Force in 1975 at the rank of brigadier general. Even after his retirement from the Air Force, Yeager continued to set world aviation records for private passenger jet planes.

Dana P. McDermott

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See also: Air force, U.S.; Fighter pilots; Record flights; Sound barrier; Supersonic aircraft; Test pilots; World War II; X planes

Ferdinand von Zeppelin

Date: Born on July 8, 1838, at Konstanz, Baden, Germany; died on March 8, 1917, at Charlottenburg, Germany

Definition: A pioneering builder of rigid airships.

Significance: Zeppelin helped build the first practical airships capable of navigating over long distances, stimulating aeronautical experimentation and paving the way for military and commericial applications of airships.

Trained as a civil engineer, Ferdinand von Zeppelin received his military commission in 1858. He was in the United States throughout much of the American Civil War (1861-1865), when he worked as an observer of hot-air balloons. After forty-four years in the military, Zeppelin retired in 1890 and began designing and building rigid airframe airships with an engineer named Theodor Kober.

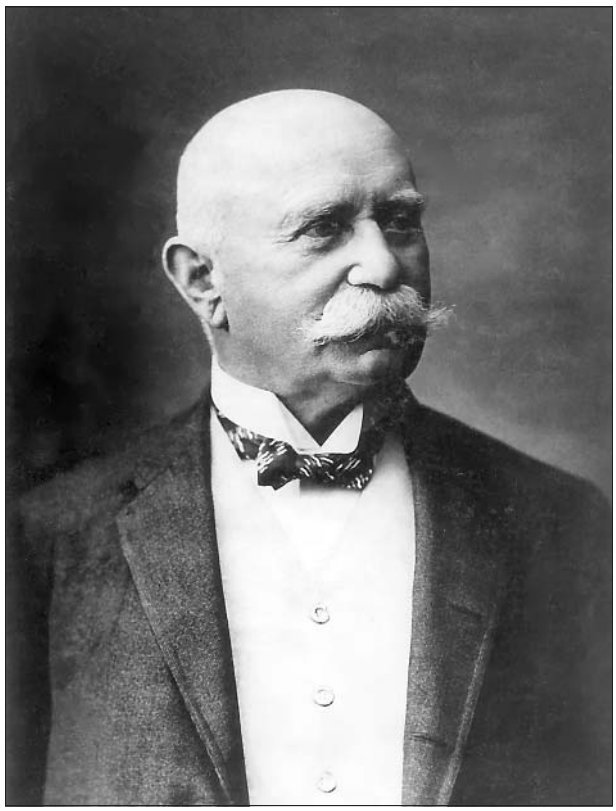
On July 2, 1900, Zeppelin and Kober flew the first rigid airship, the *LZ-1*, cautiously coaxing it out of a hangar floating on a lake. The flight, which lasted eighteen minutes, was considered a success despite difficulties with directional controls. For the next dozen years, Zeppelin worked tirelessly on the design and testing of a series of airships. In 1908, airship *LZ-8* remained in the air for twenty-four hours as a demonstration of airworthiness.

So intensely had airships captured the popular imagination, that the German emperor, William II, publicly supported Zeppelin's work. Zeppelin backed his early work with his own private fortune, and his name eventually became a generic term for rigid airships. A campaign was begun to raise money through popular contributions, which became the capital for a new company, Luftschiffbau Zeppelin. Zeppelin's company eventually formulated a strong lightweight metal, Duraluminum, which became the basis for many new developments in all-metal airplane frames.

In November, 1909, Zeppelin and his partner founded the world's first airline, the Deutsche Luftschiffahrts Aktien-Gesellschaft, or Delag, which provided short flights from airfields throughout Germany, largely for members of high society, thousands of whom paid to ride in the new airships. Zeppelins were soon under contract for regular mail delivery throughout Germany.

Although William II had initially opposed the bombing of civilian areas, during World War I more than one hundred zeppelins were eventually deployed across the English Channel to bomb areas around London. Over the course of the war, the German airship raids caused more than seven million dollars in damage and killed more than five hundred people.

At the beginning of the war, rigid airships' key advantage over airplanes was that they could climb to much higher altitudes. As airplane designs improved during the war, airplanes were able to gain greater altitude, and the British began using incendiary bullets to damage the hy-



Ferdinand von Zeppelin designed the first rigid airship, or dirigible, the LZ-1, which had its first flight on July 2, 1900. Nine years later, he and a partner founded the world's first airline, providing dirigible passenger and airmail service throughout Germany. (Library of Congress) drogen bags placed inside the zeppelins' airframes. This development was countered by lightweight zeppelins, called height climbers, which were able to reach altitudes of 20,000 feet. The height climbers represented special perils for their crews, however, because parachutes were banned as excess weight.

When Zeppelin died of pneumonia in March, 1917, he had not yet achieved his goal of transatlantic flight, which would later be achieved by both the *Graf Zeppelin*, christened on his birthday in 1928, and the ill-fated *Hindenburg*, the largest lighter-than-air ship ever built.

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See also: Balloons; Bombers; Dirigibles; *Hindenburg*; Hot-air balloons; Lighter-than-air craft; Reconnaissance

Glossary

Aileron roll: A 360-degree roll accomplished by applying and maintaining coordinated aileron pressure. The maneuver is begun with the nose slightly raised, because, as the airplane rolls, its lift vector is no longer countering its weight, so the nose of the ariplane drops significantly during the maneuver. Back stick pressure is maintained throughout, so that even when the aircraft is upside down, positive seat pressure of about 1 g (1 times the force of gravity) will be felt. As the airplane approaches wings-level at the end of the maneuver, aileron pressue is removed and the roll stops.

Ailerons: Control surfaces located on the outer part of the wing of an airplane, used to help the airplane turn. As the ailerons hinge down on one wing, they push the air downward, making that wing tilt upward. This motion tips the airplane to the side and helps it to turn, a process also known as banking. The pilot manipulates the ailerons from the cockpit by moving the control column or stick left and right. Right movement rolls the airplane to the right, and left movement rolls the airplane to the left.

Air density: The product of altitude and air temperature.

Airfoil: A structure designed to obtain reaction upon its surface from the air through which it moves. Early airfoils typically had little more than a slightly curved upper surface and a flat undersurface. Over the years, airfoils have been adapted to meet changing needs. By the 1920's, airfoils typically had a rounded surface, with the greatest height being reached in the first third of the chord line, or width. In time, both upper and lower surfaces were curved to a greater or lesser degree, and the thickest part of the airfoil gradually moved backward. By moving forward in the air, the wing's airfoil obtains a reaction useful for flight from the air passing over its surface. In flight, the airfoil of the wing normally produces the greatest amount of lift, but propellers, tail surfaces, and the fuselage also function as airfoils and generate varying amounts of lift. If the velocity of air is increased over a certain point of an airfoil, the pressure of the air is decreased. Air flowing over the curved top surface of the wing's airfoil moves faster than the air flowing on the bottom surface, decreasing the pressure on top. The higher pressure from below pushes or lifts the wing up to the lower-pressure area. Simultaneously, the air flowing along the underside of the wing is deflected downward, providing an equal and opposite reaction and contributing to total lift.

Airplane: Any of a class of heavier-than-air, fixed-wing aircraft propelled by a screw propeller or by a high-velocity jet, and supported by the dynamic reaction of the air against its wings.

Airspeed: Wind velocity.

Bank: The angle between an aircraft's wings and the horizon, as viewed from the rear of the aircraft. An airplane with its wings level has zero degrees of bank.

Banking: The turning of an airplane by pushing the control stick in the cockpit to the left or right, which makes the ailerons on one wing go down and the ailerons on the other wing go up and makes the airplane tip to the left or right.

Biplane: An airplane with two sets of wings, one above the other. Between 1903 and 1909, the Wright brothers' biplanes inaugurated the era of powered flight, and biplanes predominated in military and commercial aviation from World War I through the early 1930's. However, the biplane's greater maneuverability could not offset the speed advantage of the lighter monoplane, with one set of wings. After World War II, biplanes were used only for special purposes such as crop dusting and sport flying. A biplane with one much smaller, usually lower, wing is called a sesquiplane.

Civil aircraft: All nonmilitary airplanes, including private and business planes and commercial airliners. Private aircraft are personal planes used for pleasure flying and are often single-engine monoplanes with nonretractable landing gear. They can be very sophisticated, however, and may include such variants as "warbirds," ex-military planes flown for nostalgic reasons; primary trainers; large bombers; and homebuilts, aircraft built from scratch or from kits by the owner.

Business aircraft are used to generate revenues for their owners and include everything from small single-engine aircraft used to train pilots or to transport small packages over short distances to four-engine executive jets that can travel across continents and oceans. They are used by salespeople, prospectors, farmers, doctors, missionaries, and many others, and their primary purpose is to free their users from airline schedules and airport operations. They also serve as executive perquisites and as sophisticated inducements for potential customers. Other business aircraft include those used for agricultural operations, traffic reporting, forest-fire fighting, medical evacuation, pipeline surveillance, and freight hauling.

Commercial airliners are used to haul passengers and freight on a scheduled basis between selected airports. They range in size from single-engine freight carriers to Boeing 747 jumbojets and in speeds from less than 200 miles per hour to those greater than the speed of sound.

Cockpit: The pilot's seat in an airplane, where all of the controls and instruments are located.

Control stick: The airplane control, located in the cockpit, to which the ailerons are connected. Pushing the stick to the left or the right makes the ailerons on one wing go down and the ailerons on the other wing go up. This action makes the plane tip to the left or the right and is called banking.

Drag: One of the four principles of flight, along with thrust, weight, and lift. Drag is the force encountered as an airplane pushes through the air, which tends to slow the airplane down. There are two types of drag, and an airplane must fight its way through both kinds in order to maintain steady flight. Profile or parasite drag is the same kind of drag experienced by all kinds of objects in a flow. This type of drag is caused by the airplane as it pushes the air out of the way as it moves forward. This drag can be easily experienced by a motorist if he or she places his or her hand out of the window of a moving vehicle. Induced drag is the result of the generation of lift. This drag is the part of the force produced by the wing that's parallel to the relative wind. Objects that create lift must also overcome this induced drag.

Elevators: Movable flaps attached to the horizontal stabilizer used to change the angle of attack of the wing which will, in turn, change the pitch, moving the airplane up and down. The angle of attack is the angle between the wing and the relative wind. Moving the control stick forward or backward operates the horizontal stabilizer, which in turn moves the elevator down or up, respectively.

Engine: This part of the airplane produces thrust or forward movement necessary to sustain flight. Thrust is one of the four basic principles of flight, and all aircraft need some type of thrust to propel themselves aloft. The most common means of generating thrust on powered airplanes comes from propellers or jets. Whether an aircraft has a propeller or jet, both of these produce thrust by accelerating a mass of air to the rear of the aircraft. The movement of this air to the rear creates an unbalanced force pushing the aircraft forward. Propellers are essentially revolving wings situated so that the lift that they produce is used to pull or push the airplane. Most modern high-speed aircraft use jet engines rather than propellers. Jets produce thrust by burning propellant or jet fuel mixed with air and then by forcing the rapidly expanding gases rearward. In order to operate from zero airspeed on up, jets use enclosed fans on a rotating shaft to compress the incoming air and channel it into a combustion chamber where fuel is added and ignited. The burning gases keep the shaft turning by rotating a fan before exiting the engine.

In a jet engine, the inlet area is small compared to that of a propeller. As the air exits the compressor section of the engine, it enters the combustion chamber, where fuel is added. This densely packed air-fuel mixture is ignited, and the resultant explosion accelerates the gases out of the rear of the engine at a very high rate of speed. This chemical acceleration of the air or combustion adds to the thrust produced by the engine. Most jet fighter aircraft have afterburners, which add raw fuel into the hot jet exhaust and thereby generate even more thrust through higher accelerations of the air. The jet generates large amounts of thrust by chemically accelerating the air as the result of combustion. The fact that the jet compresses the air as much as 40 times allows the jet aircraft to fly at higher altitudes, where the air is too thin for propellers. Engine thrust is controlled by a throttle for each respective engine. As the throttle is moved forward, more fuel is added and the engine rotates faster and produces more thrust. Thrust is also directly related to engine revolutions per minute (RPM). The amount of thrust is often referred to as percentage RPM.

Flaps: Extensions of the trailing or inner edge of the wing, which can be deflected downward as much as 45 degrees. They help the airplane to fly slower. Many flaps effectively increase the wing area, adding to lift and drag. The angle to which the flaps are deployed determines the relative amount of additional lift or drag obtained. At smaller angles, lift is typically increased over drag, while at greater angles, drag is dramatically increased over lift. The flaps slide back and forth and are controlled by a lever in the cockpit. Flaps come in a wide variety of types, including the simple split flap, in which a hinged section of the undersurface of the trailing edge of the wing can be extended. The Fowler flap extends the wing area by deploying on tracks, creating a slotted effect.

Fly-by-light: Flight control system in which signals pass between computers and actuators along fiber optic leads.

Fly-by wire: Flight control system with electrical signaling, without mechanical interconnection between cockpit controls and control surfaces.

Fuselage: The central body of the airplane to which the wings, tail, and engines are all attached. In a modern passenger airplane, passengers sit only in the top half of the fuselage. The fuselage also houses the cockpit, where all of the controls necessary for operating and controlling the airplane are located. Cargo is housed in the bottom half of the fuselage. The fuselage is generally streamlined as much as possble.

Global Positioning System (GPS): U.S. civil-military satellite-based precision navigational aid.

Gravity: The earth's attractive force and one of the four forces of flight.

Green aircraft: Unpainted flyable aircraft that are furnished with only basic equipment.

Horizontal stabilizer: A fixed-position airfoil that stabilizes the pitch of the airplane. When a wing produces lift, it also develops a force that tries to pitch the airplane forward. The horizontal stabilizer prevents this unwanted pitch from occuring.

Landing gear: On conventional aircraft, the landing gear consists of wheels or tires with supports and shock absorbers that assist in takeoffs and landings. To reduce drag while the airplane is flying, most wheels fold up into the body of the airplane after takeoff. On many smaller aircraft, the wheels do not fold up after takeoff.

Lift: An upward force that causes an object to rise. In aircraft it may be produced by downward-facing propellers, or by a moving wing with an airfoil shape, or the specially curved shape of an airplane wing. Lift is one of the four basic principles of flight. Forces are produced by the wing as the air flows around it. Lift is the part that is perpendicular to the relative wind. The other part contributes to drag.

Loop: A 360-degree change in pitch. Because the airplane will climb several thousand feet during the maneuver, it is started at a relatively high airspeed and power setting. The pilot, once satisfied with the airspeed and throttle setting, will pull back on the control stick until about 3 gs are felt. The nose of the ariplane will go up and steadily increasing climb will be established. As the maneuver continues, positive g is maintained by continuing the pull. The airplane continues to increase its pitch until it has pitched through a full circle. When the world is right-side-up again, the pilot releases the back stick pressure and returns the aircraft to level flight.

Mach number: The ratio of the speed of the aircraft to the speed of sound, named after the Austrian physicist Ernst Mach.

Maneuverability: The ability to change the speed and flight direction of an airplane. A highly maneuverable airplane, such as a fighter, has the ability to accelerate or to slow down very quickly and also to turn sharply. Quick turns with short turn radii place high loads on the wings as well as on the pilot. These loads are referred to as g forces and the ability to "pull g's" is considered one measure of maneuverability. One g is the force acting on the airplane in level flight imposed by the gravitational pull of the earth. Five g's in a maneuver exerts five times the gravitational force of the earth.

Monoplane: A type of aircraft with a single pair of wings. The monoplane design has been nearly universally adopted over multiplane configurations, because airflow interference between adjacent wings reduces efficiency. The first monoplane was constructed by the Romanian inventor Trajan Vuja, who made a flight of 40 feet on March 18, 1906. Louis Blériot of France built a monoplane in 1907 and flew it across the English Channel two years later. Monoplane design proved itself conclusively during World War II, and since then the craft has completely supplanted the biplane except for special purposes such as crop dusting.

Payload: In civil aircraft, a disposable load generating revenue such as passengers, cargo, mail, and other paid items. In military aircraft, payload loosely refers to the total load of weapons, cargo equipment, or other mission equipment carried.

Performance: The motion of the airplane along its flight path, how fast, slow, high, and far an aircraft can fly. In a general sense, performance may also refer to the ability of an airplane to accomplish the different aspects of its mission. Included in such a comprehensive designation are minimum and maximum speed, maximum altitude, maximum rate of climb, maximum range and speed for maximum range, rate of fuel consumption, takeoff and landing distance, and weight of potential payload. Differences in weather conditions such as temperature, pressure, humidity and winds strongly affect these performance indices.

Pitch: The angle between the airplane's body (lengthwise) and the ground. An airplane going straight up would have a pitch attitude of 90 degrees and one in level flight, about zero degrees.

Propeller: The part of the airplane that produces thrust or forward movement necessary to sustain flight. This turning blade on the front of the airplane moves it through the air. Propellers are basically rotating airfoils, and they include two-blade fixed-pitch, four-blade controllable- (variable) pitch, and eight-blade contrarotating-pitch propellers. The blade angle on fixed-pitch propellers is set for only one flight regime, and this restriction limits their performance. Some fixed-pitch propellers can be adjusted on the ground to improve performance in one part of the flight regime. Variable-pitch propellers permit the pilot to adjust the pitch to suit the flight condition, using a low pitch for takeoff and a high pitch for cruising flight. Most modern aircraft have an automatic variable-pitch propeller, which can be set to operate continuously in the most efficient mode for the flight regime. If an engine fails, most modern propellers can be feathered or mechanically adjusted so that they present the blade edgewise to the line of flight, thereby reducing drag.

Range: The distance that an aircraft can fly before running out of fuel. The range of a fighter airplane or bomber, for example, is one-half of its radius. A range of 1,000 miles, then, means that such an airplane can fly from its base for a distance of 500 miles, drop its ordnance, and fly 500 miles back to base. Some of the many factors that influence range are very subtle, such as poor seals on cooling doors or small pockets of disturbed air around the engine inlets.

Reciprocating engine: Often an internal combustion engine; types differ based on the arrangement of the cylinders. Horizontally opposed engines employ four to six cylinders lying flat and arrayed two or three on each side. In a radial engine the cylinders are mounted in a circle around the crankshaft, sometimes in banks of two or three. Once the dominant piston-engine type, radials are now in only limited production.

Relative wind: The direction that air is going as it passes the airplane relative to the airplane. Relative wind is not related to the wind speed on the ground.

Roll: The tilting motion that the airplane makes when it turns.

Rudder: The hinged part on the back of an aircraft's tail that helps to turn the aircraft. The vertical part of the tail, the rudder controls the sideways movement of the airplane, called the yaw. The rudder is one of the least frequently used airplane controls, and most flying can be safely accomplished without it.

Seaplane: Any of a class of aircraft that can land, float, and take off on water. Seaplanes with boatlike hulls are also known as flying boats; those with separate pontoons or floats are known as floatplanes. The first practical seaplanes were built and flown in the United States by Glenn H. Curtiss in 1911 and 1912. Curtiss's inventions led to British aircraft called F-boats of World War I. Such boats originated naval air missions such as over-ocean patrol, antisubmarine warfare, mine laying, and air-sea rescue. After the war, commercial versions of the same seaplanes set the range and endurance records of the time. In 1919, the U.S. Navy's water-based NC-4 made the first crossing of the North Atlantic, via the Azores. By the late 1920's, the largest and fastest aircraft of the world were seaplanes. Their utility and versatility were dramatized by a 1929 Soviet flight from Moscow to New York City via Siberia of a Tupolev ANT-4 fitted with floats and by fleets of Italian planes that flew from Rome to Rio de Janeiro and from Rome to Chicago in the 1930's. After the outbreak of World War II, the military and commercial significance of seaplanes gradually diminished, partly because of the increased range of land-based planes and partly because of the construction of land bases and aircraft carriers. Following World War II, the development of water-based aircraft continued, but only on a small scale.

A seaplane must have sufficient buoyancy to float on water and must also have some means for supporting its weight while moving along the water surface at flying speeds. It must be able to take off and land with a margin of stability and control on the part of the pilot. Its structure must be strong enough to withstand the shock of landing, and its water resistance must be low enough to permit reasonably short takeoff runs. Curtiss provided two ways of meeting these requirements. First, he developed the float seaplane, which was essentially a land plane with buoyant floats or pontoons substituted for the landing wheels. Second, he created the flying boat, in which the main float and the fuselage are combined in a single boatlike body. In either case, float design includes a stepped bottom to facilitate takeoff. As speed and lift increase, the seaplane lifts onto its step so that it is barely skimming the water with friction at a minimum. Curtiss also added a retractable landing wheel gear to a float seaplane or flying boat, thereby creating the amphibian aircraft capable of operating from land runways or water.

Short takeoff and landing (STOL) aircraft: Any of several fixed-wing aircraft capable of taking off and landing on runways considerably shorter than those needed by conventional aircraft. Most aircraft of this type require a runway no more than 500 feet long, which is about ten times shorter than the average runway. STOL aircraft were developed to meet the needs exemplified by bush or wilderness flying, where steep climb and approach angles and low landing speed are more important than high cruising speeds. These capabilities are provided by a combination of aerodynamic devices, such as the augmentor wing, which was introduced during the early 1960's. It consists of full span slats at the leading or front edge of the wing and full span double-slotted flaps at the trailing or rear edge. Manipulation of these devices and an air-duct system allow use of air turbulence and prop wash for added lift and drag.

The first version of the STOL was test-flown in 1954 by the U.S. Navy. Since then, the STOL has been adopted by the armed forces of the United States and the United Kingdom for combat operations.

Stall: The reaction of a wing in flight when a given angle of attack is exceeded. The stall is characterized by a progressive loss of lift for an increase in angle of attack.

Straight and level flight: Flight maintained at a given altitude, airspeed, and heading. This condition is achieved and maintained by equalizing all opposing forces. Lift must equal weight so that the airplane does not climb or descend. Thrust must equal drag so that the airplane does not speed up or slow down. The wings are kept level so that the airplane does not turn. Any imbalance will result in a change in altitude or airspeed and hence an interruption of straight and level flight.

Tail: The rear section of an aircraft with many movable parts. The pilot controls these parts from the cockpit. The tail includes the rudder and the elevators.

Thrust: The force produced by the engines. Thrust works opposite of and counteracts drag. Thrust is the forward movement that is necessary to sustain flight and is one of the four basic principles of flight.

Trim: When the controls of an airplane are moved from neutral, it takes a certain amount of pressure to hold them in position in the airflow. Trim gets rid of this pressure and effectively changes the center of the controls, or the neutral position where there is no stick pressure.

Vertical stabilizer: The yaw stabilizer of the airplane. This keeps the nose of the airplane pointed into the relative wind.

Vertical takeoff and landing (VTOL) aircraft: Any of several unconventional aircraft with rotating wing systems, such as the helicopter and autogiro. They may also have rotatable jet systems capable of vertical liftoff and landing in areas that only slightly exceed the overall dimensions of the aircraft. The first operational VTOL jet aircraft was the British Royal Air Force Harrier. Its jet engines are mounted horizontally, with their blast deflected downward to effect vertical thrust for takeoff. It achieves high subsonic speeds in level flight.

Weight: The force produced by the mass of the airplane interacting with the earth's gravitational field. The force must be counteracted by lift in order to maintain flight and is one of the four principles of flight. There are five types of weight. Basic weight is the weight of the basic aircraft plus weapons, unusable fuel, oil, ballast, survival kits, oxygen, and any other internal or external equipment that is on board the aircraft and will not be disposed of during flight. Operating weight is the sum of basic weight and items such as crew, crew baggage, steward equipment, pylons and racks, emergency equipment, special mission fixed equipment and all other nonexpendable items not in basic weight. Gross weight is the total weight of an aircraft, including its contents and externally mounted items, at any time. Landing gross weight is the weight of the aircraft, its contents, and external items when the aircraft lands. Zero-fuel weight is the weight of the aircraft without any usable fuel, determined by structural limitations of the aircraft.

Wing: The appendages or arms of an airplane. Wings provide the principal lifting force of the aircraft. They hold the airplane aloft by creating lift from the air rushing over them. Like all airplane parts, the wings should be light and strong, but also flexible to absorb sudden gusts of wind. The shape of a wing resembles an elongated drop of water lying on its side. Usually the top is curved more than the bottom, making the upper surface slightly longer than the bottom. Since air passing over the top and bottom must reach the rear of the wing at the same time, the air passing over the top must not only travel faster but also changes direction and is deflected downward. It is a wing's ability to produce efficiently a force perpendicular to the air passing over it that makes heavier-than-air flight possible. All wings essentially produce lift the same way by pushing down on the air.

They thereby force air downward relative to the wing. Most of the time, the top of the wing does the majority of the pushing on the air. The top and the bottom of the wing combine to produce a force, and part of this force perpendicular to the relative wind is lift.

The wing planform is the shape that it forms when seen from above. Delta wings are triangular wings lying at roughly a right angle to the fuselage. The supersonic Concorde passenger jet airliner features delta wings. Swept wings are angled, usually to the rear and often at an angle of about 35 degrees. Forward-swept wings also are used on some research craft. Some aircraft have wings that may be adjusted in flight to attach at various angles to the fuselage. These are called variable-incidence wings. Variable-geometry wings, or swing wings, can vary their sweep in flight. The sweep is the angle of a wing with respect to the plane perpendicular to the longitudinal axis of the craft. Swept-wing aircraft have military applications. Another configuration limited to military craft is the so-called flying wing, a tailless craft having all of its elements encompassed within the wing structure. One example of such an aircraft is the B-2 bomber of the U.S. Air Force. The lifting-body aircraft, such as the U.S. space shuttle, generates lift in part or totally by the shape of the fuselage rather than the wing, which is consequently severely reduced in size or altogether absent.

Yaw: The angle between the fuselage of the airplane and the relative wind as seen from above the airplane. Yaw is the term that pilots use to describe the turning left or right of the airplane. Yaw is the sideways movement of the airplane. Normally an airplane is flown without yaw.

Oliver Griffin

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Web Sites

The Internet has proven to be a valuable research tool. Information about almost any topic is available on-line. Finding that information, however, can be difficult. The Web sites listed below relate specifically to articles in this work. Although every effort has been made to ensure their accuracy, readers must be aware that Web sites are continually being updated and hence there may be changes in the homepages listed. Please note when entering these Universal Resource Locators (URLs) that proper capitalization and punctuation are required. The standard prefix "http://," often automatically inserted by one's Web browser, has been excluded from the below-listed URLs in order to avoid redundancy.

GENERAL AVIATION INFORMATION

AVStop Magazine Online
(avstop.com)

AvStop Magazine Online provides readers with general aviation information, news stories (both contemporary and historical), as well as research tools, editorials, and classifed advertising.

National Air and Space Museum
(www.nasm.si.edu)

The Smithsonian Institution's National Air and Space Museum Web site contains in-depth information about the museum and its holdings.

Science Daily
(www.sciencedaily.com)

An on-line magazine devoted to science, technology, and medicine. Articles are selected from news releases submitted by universities and research organizations around the world.

ADVANCED PROPULSION

Advanced Propulsion Researches
(jnaudin.free.fr/advpmnu.htm)

A personal site showcasing a collection of advanced propulsion research, complete with images and subject-specific links to additional papers, publications, and Web sites.

Chemical Propulsion Information Agency
(www.cpia.jhu.edu)

A program of The Johns Hopkins University, the Chemical Propulsion Information Agency Web site provides readers with a list of propulsion news and technology reviews related to the propulsion industry, a calendar of events database related to the aerospace industry, and a comprehensive list of propulsion acronyms and trade names.

Meridian International
(www.mirl.demon.co.uk/proplsn.htm)

This informative Web page discusses advanced propulsion systems in a clear and easy-to-read manner. The home page host is Meridian International, an aerospace market research firm.

Stanford University
(navier.stanford.edu/hanson/propulsion/propulsion.html)

A university research site for information on scramjets, advanced propulsion, and pulse detonation engines.

AERONAUTICAL AND AEROSPACE ENGINEERING AND DESIGN

Eng-tips
(www.eng-tips.com)

This site hosts multiple forums for professional engineers in a variety of disciplines to discuss work-related topics in a noncommercial setting. Specific forum headings include aeronautic engineers and aerospace engineers.

NASA Quest
(quest.arc.nasa.gov/aero/index.html)

Designed specifically for the kindergarten through twelfth grade classroom, this NASA Quest site, sponsored by the National Aeronautics and Space Administration, provides a firsthand look into aerodynamic design research.

Space and Tech
(www.spaceandtech.com/spacedata/engines/engines.shtml)

This section, of a larger, informative space-related Web site, gives a brief overview of rocket engines, as well as providing a large list of specific engine types and a summary of each.

TransOrbital
(www.transorbital.net)

A private company providing a variety of engineering services for the commercial development and exploration of space. The site contains a library of contracted study reports and research papers.

AIR CARRIERS

Most major airlines around the world maintain Web sites that provide travelers with information about the airline's history, fleet, schedule, and pricing information. A comprehensive but by no means all-inclusive list follows.

North America

Aeromexico
(www.aeromexico.com)

Air Canada
(www.aircanada.ca)

AirTran Airways (formerly ValuJet)
(www.airtran.com)

Alaska Airlines
(www.alaskaair.com)

Aloha Airlines
(www.alohaairlines.com)

America West Airlines
(www.americawest.com)

American Airlines
(www.aa.com)

American Trans Air
(www.ata.com)

Continental Airlines
(www.continental.com)

Delta Air Lines
(www.delta.com)

Frontier Airlines
(www.flyfrontier.com)

Hawaiian Airlines
(www.hawaiianair.com)

JetBlue Airways
(www.jetblue.com)

Mexicana Airlines
(www.mexicana.com)

Midwest Express
(www.midwestexpress.com)

National Airlines
(www.nationalairlines.com or www. southwest.com)

Southwest Airlines
(www.iflyswa.com or www.southwest.com)

United Air Lines
(www.ual.com)

US Airways
(www.usairways.com)

Caribbean and South America

Air Jamaica (Jamaica)
(www.airjamaica.com)

Lan Chile (Chile)
(www.lanchile.com)

Lloyd Aereo Boliviano (Bolivia)
(www.labairlines.com)

VASP (Brazil)
(www.vasp.com.br)

Europe

Aer Lingus (Ireland)
(www.aerlingus.ie)

Aeroflot (Russia)
(www.aeroflot.com)

Air Atlanta Icelandic (Iceland)
(www.atlanta.is)

Air Europe (Italy [non-English site])
(www.aireurope.it)

Air France (France)
(www.airfrance.com)

Alitalia (Italy)
(www.alitalia.com)

Austrian Airlines (Austria)
(www.aua.com or www.austrianair.com)

British Airways (United Kingdom)
(www.britishairways.com)

British Midland (United Kingdom)
(www.flybmi.com)

Czech Airlines (Czech Republic)
(www.csa.cz)

Finnair (Finland)
(www.finnair.com)

Greenlandair (Greenland)
(www.greenland-guide.dk/gla)

Iberia (Spain)
(www.iberia.com)

KLM Royal Dutch Airlines (the Netherlands)
(www.klm.nl)

Lauda Air (Austria)
(www.laudaair.com)

Lufthansa (Germany)
(www.lufthansa.com)

Malev Hungarian Airlines (Hungary)
(www.malev.hu)

Portugalia Airlines (Portugal)
(www.pga.pt)

SAS Scandinavian Airlines (Scandinavia)
(www.scandinavian.net)

Swissair (Switzerland)
(www.swissair.com)

Turkish Airlines (Turkey)
(www.turkishairlines.com)

Virgin Atlantic (United Kingdom)
(www.virgin-atlantic.com)

Asia

Air Macau (Macau)
(www.airmacau.com.mo)

AirAsia (Malaysia)
(www.airasia.com)

Air-India (India)
(www.airindia.com)

All Nippon Airways (Japan)
(www.ana.co.jp/index_e.html)

Asiana Airlines (Korea)
(www.asiana.co.kr)

Cathay Pacific (Hong Kong)
(www.cathaypacific-air.com)

China Airlines (China)
(www.china-airlines.com/us/index.htm#)

EVA Air (Taiwan)
(www.evaair.com.tw)

JAL Japan Airlines (Japan)
(www.japanair.com)

Korean Air (Korea)
(www.koreanair.com)

Malaysia Airlines (Malaysia)
(www.malaysiaairlines.com.my)

MIAT Mongolian Airlines (Mongolia)
(www.miat.com.mn)

Philippine Airlines (Philippines)
(www.philippineair.com)

Singapore Airlines (Singapore)
(www.singaporeair.com)

Thai Airways International (Thailand)
(www.thaiair.com)

Uzbekistan Airways (Uzbekistan)
(www.uzbekistan-airways.com)

Africa and the Middle East

Air Zimbabwe (Zimbabwe)
(www.airzimbabwe.com)

EgyptAir (Egypt)
(www.egyptair.com.eg)

El Al (Israel)
(www.elal.co.il)

Emirates (United Arab Emirates)
(www.emirates.com)

Ethiopian Airlines (Ethiopia)
(www.flyethiopian.com)

Ghana Airways (Ghana)
(www.ghana-airways.com)

Gulf Air (United Arab Emirates)
(www.gulfairco.com)

Qatar Airways (Qatar)
(www.qatarairways.com)

Royal Air Maroc (Morocco)
(www.royalairmaroc.com)

South African Airways (South Africa)
(www.saa.co.za)

Australia and the Pacific Islands

Air New Zealand (New Zealand)
(www.airnz.com)

Air Pacific (Fiji)
(www.airpacific.com)

Air Vanuatu (Vanuatu)
(www.pacificislands.com/airlines/vanuatu.html)

Aircalin Air Caledonie International (New Caledonia)
(www.aircalin.nc/index_en.htm)

Ansett (Australia)
(www.ansett.com.au)

Qantas (Australia)
(www.qantas.com.au)

AVIATION CAREERS

U.S. Department of Labor, Bureau of Labor Statistics
(stats.bls.gov/oco/ocos107.htm)

Provided by the U.S. Department of Labor, Bureau of Labor Statistics, this Web page gives significant information on the training requirements, working conditions, and general nature of the work of aircraft pilots and flight engineers.

U.S. Department of Labor, Bureau of Labor Statistics
(stats.bls.gov/oco/ocos171.htm)

Provided by the U.S. Department of Labor, Bureau of Labor Statistics, this Web page gives significant information on the training requirements, working conditions, and general nature of the work of flight attendants.

ISSUES

AirSafe.com
(www.airsafe.com)

A comprehensive on-line database of aviation safety information, aviation facts, and information on aviation disasters, founded by a former aviation safety analyst with Boeing.

Airshows
(www.airshows.com)

An on-line database of air shows in the United States and around the world. Also included are links to individual performers and performance groups.

Bermuda Triangle.Org
(www.bermuda-triangle.org)

Provides current and in-depth information about the phenomenon of the Bermuda Triangle.

The Golden Age of Aviation and Antique/Classic Airplane Site
(www.geocities.com/CapeCanaveral/Lab/4515/map.htm)

A personal Web site dedicated to the "golden age of aviation." The site includes a history of air racing, pictures of classic airplanes, and links to additional aviation sites and organizations.

Skydiving.Com
(www.skydiving.com)

This site lists skydiving centers across the United States, with links to those centers, own Web sites. Also included are answers to frequently asked questions and descriptions of skydiving courses.

Skyrage Foundation
(www.skyrage.org)

The Skyrage Foundation's Web site was started by a flight attendant and her husband shortly after she had been injured by a passenger while inflight. The site lists current and archived articles on air rage as well as several articles on research studies on the issue of air rage.

MANUFACTURERS

The manufacturer sites listed below all contain information on the companies' histories and product lines and an assortment of news features, press releases, and photos.

Airbus
(www.airbus.com)

Beechcraft
(www.raytheon.com)

Boeing
(www.boeing.com)

Cessna Aircraft Company
(www.cessna.com)

Fokker aircraft
(www.fokkernl.com)

Gulfstream jets
(www.gulfstream.com)

Hughes aircraft
(www.raytheon.com)

Learjets
(www.learjet.com)

Lockheed Martin
(www.lockheedmartin.com)

Northrop Grumman
(www.northgrum.com)

Piper aircraft
(www.newpiper.com)

ORGANIZATIONS, PROGRAMS, AND AGENCIES

Academy of Model Aeronautics
(www.modelaircraft.org)

The official Web site of the Academy of Model Aeronautics. It lists its membership services, links to publications, and a calendar of competitions.

Advanced Space Transportation Program
(astp.msfc.nasa.gov)

NASA's Advanced Space Transportation Program site contains information about reusable launch vehicles.

Association of Professional Flight Attendants
(www.apfa.org)

The Association of Professional Flight Attendants Web site, and the organization itself, is designed for the flight attendants of American Airlines. Most areas are password protected, but the News & Events feature is open to the public and contains relevant news stories on the airline industry and stories that would be of interest to flight attendants. Related sites of flight attendant organizations for other airlines include those of United Air Lines (www.unitedafa.org), US Airways (www.afausairways.org), and Northwest Airlines (www.local2000.org).

Astronaut Hall of Fame
(www.astronauts.org)

The Astronaut Hall of Fame in Titusville, Florida, is the organization responsible for this Web site. It offers readers biographies on the Mercury, Gemini, and Apollo astronauts, press releases and photos, and a virtual tour of the hall of fame.

Blue Angels
(www.blueangels.navy.mil)

The official Web site of the United States Navy Blue Angels lists the squadron's history, current officers, show schedules, and photos.

Federal Aviation Administration
(www.faa.gov)

The Federal Aviation Administration's Web site lists traveler information and tips, a real-time map display of the status of airports across the United States, and press releases, reports, and fact sheets.

FlightAttendants.Org
(www.flightattendants.org)

Created primarily as a message board in late 1998 by an individual flight attendant, FlightAttendants.Org has become a warehouse of information, news stories, and other areas of interest to flight attendants worldwide. The site offers individual e-mail accounts, reports on "air rage" incidents, and a large listing of related Internet links.

International Aerobatics Club
(www.iac.org)

The Web site for the International Aerobatics Club. This site answers frequently asked questions including how to begin and locate aerobatic flight schools, lists a calendar of regional and national events, and includes aviation photos and Internet links.

National Aeronautics and Space Administration
(www.nasa.gov)

The National Aeronautics and Space Administration Web site, this government organization's site provides Internet researchers with everything from aerospace technology and space exploration information, to jobs and internship listings, to a multimedia image/video/audio gallery.

National Air Disaster Alliance/Foundation
(www.planesafe.org)

The mission of the National Air Disaster Alliance/Foundation is "To raise the standard of safety, security and survivability for aviation passengers and to support victims' families." The site features sections devoted to news articles, discussions, and assistance, such as family support, training, and the Red Cross.

National Transportation Safety Board
(www.ntsb.gov/aviation/aviation.htm)

The aviation section of the National Transportation Safety Board contains over 46,000 descriptions of aviation accidents, as well as reports of major investigations and public hearings.

Ninety-nines
(www.ninety-nines.org)

The official Web site of the International Organization of Women Pilots, commonly known as the Ninety-nines, contains articles on the history of the organization and advances for women pilots and programs such as grants and scholarships.

Royal Air Force
(www.raf.mod.uk/rafhome.html)
This is the official Web site of the United Kingdom's Royal Air Force (RAF). The site contains, among many other items, news stories, a picture gallery, and a listing of links to stations, squadrons, and RAF associations.

Women's Airforce Service Pilots
(www.wasp-wwii.org/wasp/home.htm)
This site is dedicated to the Women's Airforce Service Pilots (WASPs) of World War II, and includes official government records and reports, a gallery of photographs, audio and video clips, and resource guides such as a timeline and glossary of World War II terms.

PEOPLE

Armstrong, Neil
(www.astronautix.com/astros/armtrong.htm)
Features include an extensive biography and a log of Armstrong's flights.
(www.astronauts.org/discover_heroes/armstrong.htm)
A brief biography of Neil Armstrong.
(www.nationalaviation.org/enshrinee/armstrongn.html)
A lengthy biography of Armstrong's career.

Branson, Richard
(www.execpc.com/~shepler/branson.html)
An informative biography of the multimillionaire entrepreneur.
(www.ltbn.com/fame/Branson.html)
A brief biography and article focusing on Branson's entrepreneurial achievements.
(www.time.com/time/magazine/archive/1996/dom/960624/entrepreneurs.html)
A 1996 *Time* magazine article focusing on Branson's business ventures.

Braun, Wernher von
(history.msfc.nasa.gov/vonbraun/index.html)
A biographical sketch with a photo gallery and sound files.
(www.hq.nasa.gov/office/pao/History/sputnik/braun.html)
A brief biography of von Braun.
(liftoff.msfc.nasa.gov/academy/history/vonBraun/vonBraun.html)
An extensive personal and professional biography.
(www.nationalaviation.org/enshrinee/vonbraun.html)
A lengthy biography of von Braun's career.
(www.redstone.army.mil/history/vonbraun/welcome.html)
A brief biography with extensive photograph and video collections.

Byrd, Richard E.
(www-bprc.mps.ohio-state.edu/AboutByrd/AboutByrd.html)
A detailed biography with a separate chronological list of major events in Byrd's life.
(www.nationalaviation.org/enshrinee/byrd.html)
Lengthy biography of Byrd's career.
(www.pbs.org/wgbh/amex/ice/peopleevents/pandeAMEX86.html)
A brief but informative biography.
(www.south-pole.com/p0000107.htm)
A lengthy biography of Byrd.

Chanute, Octave
(www.aerofiles.com/bio_c.html)
A very brief biography of Chanute, with a bibliography of related titles.
(www.crown.net/~sspicer/chanute/chan_ind.html)
A review of Chanute's contributions to aviation, particularly his glider experiments.
(hawaii.psychology.msstate.edu/invent/i/Chanute/Chanute_articles.html)
Features diary entries, papers, and correspondence by Chanute, as well as several newspaper articles.
(www.loc.gov/exhibits/wright/wb005.html)
A brief biography and links to multiple photographs taken by Chanute of the Wright brothers' experiments at Kill Devil Hill, North Carolina.
(www.nationalaviation.org/enshrinee/chanute.html)
An informative biography of Chanute's career.
(www.wam.umd.edu/~stwright/WrBr/inventors/Chanute.html)
A very brief biography, featuring several clear photographs of early gliders.
(www.wpafb.af.mil/museum/history/preww1/pw1.htm)
A brief article on Chanute's glider.

Cochran, Jacqueline
(www.aerofiles.com/bio_c.html)
A very brief biography of Cochran.
(www.firstflight.org/shrine/jacqueline_cochran.html)
A very brief account of Cochran's aviation career.
(www.nasm.edu/nasm/aero/women_aviators/jackie_cochran.htm)

A brief biography with photo.
(www.nationalaviation.org/enshrinee/cochran.html)
A brief biography of Cochran's career.

Coleman, Bessie

(www.aerofiles.com/bio_c.html)
A very brief biography.
(www.bessiecoleman.com)
Simple site with an extensive biography, broken into separate sections, and links to additional relevant sites.
(www.faa.gov/avr/news/Bessie.htm)
A lengthy biography of Coleman.
(www.firstflight.org/shrine/bessie_colman.html)
A brief biography of Coleman.
(www.nasm.edu/nasm/aero/women_aviators/bessie_coleman.htm)
A brief biography, with photo, links to a more complete biography within the same Smithsonian site.
(www.pbs.org/wgbh/amex/flygirls/peopleevents/pandeAMEX02.html)
A lengthy biography of Coleman.

Doolittle, Jimmy

(www.aerofiles.com/bio_d.html)
A brief biography of Doolittle, with a bibliography of related titles.
(www.firstflight.org/shrine/jimmy_doolittle.html)
A very brief biography of Doolittle.
(www.nationalaviation.org/enshrinee/doolittle.html)
A very brief biography of Doolittle's career.

Earhart, Amelia

(www.aerofiles.com/bio_e.html)
A brief biography of Earhart, with a bibliography of related titles.
(www.ameliaearhart.com)
The official Web site of the estate of Amelia Earhart contains biography, quotes, photos, and links.
(ellensplace.net/eae_intr.html)
An informative personal Web site, broken into "The Early Years," "The Celebrity," and "The Last Flight."
(www.history.navy.mil/faqs/faq3-1.htm)
A brief biography with a bibliography.
(www.nasm.edu/nasm/aero/women_aviators/amelia_earhart.htm)
A brief illustrated biography.
(www.nationalaviation.org/enshrinee/putnam.html)
A lengthy biography of Earhart's career.

Gagarin, Yuri

(www.abamedia.com/rao/gallery/gagarin)
An extensive, multipage biography that includes numerous personal and public photographs.
(www.allstar.fiu.edu/aerojava/gagarin.htm)
A brief biography.
(www.astronautix.com/astros/gagarin.htm)
Brief biography and a log of Gagarin's flights.
(www.kosmonaut.se/gagarin)
An informal, but informative and lengthy biography that includes an audio file of the Soviet national anthem.

Glenn, John

(www.astronautix.com/astros/glenn.htm)
A detailed biography and log of Glenn's flights.
(www.astronauts.org/discover_heroes/glenn.htm)
A brief biography of Glenn.
(www.grc.nasa.gov/WWW/PAO/html/glennbio.htm)
The official NASA biography of astronaut John Glenn.
(www.nationalaviation.org/enshrinee/glenn.html)
Lengthy biography of Glenn's career, including a 1998 NASA press release.

Goddard, Robert H.

(www.allstar.fiu.edu/aero/goddard.htm)
An informative biography.
(www.clarku.edu/offices/library/archives/GoddardBio.htm)
A biographical chronology.
(www.gsfc.nasa.gov/gsfc/service/gallery/fact_sheets/general/goddard/goddard.htm)
A lengthy NASA biography, including Goddard's historic "firsts."
(www.nationalaviation.org/enshrinee/goddardrobert.html)
An informative biography of Goddard's career.
(www.time.com/time/time100/scientist/profile/goddard.html)
Lengthy biographical article from *Time* magazine Web site.

Hughes, Howard

(www.aerofiles.com/bio_h.html)
Brief biography of Hughes.
(www.myprimetime.com/work/ge/hughesbio/index.shtml)
An informative biography.
(www.nationalaviation.org/enshrinee/hughes.html)
Brief biography of Hughes's aviation career.

Johnson, Amy

(www.nasm.edu/nasm/aero/women_aviators/amy_johnson.htm)
A very brief biography with photo.
(www.ninety-nines.org/johnson.html)
A brief but informative biography.
(www.pbs.org/wgbh/amex/flygirls/peopleevents/pandeAMEX04.html)
Informative biography of Johnson's career.
(www.raf.mod.uk/history/amyjohnson.html)
An extensive three-part biography of Britain's "Queen of the Air."

Langley, Samuel Pierpont

(aviation-history.com/early/langley.htm)
Brief biography of Langley's career, with several photos.
(earthobservatory.nasa.gov/Library/Giants/Langley)
Extensive four-part biography, including links and references.
(hawaii.psychology.msstate.edu/invent/i/Langley/Langley.html)
Brief biography of Langley's career.
(www.nationalaviation.org/enshrinee/langley.html)
Brief biography of Langley's career.

Leonardo da Vinci

(www.devine-ent.com/shows/inventors/davinci-bio.shtml)
Informative, somewhat brief biography.
(www.flight100.org/history/davinci.html)
Biography focusing on da Vinci's interest in flight.
(galileo.imss.firenze.it/news/mostra/6/)
Biographical site with sections devoted to engineering and da Vinci's studies of flight.
(www.webgod.net/leonardo/Flight/)
A listing of images of da Vinci's flight-related sketches.

Lilienthal, Otto

(home.t-online.de/home/LilienthalMuseum/ehome.htm)
Sponsored by the Otto Lilienthal Museum, this site contains a short, chronological biography, a detailed annotated bibliography, and several galleries of photos.
(www.nasm.edu/nasm/aero/aircraft/lilienth.htm)
Biography focusing on Lilienthal's glider designs.
(www.wam.umd.edu/~stwright/WrBr/inventors/Lilienthal.html) A brief biography of Lilienthal's career.

Lindbergh, Charles A.

(www.aerofiles.com/bio_l.html)
An informative biography with lengthy bibliography.
(www.firstflight.org/shrine/charles_lindbergh.html)
A brief biography of Lindbergh's career.
(www.geocities.com/CapeCanaveral/Hangar/5460/lindbergh.html)
Informative biography from a personal aviation buff's Web site.
(www.lindberghfoundation.org)
The Web site of the Charles A. and Anne Morrow Lindbergh Foundation.
(www.nationalaviation.org/enshrinee/lindberghch.html)
A lengthy biography of Lindbergh's career.
(www.time.com/time/time100/heroes/profile/lindbergh01.html)
A lengthy biographical article from *Time* magazine's Web site, written by Lindbergh's youngest child.

Markham, Beryl

(www.leicesteroverseas.com/Beryl_Markham.htm)
A lengthy, informative biography of Markham.
(www.xs4all.nl/~blago/planewriting/bios.html)
Brief biography mixed between other pilot biographies on the same page.

Mitchell, Billy

(www.aerofiles.com/bio_m.html)
Very brief biography with a lengthy bibliography of related titles.
(www.nationalaviation.org/enshrinee/mitchell.html)
An informative biography of Mitchell's career.
(www.thehistorynet.com/aviationhistory/articles/1997/0997_text.htm)
A lengthy biography of Mitchell's life and career.

Montgolfier brothers

(www.allstar.fiu.edu/aero/montgolgiers.htm)
A very brief biography of the brothers' career.
(www.newadvent.org/cathen/10541a.htm)
A brief biography of Joseph-Michel Montgolfier.

Oberth, Hermann

(www.flight100.org/history/oberth.html)
Brief biography of Oberth.
(www.kiosek.com/oberth)
A lengthy, informative biography, including extensive Web site links to related information.

Piccard, Auguste
(www.allstar.fiu.edu/aero/piccard.htm)
An informative biography of Piccard includes biographical information on his twin brother, Jean.

Post, Wiley
(www.acepilots.com/post.html)
An extensive biography of Post's life and career, including partial logbook entries.
(www.centennialjournal.com/jan2001stories/TrailblazerWileyPost.htm)
An informative and lengthy biography.
(www.geocities.com/CapeCanaveral/Hangar/5460/post.html)
Informative and brief biography of Post from a personal aviation buff's Web site.
(www.nationalaviation.org/enshrinee/post.html)
Brief biography of Post's career.

Prandtl, Ludwig
(www.eng.vt.edu/fluids/msc/prandtl.htm)
Biography of Prandtl's career.
(mech.postech.ac.kr/fluidmech/history/Prandtl.html)
Brief biography of Prandtl's career.

Reitsch, Hanna
(avstop.com/History/AroundTheWorld/German/hanna.html)
Brief biography of Reitsch's career.
(www.geocities.com/CapeCanaveral/Hangar/5460/hanna.html)
Informative biography from a personal aviation buff's Web site.

Richthofen, Manfred von
(www.allstar.fiu.edu/aerojava/richthofen.htm)
Brief biography of Richthofen's career.
(www.briggsenterprises.com/bluemax)
Lengthy, informative biography that includes a chart of Richthofen's numerous air victories.
(www.richthofen.com)
An on-line version of Richthofen's 1917 book *Der Rote Kampfflieger* (The red fighter pilot), based on a 1918 English translation.
(www.worldwar1.com/biocmvr.htm)
A very brief biography.

Rickenbacher, Eddie
(www.lib.auburn.edu/archive/flyhy/101/eddie.htm)
Extensive biography of Rickenbacker's life and career.
(www.nationalaviation.org/enshrinee/rickenbacker.html)
Lengthy biography of Rickenbacker's career.
(www.thehistorynet.com/aviationhistory/articles/1999/0199_text.htm)
Informative, lengthy biography of Rickenbacker's life and career.

Ride, Sally K.
(www.astronautix.com/astros/ride.htm)
A brief biography and log of Ride's flights.
(www.chron.com/content/interactive/space/archives/87/870921.html)
A lengthy article about Ride's departure from NASA.
(www2.lucidcafe.com/lucidcafe/library/96may/ride.html)
A brief biography of Ride's life and career, including a bibliography and related links.
(www.nasm.edu/nasm/aero/women_aviators/sally_ride.htm)
A brief biography with photo.
(quest.arc.nasa.gov/people/bios/women/sr.html)
An informative NASA biography of Ride.

Rutan, Dick
(www.dickrutan.com)
Rutan's personal Web site, containing extensive biographical information about his personal life, travels, and career experiences.

Saint-Exupéry, Antoine de
(www.pbs.org/kcet/chasingthesun/innovators/aexupery.html)
A brief biography of Saint-Exupéry's aviation career.
(www.villastjean.com/saint-exupery/Biography.htm)
A very brief biography of Saint-Exupéry.

Santos-Dumont, Alberto
(educate.si.edu/scitech/impacto/graphic/aviation/alberto.html)
A lengthy biography of Santos-Dumont, focusing on his aviation career.
(www.firstflight.org/shrine/santos_dumont.html)
A brief biography of Santos-Dumont's career.
(www.maria-brazil.org/SDumont.htm)
Informative biography of Santos-Dumont's life and career.

Shepard, Alan
(www.astronautix.com/astros/shepard.htm)
An extensive biography and log of Shepard's flights.

(www.astronauts.org/discover_heroes/shepard.htm)
A brief biography of Shepard.
(www.jsc.nasa.gov/pao/shepard/)
NASA site devoted to Shepard includes a biography of his life and career, a photo gallery, and video clips.
(www.nationalaviation.org/enshrinee/shepard.html)
An informative biography of Shepard's career.
(www.space.com/news/spacehistory/shepard_anniversary_010504-1.html)
A lengthy and informative article about Shepard's place in the history of spaceflight.
(www.time.com/time/search/article/0,8599,14136,00.html)
A brief obituary article from *Time* magazine's Web site.

Sikorsky, Igor

(www.aerofiles.com/bio_s.html)
A lengthy biography with a bibliography of related titles.
(www.nationalaviation.org/enshrinee/sikorsky.html)
A lengthy biography of Sikorsky's career.
(www.sikorskyarchives.com)
The online Igor I. Sikorsky Historical Archives include a listing of Sikorsky's honors and awards, a photo gallery, and numerous biographical and technical articles.

Tereshkova, Valentina

(www.astronautix.com/astros/terhkova.htm)
A relatively detailed biography of Tereshkova and a log of her flights.
(gos.sbc.edu/t/tereshkova.html)
An interview *Russia Magazine* conducted with Tereshkova.
(www.nasm.edu/nasm/aero/women_aviators/valentina_tereshkova.htm)
A very brief biography.
(www.nauts.com/bios/cosmonaut/tereshkova.html)
A brief biography of Tereshkova's career.

Tsiolkovsky, Konstantin

(www.hq.nasa.gov/office/pao/History/sputnik/kon.html)
A brief biography of Tsiolkovsky's career.

Verne, Jules

(www.applebookshop.co.uk/author/verne.htm)
A lengthy and informative biography.
(www.kirjasto.sci.fi/verne.htm)
Lengthy biography with an extensive bibliography and further readings section.

Wright brothers

(www.aerofiles.com/bio_w.html)
A biography with a lengthy bibliography.
(www.hfmgv.org/histories/wright/wrights.html)
An interesting biography on the lives and careers of the Wright brothers, along with an informative chronology of events in their lives.
(www.lucidcafe.com/library/95aug/wright.html)
Brief account of Orville Wright's life and career that includes related Web site links.
(www.lucidcafe.com/library/96apr/wrightw.html)
A brief biography of the life and career of Wilbur, includes related Web site links.
(www.pbs.org/wgbh/aso/databank/entries/btwrig.html)
A brief biography of the brothers' lives.
(www.time.com/time/time100/scientist/profile/wright.html)
A lengthy article from *Time* magazine's Web site.
(www.wam.umd.edu/~stwright/WrBr/Wrights.html)
A brief biography focusing on the brothers' personal lives.

Yeager, Chuck

(www.acepilots.com/usaaf_yeager.html)
A lengthy biography of Yeager's life and career.
(www.astronautix.com/astros/yeager.htm)
A detailed biography of Yeager and a log of his flights.
(www.chuckyeager.com)
An unofficial Yeager fan site includes chronological biography, photo gallery, and several video clips.
(www.hq.nasa.gov/office/pao/History/x1/yeagphoto.html)
A gallery of Yeager-related photos.
(www.nationalaviation.org/enshrinee/yeager.html)
An informative biography of Yeager's career.

Yeager, Jeana

(www.nasm.edu/nasm/aero/women_aviators/jenna_yeager.htm)
A very brief biography with photo.

Zeppelin, Ferdinand von

(www.allstar.fiu.edu/aero/vzeppelin.htm)
A brief biography.
(www.uni-konstanz.de/FuF/Philo/Geschichte/Zeppelin/english/bio.htm)
A short but informative biography, with accompanying photos.

SPACEFLIGHT AND SPACE EXPLORATION

Encyclopedia Astronautica
(www.astronautix.com)

This highly organized Web site is packed with information and articles concerning rockets, spacecraft, space programs, and biographies of people, past and present, associated with space exploration.

Jet Propulsion Laboratory
(www.jpl.nasa.gov)

The Jet Propulsion Laboratory is NASA's lead center for robotic exploration in space. Contains links to images of spacecraft, NASA reports and publications, and other spaceflight Web sites.

Marshall Space Flight Center
(www.spacetransportation.com)

This site is for the Marshall Space Flight Center in Huntsville, Alabama, NASA's lead center for space transportation systems development. The site contains flight center research, news releases, and a gallery of images. See also: (www.msfc.nasa.gov)

NASA Quest
(quest.arc.nasa.gov/space/index.html)

Designed specifically for the kindergarten through twelfth grade classroom, this NASA Quest site allows Web browsers to learn about the men and women of the NASA space program.

Space and Tech
(www.spaceandtech.com)

This Web site is run by Andrews Space and Technology, a private company focused on providing highly technical engineering, product development, and research for the space industry. The site displays a calendar of upcoming launches, a comprehensive archive of news articles, and a short list of Webcam sites.

Space.Com
(www.space.com)

This multimedia company, based on the Internet, offers news, research, and educational material on space and space-related content as well as on-line entertainment, games, and software.

SpaceDaily
(www.spacedaily.com)

SpaceDaily is a comprehensive, up-to-date Web site of news articles and information on space, space exploration, and related topics.

TYPES OF CRAFT AND TYPES OF FLIGHT

Airship: The Home Page for Lighter-Than-Air Craft
(spot.colorado.edu/~dziadeck/airship.html)

A personal site dedicated to lighter-than-air craft, specifically airships (sometimes referred to as blimps). The site contains answers to frequently asked questions, links to similar sites, and a listing of manufacturers.

Boeing
(www.boeing.com/defense-space/military/af1)

This Web page devoted to Boeing-manufactured *Air Force One* contains a fact sheet, photos, and specifications of the presidential aircraft.

Evergreen Aviation Museum
(www.sprucegoose.org)

Howard Hughes's *Spruce Goose* is housed in the Evergreen Aviation Museum, and this is that organization's Web site. The site lists a brief history of the aircraft, design specifications, and photographs.

Helicopter History Site
(www.helis.com/default)

A site dedicated to the history of helicopters. It contains multimedia files of sound and images, a listing of helicopter manufacturers, and a chat room.

Hot Air Balloons USA
(www.hot-airballoons.com)

This site lists ballooning companies across the United States, with information and links to those companies' own Web sites. Also included are answers to frequently asked questions about ballooning.

Kitez.Com
(www.kitez.com)

A very simple Web site, this page features a list of kite topics such as plans, manufacturers, places to fly kites, and kite clubs. All categories list numerous links to related sites.

National Air and Space Museum
(www.nasm.edu/galleries/gal100/stlouis.html)

The *Spirit of St. Louis* page on the Smithsonian Institution's National Air and Space Museum's Web site documents Charles A. Lindbergh's historic flight, lists the design specifics of the aircraft, and provides images.

National UFO Reporting Center
(www.nwlink.com/~ufocntr)

This Web site of the National UFO Reporting Center is "dedicated to the collection and dissemination of objective UFO Data." The site maintains a database of reported sightings, several in-depth reports, and a telephone hotline number for reporting UFO sightings.

Official Web Site of Brigadier General Paul W. Tibbets (USAF Ret.)
(www.theenolagay.com)
This site features detailed information about and photos of Tibbets, the Enola Gay, and the August 6, 1945, dropping of the atomic bomb on Hiroshima, Japan.

Space and Tech
(www.spaceandtech.com/spacedata/rlvs/rlvs.shtml)
Part of a larger space-related Web site by Andrews Space and Technology, this section gives an overview of reusable launch vehicles, as well as listing several specific vehicles and providing a summary of each.

U.S. Navy
(www.chinfo.navy.mil/navpalib/ships/carriers)
This Web site gives information about the United States Navy's aircraft carriers and includes a listing of carriers with specifications and photos, and a history of the aircraft carrier.

Mark Miller

Organizations and Agencies

Air Combat Command. The Air Combat Command was activated on July 1, 1992, as part of the Department of Defense reorganization. The responsibilities of the Strategic Air Command (SAC) were divided between the Air Combat Command and the Air Mobility Command. The Air Combat Command controls the bulk of the Air Force's fighting strength. An interesting publication on the ACC is *ACC Bomber Triad: The B-52's, B-1's, and B-2's of Air Combat Command* (1999), by Don Logan. *Contact information:* (www.acc.af.mil).

Air Force, U.S. The branch of the U.S. military whose mission is to defend the country through control of the airspace above the United States as well as through the exploitation of space and space-based technologies. There are more than 700,000 personnel employed by the Air Force including 355,00 active-duty individuals. Of these personnel, approximately 12,000 are pilots. The four largest categories of pilots in the Air Force are fighter pilots, airlift pilots, tanker pilots, and bomber pilots. Air Force pilots are also utilized in training, special operations, and surveillance roles. The Air Force became a separate branch of the U.S. military in 1947. The Air Force Academy is located in Colorado Springs, Colorado. There are a number of books on the Air Force and its key figures. Ron Dick has published a general history entitled *American Eagles: A History of the United States Air Force* (1997). *Contact information:* U.S. Air Force HQ, Randolph Air Force Base, TX 98150-4527 (www.af.mil).

Air Transport Association (ATA). The Air Transport Association was founded in 1936 by a group of fourteen U.S. airlines and continues to be the main trade organization for the large U.S. airlines. ATA member airlines account for over 93 percent of the total passengers enplaned in the United States. The purpose of the ATA is to promote the air transportation industry, encourage safe and cost-effective operations, and advocate industry positions before governmental agencies and the public. Its Web site contains valuable information and statistics on air travel in the United States. The association also sponsors various events and forums throughout the country on aviation-related issues. *Contact information:* Air Transport Association of America, 1301 Pennsylvania Avenue NW, Suite 1100, Washington, DC 20004; Ph.: (202) 626-4000 (www.air-transport.org).

Aircraft Owners and Pilots Association (AOPA). AOPA was originally founded in 1939. Its mission is to keep general aviation safe, fun, and affordable. To this end, they work to support programs and legislation that encourage safety, aircraft ownership and manufacturing, and maintain general aviation access to landing facilities. The membership includes more than 360,000 pilots and aircraft owners. The International Aircraft Owners and Pilots Association was formed in 1962 and is associated with the International Civil Aviation Organization. This organization provides general aviation with a voice in matters of international aviation. *Contact information:* 421 Aviation Way, Frederick, MD 21201; Ph.: (301) 695-2000 (www.aopa.org).

Airports Council International. The Airports Council International was established in 1991 to help foster cooperation among airports. The council's membership includes most major U.S. and international airports. *Contact information:* ACI, P.O. Box 16, 1215 Geneva 15 Airport, Geneva, Switzerland; Ph.: +41.22 717-8585 (www.airports.org).

Army pilots, U.S. The U.S. Army maintains a standing force of just under 500,000 soldiers with an additional 500,00 Army Reserve and 350,000 Army National Guard troops as backup in times of need. The Army maintains ten active divisions, which include the Eighty-second Airborne Division. The Army Air Corps was established in 1907 to explore the military use of aircraft and dirigibles. During World War I, the Army Air Corps proved the potential of aircraft in combat. However, it was during World War II that air power became a significant force in the conduct of war. In 1947, the Army Air Corps was officially split from the Army to become the United States Air Force. This did not end the involvement of the Army in aviation, as the Eighty-second Airborne, stationed at Fort Bragg, North Carolina, can attest. An excellent book on the Army Air Force is *U.S. Army Air Forces in World War II: Combat Chronology* (1991), by Kit Carter. *Contact information:* (www.goarmy.com) for recruitment information or (www.army.mil) for general information.

Black Sheep Squadron. The Black Sheep Squadron is the name of a unit of Marine pilots who fought during World War II. They were commanded by Major Gregory "Pappy" Boyington, who was credited with shooting down twenty-eight enemy aircraft, more than any other Marine pilot. The Black Sheep are famous for their offer to shoot down an enemy aircraft for every major-league baseball cap they received. Boyington was shot down in January, 1944, and spent the remainder of the war in a prison camp. An excellent book on the Black Sheep Squadron is *Once They Were Eagles: The Men of the Black Sheep Squadron* (1986), by Frank Walton.

Blue Angels. This is the popular name for the U.S. Navy Flight Demonstration Team. The Blue Angels were created in 1946 by Admiral Chester W. Nimitz, the Chief of Naval Operations, and have now performed their aerial show for more than 374 million people worldwide. They are currently based out of Forrest Sherman Field, Naval Air Station, Pensacola, Florida. *Contact information:* Navy Flight Demonstration Team, 390 San Carlos Road, Suite A, Pensacola, FL 32508; Ph.: (850) 452-BLUE (www.blueangels.navy.mil).

Bureau of Transportation Statistics. The Bureau of Transportation Statistics was established in 1991 by the Intermodal Surface Transportation Efficiency Act to collect, analyze, and report data on national transportation and is housed in the Department of Transportation. Its Web site contains facts, figures, and statistics about various forms of transportation including aviation. *Contact information:* Bureau of Transportation Statistics, 400 Seventh Street SW, Room 3430, Washington, DC 20590; Ph.: (800) 853-1351 (www.bts.gov).

Coast Guard pilots, U.S. The U.S. Coast Guard traces its beginnings back to the Revenue Cutter Service created in 1790. At this time, the service was part of the Department of the Treasury and was stationed primarily at U.S. ports of entry. With more than two hundred years of continuous service, the Coast Guard is the oldest, continuous seagoing service in the United States. Its mission today includes the regulation of marine and boating safety including certification and inspection as well as law enforcement and search and rescue activities. The Coast Guard was placed under the Department of Transportation when that department was created in 1966, but during times of war, the Coast Guard answers to the Secretary of the Navy. Coast Guard personnel have participated in all modern military actions. To carry out its various missions, the Coast Guard maintains a fleet of more than two hundred aircraft, including both fixed- and rotor-wing craft. There are several interesting books on the Coast Guard, including *Wonderful Flying Machines: A History of the U.S. Coast Guard Helicopter* (1996), by Barrett Thomas Beard and *History of the United States Coast Guard Aviation* (1989), by Arthur Pearcy. *Contact information:* U.S. Coast Guard, 4200 Wilson Boulevard, Suite 450, Arlington, VA 22203; Ph.: 1-800-GET-USCG (www.uscg.mil).

Council on Aviation Accreditation (CAA). The Council began in 1974 as the Academic Standards Committee of the University Aviation Association. It adopted its present name in 1988 and issued the Academic Standards Manual for Aviation Programs. The CAA is the main body accrediting universities and schools with programs related to aviation. *Contact information:* CAA, 3410 Skyway Drive, Auburn, AL 36830; Ph.: (934) 844-2432 (www.caaaccreditation.org).

Department of Transportation (DOT). The Department of Transportation is an executive department of the U.S. government. It was established by the Department of Transportation Act of 1966 for the purpose of developing national transportation policies and programs. The Coast Guard, the Federal Aviation Administration, the Federal Railroad Administration, and several other operating units are all housed under the Department. An excellent history of the department is *U.S. Department of Transportation: A Reference History* (1998), by Donald R. Whitnah. *Contact information:* 400 Seventh Street SW, Washington, DC 20590; Ph.: (202) 366-4000 (www.dot.gov).

Eurocontrol. The European Organization for the Safety of Air Navigation was founded in 1960 to oversee air traffic control in the upper airspace of its member nations. It currently has thirty European members. One of the key concerns for the organization is airspace congestion in Europe and the consequent flight delay this causes at European airports. *Contact information:* Headquarters-Brussels, Rue de la Fusee 96, B-1130, Brussels, Belgium; Ph.: +32.2.729-9011 (www.eurocontrol.be).

European Commission-Directorate of Energy and Transportation. This is the directorate of the European Union that deals with regulatory issues relating to aviation and aerospace. The Commission itself is the administrative arm of the European Union. The Web site contains information on the issues relating to aviation matters such as environmental restrictions, safety, and foreign access. The Directorate of Competition oversees issues of mergers and acquisitions in the aviation and aerospace industries. *Contact information:* (www.europa.eu.int). A directory of other locations is available at this site.

Federal Aviation Administration (FAA). The FAA is the agency of the U.S. government charged with controlling the use of U.S. airspace. Its responsibilities include the regulation of air commerce, certification of aircraft, development and operation of air traffic control and air navigation, and the promotion of a national system of airports. The Federal Aviation Agency was created in 1958 to promote air safety and changed its name to the Federal Aviation Administration in 1967 when it became part of the Department of Transportation. The FAA Web site contains information on aviation statistics as well as the database on aviation safety. There are a number of publications about the FAA. Two examining the historical development of the FAA are *Flight Check: The Story of FAA Flight Inspection* (1993), by Scott A. Thompson; *Safe, Separated, and Soaring: A History of Federal Civil Aviation Policy, 1961-1972* (1980), by Richard J. Kent; and *Troubled Passage: The FAA During the Nixon-Ford Term 1973-1977* (1987), by Edmund Preston. *Contact information:* 800 Independence Avenue SW, Washington, DC 20591; Ph.: (800) 322-7873 (www.faa.gov).

Flying Tigers. This is the popular name for the American Volunteer Group that served with the Chinese Air Force under Claire Chennault. Chennault joined the U.S. Army Air Corps during World War I and pioneered aviation pursuit tactics as well as developing the idea of the paratrooper. He resigned from the Army in 1937 and became the aviation advisor to the Chinese government. The pilots fought in both China and Burma with the Chinese forces under the command of Chiang Kai-shek. The Flying Tigers became famous for their defense of the Burma Road, a Chinese supply route from India. One of the most famous pilots associated with the Flying Tigers was “Pappy” Boyington, who later went on to command the Black Sheep Squadron. Chennault was recalled to American service during World War II and given the rank of brigadier general. The Flying Tigers were also inducted into the regular U.S. military in July, 1942. After World War II, Chennault returned to China to organize a commercial airline. His autobiography, *Way of a Fighter*, was published in 1949. Other books on the Flying Tigers include *Flying Tigers: Claire Chennault and the American Volunteer Group* (1991), by Daniel Ford, and *Chennault: Giving Wings to the Tigers* (1987), by Martha Byrd. *Contact information:* (www.flyingtigersavg.com).

International Air Transport Association (IATA). Prior to the outbreak of World War II in Europe, IATA was concerned solely with aviation issues in Europe. Following the end of the war, IATA expanded worldwide to serve its mission of promoting safe, economical international transport through the collaboration among the world’s airlines and with the newly created International Civil Aviation Organization. IATA membership is composed of international air carriers. In 1979, the U.S. government called on IATA to show that it was not an illegal cartel subject to U.S. antitrust law. As a result, U.S. airlines were required to withdraw from the IATA traffic conferences that set international fares. Today, IATA focuses mainly on improving aviation safety through education and training. Its Web site contains valuable information on international travel as well as links to other aviation sites and a listing of the IATA’s educational programs and materials. The IATA published its history in *IATA, The First Six Decades: The Development of the Air Transport Industry Since 1919* (1986). *Contact information:* IATA, Route de l’Aeroport, P.O. Box 672, 1215 Geneva 15 Airport, Geneva, Switzerland; Ph.: +41 22 799 25 25 (www.iata.org).

International Civil Aviation Organization (ICAO). The International Civil Aviation Organization was born in 1944 at what has come to be called the Chicago Convention. The Chicago Convention met in early 1944 to discuss the post-war future of international aviation. The ICAO did not officially come into existence until 1947, when it was ratified by twenty-six nations. At that time, it also became a specialized agency of the newly created United Nations. Membership is open to representatives from all nations involved in international aviation. The ICAO’s mission is to develop the principles and techniques of air navigation and transportation including the development of air traffic control systems, airports, and safety rules and procedures. In 1991, Eugene Sochor published a book on the early history and mission of the ICAO, entitled *The Politics of International Aviation*. The book is a fascinating look at the political forces that have shaped international aviation and the organizations that oversee them. *Contact information:* International Civil Aviation Organization, Public Information Office, 1000 Sherbrooke Street West, Montreal, Quebec, Canada, H3A 2R2 (www.icao.int).

International Women’s Air and Space Museum. The museum was established in 1986 to celebrate the achievements of women in aviation. The museum houses historical artifacts and displays detailing the contributions of women, such as Katherine Wright, the sister of Wilbur and Orville Wright; Amelia Earhart, the first woman to fly across the Atlantic; and Valentina

Tereshkova, the first woman in space. *Contact information:* International Women's Air and Space Museum, Burke Lakefront Airport, 1501 North Marginal Road, Cleveland, OH 44114; Ph.: (216) 623-1111 (www.iwasm.org).

Johnson Space Center. The Johnson Space Center was established in 1961 and continues to be the main NASA center for the selection and training of astronauts for the U.S. space program. Located in Houston, Texas, the center is open to the public for tours of its facilities. A good publication on air and space museums is *Kitty Hawk to NASA: A Guide to U.S. Air and Space Museums and Exhibits* (1991), by Michael Morlan. *Contact information:* Johnson Space Center, 2101 BASAL Road 1, Clear Lake, TX; Ph.: (281) 483-0123 (www.jsc.nasa.gov).

Kennedy Space Center. The Kennedy Space Center is located at Cape Canaveral, Florida, and is the main launch site for the crewed space shuttle program as well as the launch of uncrewed vehicles. The center is open to the public for tours of its facilities as well as viewing of space shuttle launches. The Web site contains information on the facilities and launch schedule. A history of the Kennedy Space Center is contained in *Gateway to the Moon: Building the Kennedy Space Center Launch Complex* (2001), by Charles D. Benson and William B. Faherty. A good general publication on air and space museums is *Kitty Hawk to NASA: A Guide to U.S. Air and Space Museums and Exhibits* (1991), by Michael Morlan. *Contact information:* Spaceport, Kennedy Space Center, FL 32897; Ph.: (321) 449-4400 (www.ksc.nasa.gov).

Luftwaffe. Luftwaffe literally means "air weapon" in German and is the popular name for the German air force. The Luftwaffe was officially formed in 1935, although it had existed in secret since 1919, when the Treaty of Versailles ended World War I with a provision banning Germany from having an air force. During its years of secrecy, the Luftwaffe experimented with a number of aviation innovations, which were put to the test during World War II. Although the Allied forces had numerical superiority over the Luftwaffe, the Luftwaffe achieved some impressive victories during the war. Under the command of Hermann Göring, the Luftwaffe was also in charge of Germany's antiaircraft defenses. There are numerous books and Web sites dedicated to the history, insignia, and aircraft of the Luftwaffe. Two recent publications are *Luftwaffe Bomber Aces: Men, Machines, and Methods* (2001), by Mike Spiek, and *Luftwaffe Album: Fighters and Bombers of the German Air Force, 1933-1945* (1999), by Joachim Dressel.

Marine pilots, U.S. The U.S. Marine Corps is composed of 174,000 active-duty and 42,000 reserve personnel. The Marines are capable of conducting a number of missions, including amphibious warfare, rapid deployment, and land support for the U.S. Navy. The Marine Corps is organized into three divisions and three air wings. The main combat force of each division is the Marine Expeditionary Unit, which is a self-contained naval, air, and ground task force capable of rapid response. Only about thirty countries in the world maintain a marine corps, and only the U.S. Marine Corps is a truly independent fighting force. The Continental Congress authorized the formation of two battalions of marines in 1775. The Marines were reactivated in 1798. The first Marine aviation missions were flown in support of the Marine Corps troops in World War I. Marine Corps officers earn their commissions at either the United States Naval Academy, Officer Candidate School or from a university offering a Reserve Officer Training Corps (ROTC). Marine aviators attend the Aviation Officer Candidate School at the Naval Air Station in Pensacola, Florida. Marine aviators fly either helicopters or fixed-wing aircraft and are mostly based off of the Navy's twelve aircraft carriers. A good history of the U.S. Marines is found in *History of the U.S. Marines* (1994), by Jack Murphy. *Contact information:* (www.marines.com).

National Advisory Committee for Aeronautics (NACA). The National Advisory Committee for Aeronautics was the predecessor of the National Aeronautics and Space Administration (NASA). It was created in 1915, twelve years after the Wright brothers flew at Kitty Hawk. Its mission was to direct and supervise the scientific study of the problems of flight. The NACA was disbanded in 1958. Frank W. Anderson, Jr. wrote a history of NACA called *Orders of Magnitude: A History of NACA and NASA* (1976). Information on some of its actions and recommendations is available at (www.naca.larc.nasa.gov).

National Aeronautics and Space Administration (NASA). The National Aeronautics and Space Administration was established in 1958 to conduct research into problems of flight within and outside the earth's atmosphere. This has included research activities relating to the development and design of space and atmospheric vehicles as well the exploration of space using crewed and uncrewed craft. Recent publications on NASA include *Infinite Journey: Eyewitness Accounts* *of NASA and the Age of Space* (2000), by William F. Burrows, and *NASA and the Space Industry* (1999), by Joan Lisa Bromberg. *Contact information:* NASA HQ, 300 E Street SW, Washington, DC 20546 (www.nasa.gov).

National Air and Space Museum. The Smithsonian Institution's National Air and Space Museum contains the largest collection of historic air and spacecraft in the world, including the 1903 Wright *Flyer*, the *Spirit of St. Louis*, and the Apollo 11 Command Module. The museum also has many more artifacts housed at the Paul E. Garber Preservation, Restoration and Storage Facility in Suitland, Maryland. An excellent publication on air and space museums is *Kitty Hawk to NASA: A Guide to U.S. Air and Space Museums and Exhibits* (1991), by Michael Morlan. The Museum itself has published a guide called *Aircraft of the National Air and Space Museum* (1991). *Contact information:* National Air and Space Museum, Seventh and Independence Avenue SW, Washington, DC 20560; Ph.: (202) 357-2700 (www.basm.si.edu).

National Business Aircraft Association (NBAA). This organization is the principle representative of the business aviation industry before Congress, the U.S. government, and its regulatory agencies. The NBAA was established in 1947 to increase the safety and efficiency of business aviation. The NBAA represents more than 4,700 member companies and provides technical expertise, information, and educational forums. Recently, the NBAA celebrated its fiftieth anniversary by publishing *NBAA's Tribute to Business Aviation* (1997), by Robert A. Searles and Robert B. Parke. *Contact information:* NBAA, 1200 Eighteenth Street SW, Suite 400, Washington, DC 20036; Ph.: (202) 783-9000 (www.nbaa.org).

National Mediation Board. The National Mediation Board is composed of three individuals appointed by the U.S. president. Its primary responsibility is to mediate labor disputes under the Railway Labor Act involving rates of pay, changes in work rules, or changes in working condition when the parties involved have failed to reach a settlement. U.S. airlines are covered under this act. *Contact information:* 1301 K Street NW, Washington, DC 20572; Ph.: (202) 692-5019 (www.nmb.gov).

National Transportation Safety Board (NTSB). The National Transportation Safety Board is an autonomous agency of the U.S. government established in 1975. It investigates transportation accidents and makes recommendations to both government agencies and the transportation industry on safety measures and practices. The NTSB's Web site contains information on accident investigation and recommendations, as well as general transportation information. *Contact information:* 490 L'Enfant Plaza SW, Washington, DC 20594; Ph.: (202) 314-6000 (www.ntsb.gov).

Navy pilots, U.S. The history of the navy dates back to the Continental Navy, organized in 1775 to attack British lines of communication and seize transport ships. The Continental Navy was disbanded after the Revolutionary War. In 1798, the United States Navy was officially created by an act of Congress. Currently, the U.S. Navy has about 380,000 active-duty personnel, including a number of pilots. These pilots either serve on one of the Navy's twelve aircraft carriers or at one of the land-based naval air stations that support ocean deployment. Each aircraft carrier is capable of supporting 85 to 90 aircraft including both fixed-wing and rotor craft. The land-based forces include aircraft designed to detect and destroy submarines, track surface ships, transport troops and supplies, and refuel aircraft. The Navy maintains a fleet of approximately 6,000 aircraft. Most naval pilots either attended the U.S. Naval Academy at Annapolis or one of the ROTC programs located on civilian U.S. campuses. Pilots then attend the Aviation Officer Candidates School at the Naval Air Station in Pensacola, Florida. An interesting publication on the Navy is *History of the Navy* (1992), by Robert William Love. *Contact information:* (www.navy.mil).

Ninety-nines. This is the popular name for the International Organization of Women Pilots, which was founded in 1929. The first president of the organization was the famous aviator Amelia Earhart, the famous female aviator who disappeared over the Pacific during an attempt to fly around the world. The organization she first headed now has more than 6,500 members worldwide and continues to promote aviation and careers for women in aviation-related fields. The Ninety-nines published *History of the 99's* (1997). *Contact information:* The 99's, Box 965, 7100 Terminal Drive, Oklahoma City, OK 73159; Ph.: (800) 994-1929 (www.ninetynines.org).

Regional Airline Association. The Regional Airline Association is a U.S. organization of regional air carriers similar to the Air Transport Association. Most regional carriers in the U.S. are members. The association's Web site and publications contain valuable information on the operating statistics of the regional airline industry including major regional airports, total enplaned passengers, and average departures. *Contact information:*

Regional Airline Association, 1200 Nineteenth Street NW, Suite 300, Washington, DC 20036; Ph.: (202) 857-1170 (www.raa.org).

Royal Air Force (RAF). The history of the Royal Air Force dates back to the formation of the Royal Flying Corp (RFC) in 1912. Two years later the naval wing of the flying corps separated from the RFC. Conflict in the United Kingdom over aviation resources led to the passage of a bill creating the air force in April, 1918. The Royal Air Force (RAF) became the first independent air force in the world. The RAF distinguished themselves during the Battle of Britain in World War II. The Battle of Britain was the first major campaign to be fought between two air forces. The integrated air defense system utilized by the RAF helped to insure the RAF's ultimate success over the German Luftwaffe. The two main aircraft flown by the RAF during this period were the Hurricane and the Spitfire, which continue to be classic collectibles and favorites at air shows around the world. The efforts of the RAF during World War II have been chronicled in numerous books and movies. The RAF continues its mission to protect and defend the United Kingdom and has participated in major actions in the Arabian Gulf and Eastern Europe. There are numerous books on the RAF and the Battle of Britain, including *Spitfire: Flying Legend* (1996), by John Dibbs; *Eagle Squadron: Yanks in the RAF, 1940-1942* (1992), by Vern Haugland; and *Nation Alone: The Battle of Britain, 1940* (1989), by Arthur Ward. *Contact information:* Royal Air Force, Aberdeen AFCO, 63 Belmont Street, Aberdeen, UK, AB101JS; Ph.: 0-1224 6402251 (www.raf.mod.uk).

Soaring Society of America. The Soaring Society was established in 1932 to promote soaring and now contains more than 16,000 members worldwide. In addition to educational and informational activities, they sponsor a national soaring contest each year. *Contact information:* Soaring Society of America, P.O. Box 2100, Hobbs, NM 88241; Ph.: (505) 392-1177 (www.ssa.org).

Strategic Air Command (SAC). The Strategic Air Command was established in 1946 to organize, train, equip, administer, and prepare the strategic air forces for combat. Until 1992, when it was replaced in the Department of Defense reorganization by the Air Combat Command and the Air Mobility Command, SAC controlled most U.S. nuclear weapons and played a key role in the U.S. nuclear strategy. The so-called three legs of the nuclear defense strategy included land-based, bomber-based, and submarine-based nuclear weapons. SAC was officially in command of the first two legs. The Strategic Air Command was headquartered at Offutt Air Force Base. Following the collapse of the Soviet Union, the United States reviewed its overall strategy in regard to military strength and deployment. This review led to the Department of Defense reorganization that replaced SAC. Several recent publications on SAC are *SAC: Evolution and Consolidation of Nuclear Forces, 1945-1955* (1996), by William S. Borgiasz, and *Peace Is Our Mission: Alert Operations of the Strategic Air Command, 1957-1991* (1992).

Tactical Air Command (TAC). The Tactical Air Command was also replaced in 1992 by the Department of Defense reorganization plan. TAC was responsible for the non-nuclear forces within the department of defense. An interesting book on the aircraft in TAC is *TAC Fighters* (1991), by Robert F. Dorr and Jim Benson.

Thunderbirds. The Thunderbirds is the popular name for the U.S. Air Force Air Demonstration Squadron, which was established in 1953. In 1956, the Thunderbirds moved to their current home at Nellis Air Force Base, Nevada. Over the years, they have performed their aerial show for more than 280 million viewers worldwide. Two books on the Thunderbirds are *Summer of Thunder* (1993), by Brian Shul, and *Diamond in the Sky: A Pictorial History of the United States Air Force Thunderbirds* (1984), by Carol Knotts and Peter Moore. *Contact information:* USAF Air Demonstration Squadron, Box 9733, Nellis AFB, NV 89191 (www.thunderbirds@nellis.af.mil)

Tuskegee Airmen. This is the popular name for a group of black aviators who served in World War II. They are named for the location of the Army airfield where they trained. Of the initial trainees, 450 went on to serve in the military under the command of Benjamin Davis, Jr. In 1944, they joined with the 100th, 301st and 302nd military units to form the 332 Fighter Group. Several recent publications on the Airmen include *Black Knights: The Story of the Tuskegee Airmen* (2001), by Lynn Homan, and *Red Tails, Black Wings: The Men of America's Black Air Force* (1997), by John Holway. *Contact information:* Tuskegee Airmen, 1501 Lee Highway, Suite 130, Arlington, VA 22209.

U.S. Space and Rocket Center. The Space and Rocket Center is located in Huntsville, Alabama, near the Marshall Space Flight Center. The Center contains one of the largest collections of rockets in the world as well as actual vehicles from both the U.S. and Russian space programs. Other attractions include tours of the Marshall Space Flight Center, thrill rides simulating weightlessness, and an IMAX theater. The Center also sponsors a space camp for young adults each summer. A good publication on air and space museums is *Kitty Hawk to NASA: A Guide to U.S. Air and Space Museums and Exhibits* (1991), by Michael Morlan. *Contact information:* U.S. Space and Rocket Center, Interstate 565, Huntsville, AL 35811 (www.usrc.com or www.spacecamp.com).

Whirly-Girls. The Whirly-Girls is the popular name for the organization of International Women Helicopter Pilots. It was founded in April, 1955, to promote helicopter aviation, foster safety, and encourage the advancement of women in helicopter aviation. There are now more than 1,000 members worldwide. The organization sponsors a number of scholarships for women interested in starting or furthering their helicopter experience. A recent publication on the Whirly-Girls is *Hovering: The History of the Whirly-Girls, International Women Helicopter Pilots* (1994), by Henry M. Holden. This book also contains a brief history of many of the first 1,000 members. *Contact information:* Whirly-Girls Inc., P.O. Box 48585, Houston, TX 77058; Ph.: (713) 474-3932.

Women in Aviation International. This organization began in 1990 and was formally established in 1994 to encourage women to seek career opportunities in aviation and aviation-related fields. There are currently more than 5,500 members worldwide. In addition to a magazine and career fair held at the organization's annual meeting, the Women in Aviation International have been successful in awarding and helping to create a number of scholarships for women interested in flight training. *Contact information:* WAI HQ Office, 101 Corsair Drive, Suite 101, Daytona Beach, FL 32114; Ph.: (904) 226-7996 (www.wiai.org).

Women's Airforce Service Pilots (WASPs). The WASPs represent the first women to serve as military pilots. During World War II, 1,830 women were accepted into the U.S. Army Air Force and 38 of these women lost their lives in service. While they were considered civilian employees during the war, the Secretary of the Air Force granted them veteran status in 1979. There have been numerous articles and books on the WASPs including *Clipped Wings: The Rise and Fall of the Women Air Force Service Pilots of World War II* (1998), by M. Merryman, and *WASPs: Women Air Force Service Pilots of World War II* (1994), by Vera S. Williams.

Dawna L. Rhoades

Flight Schools and Training Centers in North America

UNITED STATES

A & M Aviation
Clow International Airport
Bolingbrook, IL
ph.: (630) 759-1555
(http://home.att.net/—'flyace/)

Offers airplane and glider pilot certificate courses for private and commercial pilots. Also offers flight instructor certificate. Airplanes and motor gliders available for rent and sale.

Adventure Aviation
Georgetown Municipal Airport
207 Corsair Drive
Georgetown, TX 78628
ph.: (512) 930-41443; fax: (512) 869-7571
(http://www.adventure-aviation.com)

In addition to courses for private and commercial pilot certificates, also offers training for airline transport pilot certificate, multiengine rating, and aerobatics and emergency maneuvers.

Aero Precision
Charlotte County Airport
28000 Airport Road, A-18
Punta Gorda, FL 33982
ph.: (941) 575-2300
(http://www.aeroflight1.com/index.html)

Courses include certification for recreational, private, and commercial pilots; instrument ratings; certified flight instructors; multiengine ratings; air transport pilots; and aerobatics and tailwheel transition.

Aero-Tech
Blue Grass Airport
Lexington, KY
ph.: (859) 254-8906; fax: (859) 255-3250
(http://www.aerotech.net/index.html)

Family-owned and managed flight school founded in 1971 with an emphasis on recreational aviation.

Aero-Wings
Mineral Wells, TX 76068
ph.: (800) 699-2466
(http://66.33.44.234/)

Offers training for all FAA private and commercial pilot licenses for European pilots; headquarters in Zurich, Switzerland.

AeroClub International
14592 SW 129 Street
Miami, FL 33186
ph. and fax: (305) 235-0040
(http://www.flyaeroclub.com)

Founded in 1962; offers basic courses in both English and Spanish for private and commercial pilot and instrument rating certification.

Aeronautical Services
Charlotte County Airport
Building 117, Mooney Avenue
P.O. Box 510637
Punta Gorda, FL 33951
ph.: (941) 639-2647; fax: (941) 575-6980
(http://www.asiflight.com/default.htm)

Offers private, professional, and commercial pilot programs; certified flight and certified instructor ratings; instrument rating, commercial single-engine and multiengine add-ons; airline transport pilot certification; courses on aviation language and for airframe/power plant mechanic.

Aerostadt Flight Academy
One Aero Plaza
Hangar 5, New Century Aircenter
New Century, KS 66031
ph.: (913) 254-9655; fax: (913) 254-0134
(http://www.airnav.comlairport/IXD/AERQSTADT)

Offers an interactive tutorial (Cessna Computer-Based Instruction Kit) to assist students preparing for written exams that are a part of the private, instrument, and commercial certification programs.

Aeroventure
561 Sky Ranch Drive
Petaluma, CA 94954
ph. (707) 778-6767; fax: (707) 778-6314
(http://www.aeroventure.com)

Offers flight training classes for private and commercial pilots and computer-assisted testing (CATS) for students ready to take any FAA exam.

Ahart Aviation
186 Airway Boulevard
Livermore, CA 94550
ph.: (925) 449-2142; fax: (925) 373-0944
(http://www.ahart.com/)

Established in 1985; specializes in flight training and aircraft rental, with courses for private and airline transport pilot certificates, and for flight instructor certificates (both instrument and multiengine).

Air D
P.O. Box 187
Backus, MN 56435
ph.: (218) 947-3100; fax: (218) 947-3967
(http://www.uslink.netkflyairdl)

Operating since 1990; offers training for the following certificates and ratings: private, instrument, commercial, multi-rating, flight instructor, and flight instructor instrument.

Airline Training Academy
Orlando Executive Airport
83 Nilson Way
Orlando, FL 32803
ph.: (407) 894-0030; fax: (407) 894-0705

Specializes in training pilots for commercial airlines.

Airtech
801 Hanger Lane, Hangar 7
Nashville, TN 32717
ph.: (615) 361-5809
e-mail: airtech@telalink.net

Operating at Nashville International Airport since 1993; offers courses for commercial and private pilot licenses, in addition to instrument and multiengine ratings, and certified flight instructor.

Alaska Float Ratings
Box 4
Moose Pass, AK 99631
ph.: (907) 288-3646; fax: (907) 288-3647
(http://www.arctic.net/akfloats/)

Instruction and training in float planes for mountain and bush flying; two- to three-day program is designed for trained pilots who want to learn float flying, including over steep mountain passes and glaciers.

Albatross Air
380 Airport Circle
Beaver, WV 25813
ph.: (304) 255-2717; fax: (304) 255-3688
(http://www.a1batrossair.com/index.html)

Courses available for recreational, private, commercial, and airline transport pilot certificates and licenses; also offers courses for instrument and multiengine flight instructor certificates.

American Flyers
DuPage Airport
3N040 Powis Road
West Chicago, IL 600185
ph.: (800) 323-0808
(http://www.amerflyers.com/default.htm)

Main office is in Chicago, with many branches located in several states: California, Florida, Illinois, Michigan, New Jersey, New York, Texas, and Washington. Programs include private pilot certification and instrument rating.

American Flying Adventures
14695 Airport Parkway
Clearwater, FL 33762
ph.: (727) 538-2088; fax: (727) 535-6794
(http://www.amfly.com)

Aviation courses for private, commercial, and airline transport pilot licenses. Also offers a course for night rating and a course for pilots with a foreign license to familiarize them with U.S. regulations so they can fly safely in U.S. airspace.

American Flying Club
1811 NW Fifty-first Street, Hangar 42A
Fort Lauderdale, FL 33309
ph.: (954) 771-1050; fax: (954) 771-6563
(http://www.americanflying.com)

Pilot courses for private and commercial licensing; single and multiengine training offered. Information available in German at Web site.

Austin Academy of Aviation
4309 General Aviation Avenue
Austin, TX 78710
ph.: (512) 385-2880
(http://flyaus.com/index.html)

Courses taught include those for private and commercial pilot licenses; for instrument and certified flight instructor ratings, and for airline transport pilot. Additional training includes instrument proficiency check; complex and high performance sign-offs; and refresher courses on emergency procedures and aircraft systems, instrument procedures, and navigation chart interpretations for instrument-rated pilots.

Aviation Atlanta
3187 Corsair Drive, Suite 250
Atlanta, GA 30341
ph.: (770) 458-8034; fax: (770) 451-3422
(http://www.aviationatlanta.com/)

Offers a private pilot course for recreational pilots of single-engine aircraft; the professional pilot course is a comprehensive program that includes private and commercial pilot and flight instructor certificates; instrument and multiengine ratings; and instrument instructor and multiengine instructor ratings.

Aviation Safety Training
8319 Thora Lane, Hangar 5
Spring, TX 77379
ph.: (281) 379-2237; fax: (281) 251-7197
(http://www.aviationsafetytraining.com/index.htm)

Offers Advanced Maneuvering Program (AMP) to provide pilots with training on unusual attitude recoveries. Program focuses on teaching pilots how to recover from unexpected turbulence, wind shear, and disorientation.

Aviationwise Pilot Ground Schools, Distance Learning Technologies
Box 746
Deerfield Beach, FL 33443
ph.: (954) 426-3743; fax: (954) 426-3744
(http://www.aviationwise.org/)

Offers complete online courses to prepare students who must take the FAA written test. Program is certified under FAR Part 91 but is not accredited.

Baker's School of Aeronautics
1645-K Murfreesboro Road
Nashville, TN 37217
ph.: (615) 361-6787; fax: (615) 361-0010
(http://www.bakerssch.com)

Operating since 1973, the school offers ground courses for airplane and helicopter pilots, both private and commercial, that prepare students to pass written FAA exams; also offers courses for an Inspection Authorization rating and for aviation mechanics who wish to take the FAA written exams.

Blue Ridge Helicopter
731 Double Church Road
Stephens City, VA 22655
ph.: (540) 869-6208
(http://www.blueridgeheli.com)

Program trains helicopter pilots, with private, commercial, and flight instructor ratings; also offers scenic rides and aerial photography.

Bode Aviation
2501 San Pedro NE, Suite 211
Albuquerque, NM 87110
ph.: (888) 884-4530; fax: (505) 884-4551
(http://www.flybode.comlindex.htm)

Offers both flight training and ground school for private and instrument rating/commercial pilot certificates; also offers programs for aerobatics instruction, tailwheel sign-offs, and spin training.

C & C School of Aeronautics
1804 Waterfall Way, Suite #302
Spring Lake, NC 28390
ph.: (910) 321-0300; fax: (910) 496-9516
(http://ccsa1.bizhosting.com/index.htm)

Courses offered for recreational, private, commercial, and airline transport pilot certification; instrument rating; aviation mechanic, pilot, and parachute-rigger examiners; and flight and ground instructors.

Caelum Tranquilitatis, Ltd.
Farmingdale, Long Island Republic Airport
New York
ph.: (631) 752-3363
(http://www.iflyctl.com/)

Founded in 1993; offers flight instruction for both private and commercial pilot licenses, instrument ratings, and flight instructor and airline transport licenses.

California Flight Academy
Gillespie Field
2045 N. Marshall Avenue
El Cajon, CA 92020
ph.: (619) 448-2212
(http://www.flycfa.com/)

Located near San Diego, California. Courses offered for private pilot and commercial pilot with multiengine rating certification; basic, instrument, multiengine flight instructor, and airline transport pilot. Assists students who need housing.

Canelas International Aviation
P.O. Box 1049
Manor, TX 78653
ph.: (512) 272-9888
(http://www.canelas.com)

Offers both ground school courses and flight training for private and commercial pilot licenses, in addition to instrument rating and flight instructor certificates. Features a 30-minute orientation flight available to novice pilots after they attend a short ground-school lecture.

Capital Aircraft
900 Capital Airport Drive
Springfield, IL 62707
ph.: (217) 525-6988; fax: (217) 525-0090
(http://www.capitalaircraft.com)

Offers lessons to obtain a private pilot license and opportunity to enjoy a short introductory flight with an instructor.

Cardinal Wings
2800 Moran Avenue
Louisville, KY 40205
ph.: (502) 459-6184
(http://www.cardinalwings.com)

Offers courses for both private and commercial ratings.

Century Flight Academy
Morristown Airport
1 Airport Road
Morristown, NJ 07960
ph.: (973) 455-1770; fax: (973) 455-1991
(http://www.centuryair.com/index2.htm)

Operating since 1975; certification courses are for student, private, commercial, and airline transport pilot. Ratings offered include instrument, multiengine, and flight instructor.

Champion Aviation
2003 S.E. Airport Road
Stuart, FL 34996
ph.: (561) 463-8188; fax: (561) 463-8187
(http://www.apexaviation.com)

Operating since 1990 at Witham Field; offers primary and advanced flight instruction at hourly rates.

Chandler Air Service
1675 E. Ryan Road
Chandler, AZ 85249
ph.: (480) 963-6420; fax: (480) 963-7639
(http://www.aerobatics.com)

Founded in 1976 and located near Phoenix; offers both aerobatic and tailwheel training, in addition to basic and advanced flight training to obtain private and commercial licenses.

Channel Islands Aviation
Camarillo Airport
305 Duxley Avenue
Camarillo, CA
ph.: (805) 987-1301; fax: (805) 987-8301
(http://www.flycia.com)

Offering flight training since 1976; features an integrated program of ground school courses (Cessna multimedia computer-based instruction) and flight time. Ratings available for private, commercial, and airline transport pilots and for flight instructors.

Cirrus Aviation
8191 N. Tamiami Trail
Sarasota, FL 34243
ph.: (941) 360-9074
(http://www.cirrusaviation.com/)

Programs for private and commercial pilot licenses, plus courses for instrument and multiengine ratings.

Comair Aviation Academy
2700 Flight Line Avenue
Sanford, FL 32773
ph.: (407) 330-7020; fax: (407) 323-3817
(http://www.comairacademy.com/index.html)

An airline-affiliated flight school that requires its students to have a Commercial Pilot Certificate with an Airplane, Multiengine Land and Instrument Rating before acceptance into the academy's First Officer prescreening process. Successful completion of process allows students to join the Airline Pilot Training Program with a conditional offer of employment when program is completed.

CP Aviation
830 East Santa Maria Street, #301
Santa Paula, CA 93060
ph.: (805) 525-2138
(http://www.cpaviation.com)

Operating since 1940; offers basic private pilot license as well as commercial pilot license, instrument ratings, and courses for tailwheel and aerobatics flying.

Dakota Ridge Aviation
3300 Airport Road, Box 5
Boulder Municipal Airport
Boulder, CO 80301
ph.: (303) 444-1017; fax: (303) 443-7038
(http://www.boulderweb.com/co/dral)

Offers courses for private and commercial pilot certificates; instrument, flight instructor, and multiengine ratings; also offers mountain instruction, scenic rides, and aerial photography.

Dulles Aviation
10501 Observation Road
Manassas, VA 20110
phone: (703) 361-2171
(http://www.dullesaviation.com)

Instruction for private pilot through airline transport pilot certification and for all flight instructor ratings. Also assists with foreign pilot license conversion and housing/transportation.

Dunkirk Aviation
3389 Middle Road
Dunkirk, NY 14048
ph.: (716) 366-6938; fax: (716) 366-6986
(http://www.dkk.com/flight school.html)

Offers a complete program for pilots that includes private, commercial, and airline pilot certificates; instrument, multiengine, and helicopter ratings; and airline transport pilot courses. Offers aerobatic and tailwheel training, flight reviews, and instrument proficiency checks.

Executive Flyers
6151 Freeport Boulevard, Suite 151
Sacramento, CA 95822
ph.: (916) 427-1888; fax: (916) 427-1881
(http://www.mother.comkcallaway/)

Operating since 1980; offers programs for private and commercial pilot licenses, multiengine and instrument ratings, and flight instructor ratings.

Fairbanks Flight Train
3580 University Avenue
S. Fairbanks International Airport
Fairbanks, AK 99709
ph.: (907) 474-0757
(http://www.flighttrain.com/)

Separate programs for private pilot ground school and flight course; also offers instrument course and tailwheel high performance.

Flatirons Aviation Corp.
Boulder Municipal Airport
3300 Airport Road, Box L
Boulder, CO 80301
ph.: (303) 440-6522
(http://www.flatironsaviation.com/)

Flight school offers a complete listing of courses for professional flight instructors; private, instrument, and commercial ratings and certificates; airline transport pilot; tailwheel transition; mountain and aerobatic flying; biennial flight reviews; and instrument competency checks.

Flight Control Academy
3701 S. Park Avenue, Suite 704
Tucson, AZ 85713
ph.: (520) 670-9583; fax: (520) 670-9588
(http://www.flightcontro1academy.com/)

Offers a course on site near the Tucson airport and also a correspondence course for aircraft dispatcher certification.

Flight School of Gwinnett, Inc.
800 Airport Road, Suite 101
Lawrenceville, GA 30245
ph.: (770) 513-0000
(http://www.theflightschool.com)

School offers both private and professional pilot certification courses; a computer-based instruction private pilot course; instrument/multiengine ratings; the certified flight instructor rating; and a “pinch-hitter” course for the general aviation passenger, which teaches the basic skills necessary to fly and land an airplane in an emergency.

Flying Lemur
Potomac Airfield
Fort Washington, MD
ph.: (703) 623-9445
(http://members.tripod.comkaerobaticmanlindex.htm)

Owner has been an instructor since 1993; company offers aerobatic flying lessons, spin training, and thrill rides.

Grant Air
8800 Overseas Highway
Marathon, FL 33050
ph.: (305) 743-1995; fax: (305) 743-6635
(http://www.grantair.com)

In addition to courses for beginning pilots, offers commercial, seaplane, and instrument ratings; aerial photography and tours also available.

Great Western Aviation
369 North 2370 West
Salt Lake City, UT 84116
ph.: (801) 359-2492
(http://www.gwaviation.com/index.php)

Certificated courses include private, commercial, and airline transport pilot certification; instrument and multiengine ratings, and certificated flight instructor with single-engine, instrument, and multiengine ratings. School also offers a mountain-flying course.

Gulfshore Helicopters
325 Danley Drive
Page Field
Fort Myers, FL 33907
ph.: (941) 274-0333
(http://www.gulfshorehelicopters.com/)

Offers training for private, commercial, and certified flight instructor helicopter ratings; also does aerial photography.

Gulfstream Academy of Aeronautics
5302 Northwest Twenty-first Terrace
Fort Lauderdale, FL 33309
ph.: (877) 359-4853; fax: (954) 771-6175
(http://www.gulfstreamacademy.comlindex2.html)

School is affiliated with airline industry and offers courses for basic flight training and First Officer training.

Hawaii Flight Academy
Gate 29
Hilo International Airport
Hilo, HI 96720
ph.: (808) 538-7590; fax: (808) 969-1925
(http://www.fly-hawaii.coml)

Courses vary from a two-day advanced instrument technique course to a twenty-one-day private pilot course. Fixed price of fourteen-day instrument rating course includes twenty-five hours airplane time and thirteen nights at oceanside resort.

Indianapolis Aviation
Indianapolis Metropolitan Airport
9913 Willowview Road
Fishers, IN 46038
ph.: (317) 849-0840; fax: (317) 849-0912
(http://www.indianapolisaviation.com/)

Flight courses include private, recreational, and commercial pilot certificates; instrument and multiengine ratings; certified flight instructor, and airline transport pilot.

Jones Aviation Service
1234 Clyde Jones Road
Sarasota, FL 34243
ph.: (941) 355-8100; fax: (941) 351-9700
(http://www.ionesav.com)

Offers lessons for private pilot certificate and for a commercial/instrument rating.

Kentucky Airmotive
709 Airport Road
Mt. Sterling, KY 40353
ph.: (859) 498-1000
(http://mountsterling-ky.comlairport.htm)

Offers charter flights and air cargo, in addition to flight instruction for private pilot license, instrument/commercial and multiengine ratings, and flight instructor certificate.

Lane Flight Technology
28715 Airport Road
Eugene, OR 97402
ph.: (541) 744-4195; fax: (541) 689-4023
(http://lanecc.edu/flight/flight.htm)

Offers training for the following certifications: private pilot, commercial pilot, instrument rating, and flight instructor.

Langa Air Flight Academy
10 Terminal Drive
East Alton, IL 62024
ph.: (618) 258-1005; fax: (618) 258-1007
(http://www.langaair.com)

Offers courses for all certificates and ratings, including private and commercial pilot licenses, instrument and multiengine ratings, certified/instrument/multiengine instructor, and airline transport pilot certificate. A flying scholarship is available for young adults, ages sixteen to nineteen.

Lantana Air
2633 Lantana Road, Suite 30, Office 5
Lantana, FL 33462
ph.: (561) 968-0019; fax: (561) 968-3836
(http://www.gate.net/'—lanair/)

Courses available for private and commercial pilot licenses, multiengine rating, certified flight instructor and instrument/multiengine instructor, and airline transport pilot. School also offers refresher training and biannual flight reviews.

Learjet Crews International
Fort Lauderdale, FL
ph. (954) 917-8365
(http://www.learjetcrews.com/home.htm)

Specializes in ground and flight training for Learjet pilots and crew, focusing on the requirements of any corporate, charter, or business Learjet operator.

Learn To Fly
P.O. Box 7075
Sussex, NJ 07461
ph.: (973) 875-9830
(http://webusers.warwick.netk-~u 1007204/)

Small, private company that offers flying lessons at an hourly rate.

Livingston Aviation
2814 Betsworth Drive
Waterloo, IA 50703
ph.: (319) 234-1783; fax: (319) 234-7763
(http://www.livingstonaviation.com/)

Utilizes computer-based instruction in its pilot training program.

Lynch Flying Service
1691 Aviation Place
Logan International Airport
Billings, MT 59105
ph.: (406) 252-0508; fax: (406) 245-9491
(http://www.wtp.net/Iynch1)

Operating since 1940; services include air charter and air freight, in addition to flight training for private, commercial, and airline transport pilot ratings.

Mac Dan Aviation
27 Wright Way
Fairfield, NJ 07004
ph.: (800) 346-2140; fax: (973) 227-8339
(http://www.macdan.com/)

Offers a private pilot and instrument rating ground school course; certification courses for private and commercial pilots, flight instructors with instrument and multiengine ratings, and airline transport pilots.

McCall Mountain/Canyon Flying Seminars
P.O. Box 1175
McCall, ID 83638
ph.: (208) 634-1344
(http://www.mountaincanyonflying.com)

Teaches mountain and canyon flying; course outline includes both classroom and flight instruction on mountain and canyon meteorology, navigation, landing areas, and emergencies.

Manassas Aviation Center
10600 Observation Road
Manassas, VA 20110
ph.: (703) 361-0575
(http://www.manassas-aviation.coni/)

Offering flight training since 1963; courses are available for private pilot certification and commercial and instrument ratings.

Mazzei Flying Service School of Aeronautics
4885 East Shields Road, Suite 201
Fresno, CA 93726
ph.: (559) 251-7501; fax: (559) 255-8900
(http://www.flymfs.com)

Established in 1936 and operating out of Fresno Airport; offers courses for airplane and helicopter pilots, with private, commercial, and airline transport ratings.

Mountain Aviation Enterprises
Albuquerque International Airport
2505 Clark Carr Loop SE
Albuquerque, NM 87106
ph.: (505) 842-6660
(http://www.mountain-aviation.com/)

Offers all certificates and ratings from private pilot through certificated flight instructor. Uses the Jeppesen-Sanderson Flight Training Program. Ground school can be completed through a self-study program or on a one-on-one basis with a flight instructor.

New Horizon Aviation
126 Club Loop, Greenville, SC 29607
ph.: (864) 299-5709; fax: (864) 299-0219
(http://www.newhorizonaviation.com)

Flight instruction offers certificate programs for recreational pilot through airline transport pilot, and for single-engine and multiengine ratings. Additional services include biennial flight reviews; instrument proficiency checks; and tailwheel, complex, and high-performance checkouts.

North American Institute of Aviation
P.O. Box 680
Conway, SC 29528

ph.: (800) 327-6242; fax: (843) 397-3776
(http://www.naiasc.com/)

Offers a six-month Professional Pilot Program that includes private and commercial pilot licenses; instructor, multiengine, and certified flight instructor ratings, and includes local housing for students. Individual flight programs are also available.

North Florida Flight Center
855-1 St. Johns Bluff Road
Jacksonville, FL 32225
ph.: (904) 642-3912; fax: (904) 642-4868
(http://www.fly-us.coml)

Individualized program of study for recreational, professional, and business pilots; instrument ratings also available.

Oahu Aviation
Honolulu, HI
ph. and fax: (808) 833-8014
(http://www.oahuaviation.comlcontactus.htm)

An airline that offers charter flights, skydiving, and flying lessons; located at Honolulu International Airport.

Pensacola Aviation Center
Pensacola, FL
ph.: (850) 434-0636; fax: (850) 434-3984
(http://www.pensacolaaviation.com/index.html)

Training students since 1972; offers flight instruction for private, commercial, and airline transport pilot licenses. Flight simulator and charter services also available.

Preiss Aviation
1680 George Bush Drive W., Suite #12
College Station, TX 77845
ph.: (979) 260-7627
(http://www.preissaviation.com)

Offers flight-training programs for private pilot licenses, instrument ratings, and multiengine ratings.

Premair
19540 International Boulevard, #200
Seattle, WA 98188
ph.: (206) 878-7271; fax: (206) 878-7269
(http://www.premair.comlmain/index.html)

A certified training center for airline crews. Trains and certifies crews for domestic and international aviation; also offers proficiency checks and variance courses.

Preston Aviation
19708 Eustis Airport Road
Eustis, FL 32736
ph.: (352) 589-1111
(http://www.flytailwheel.coml)

A tailwheel flight school that teaches proficiency in normal and crosswind takeoffs and landings, full stall and wheel landings, and go-around procedures.

Pro Flight Center
Piper Street
Beaver Falls, PA 15010
ph.: (724) 846-4900
(http://proflightcenter.com/)

Flight training is offered from private pilot through airline transport certification; tailwheel and aerobatics courses and courses for private and commercial helicopter pilot licenses and certified helicopter flight instructors are also offered.

Richmor Aviation
P.O. Box 432
Hudson, NY 12534
ph.: (518) 828-9461; fax: (518) 828-1303
(http://www.richmor.comlifldeX.htm)

Billed as the “largest flight training school in the northeast,” with offices also in Poughkeepsie, Saratoga, and Schenectady. Offers training for commercial and private pilot licenses.

Rocket Aviation
Madison County Executive Airport
358 Bolling Road
Meridianville, AL 35759
ph.: (256) 828-8616; (258) 828-8627
(http://www.rocketaviation.coflhl)

Offers complete ground and flight instruction for private, commercial, instrument, and multiengine licenses; also offers tailwheel and aerobatic training programs.

Sabena Flight Academy
14605 North Airport Drive, Suite 350
Scottsdale, AZ 85260
ph.: (480) 948-4515; fax: (480) 443-8861
(http://www.sfa.be/academY/default.htm)

Main office in Brussels, Belgium; provides high quality training for airline cockpit and crew members; theoretical pilot training and cabin crew training take place in Belgium, and flight training takes place in Arizona. Assists with possible career placement in one of the Sabena Group airlines as well as in other airlines of member nations of the Joint Aviation Authorities.

Sheble Riviera Aviation
600 Highway 95
Bullhead City, AZ 86429
ph.: (520) 754-8318
(http://www.shebleaviation.COflhI)

Offers courses for private and commercial pilot licenses, certified flight instructors, and airline transport pilots, as well as instrument rating and multiengine rating. For students who already have a private pilot's license, Sheble has a training course for single-engine seaplane license.

Shenandoah Flight Services
51 Aviation Circle, Suite 112
Weyers Cave, Virginia 24486
ph.: (540) 234-9789
(http://hometown.aol.comlpmabOY/Sf5.htm.)

Offers a professional pilot course that takes an average of six months to complete and includes private pilot's license with instrument rating; commercial pilot's single-engine and multiengine license; certified, multiengine, and instrument instructor; basic, advanced, and instrument ground instructor ratings.

Sierra Academy of Aeronautics
Oakland International Airport
9465 Earhart Road, North Field
Oakland, CA 94615
ph.: (510) 568-6100; fax: (510) 553-0747
(http://www.sierraacademY.com/index.aSP)

Offers courses for professional airline pilot, helicopter pilot, aircraft dispatcher, and aircraft mechanic certification.

Skihi, JMA Aviation Corporation
306 Fairlane Drive
Nashville, TN 37211
ph.: (615) 365-3218; fax: (615) 365-0813
(http://www.skyhinashville.com/)

Operating since 1991 at Nashville International Airport at 547 Perimeter Road, Hangar 2, Nashville, Tennessee. Offers courses for private pilot, instrument rating, commercial pilot, flight instructor, and instrument flight instructor certification.

Smith Aviation Testing
1940 Airport Court
Great Falls, MT 59404
ph.: (406) 771-0791; fax: (406) 452-5212
(http://www.smithavi.com/)

Offers ground courses using the Jeppesen-Sanderson course syllabus. Courses include those for private and commercial certification, flight and ground instructor rating, and tailwheel endorsement.

Southern Wings Flight Training Center
New Braunfels Municipal Airport
1568 Entrance Drive
New Braunfels, TX 78130
ph.: (830) 606-4141; fax: (830) 629-3293
(http://www.sat.netkswi/)

Courses for private, commercial, and airline transport pilot certificates and flight instructor, instrument, and multiengine ratings.

Sowell Aviation Co.
Municipal Airport
P.O. Box 1490
Panama City, FL 32402
ph.: (850) 785-4325; fax: (850) 763-8293
(http://www.sowellaviation.com/main.html)

Operating since 1945; extensive flight training program includes economy and deluxe courses for private and commercial pilot certifications, instrument and multiengine ratings, and airline transport pilot certificates. Certified flight instructor programs include instrument and multiengine ratings

Stinson Air Center
Hangar 9, Stinson Field
8619 Mission Road
San Antonio, TX 78214
ph.: (210) 924-6634; fax: (210) 924-6636
(http://www.stinsonaircenter.com/s)

Offers both fixed-wing and helicopter programs for private pilot through airline transport pilot ratings; also teaches emergency and aerobatic maneuvers.

Sunbird Flight Services
2475 South Airport Boulevard
Chandler, AZ
ph.: (480) 821-1521; fax: (480) 814-8534
(http://www.sunbird.org/index.htm.)

The professional pilot course includes individual courses that can also be taken separately: private and commercial pilot certification, flight instructor, and instrumental or multiengine flight instructor certificates.

Sunrise Aviation
19531 Campus Drive
Santa Ana, CA 92707
ph.: (949) 852-8850
(http://www.sunrise-aviation.coml.)

Founded in 1978 and operating out of John Wayne Airport; offers training for private, instrument, commercial, and certified flight instructor ratings. Aerobatic division is one of the largest in the western United States.

Sutton Aviation
DuPont-Lapeer Airport
1232 Roods Lake Road
Lapeer, MI 48446
ph.: (810) 667-6426
(http://www.sutton-aviation.coml)

Offers private, recreational, commercial, and flight instructor certificates and instrument and multiengine ratings.

Take Flight Alaska
ph.: (907) 274-9943; fax: (907) 273-3486
(http://www.takeflightalaska.com)

Operating from 1960 (originally as Wilbur's Flight Operations and then as Flight Safety Alaska); offers instruction for private, commercial, and airline transport pilot certificates, and for instrument, commercial, and multiengine ratings. Provides instruction for certified, instrument, and multiengine flight instructor certificates.

TallyHo Flight Training
Memorial Park
Hot Springs National Park
Arkansas
ph.: (501) 323-0812; fax: (501) 623-6448
(http://www.tallyhoflight.com)

Offers private and commercial pilot certifications and flight instructor and flight instructor instrument certificates.

Three Wing Flying Club
1000 Great Meadow Road
Stratford, CT 06497
ph.: (203) 375-5795; fax: (203) 377-8067
(http://www.threewing.com)

Pilot training includes private and commercial licenses, with instrument and multiengine ratings also offered.

Tri-Star Aviation
20130 Birchwood Loop Spur
P.O. Box 672074
Chugiak, AK 99567
ph.: (907) 688-4079
(http://www.tri-star-aviation.coml)

Provides two courses: a private course and an instrument course (twenty of the required forty hours are done in a simulator); also provides sightseeing and transportation services.

U.S. Helicopters
4225 Donald Douglas Drive, #102
Long Beach, CA 90808
ph.: (562) 497-0390; fax: (562) 497-0392
(http://www.ushelicopters.com/index.html)

Programs offered for private and commercial helicopter pilot licenses, and for certified helicopter flight instructor rating. Introductory flight lessons are offered after a 30-minute ground school briefing.

University of Michigan Flyers
1075 Airport Drive
Ann Arbor, MI 48108
ph.: (734) 994-6208
(http://www.umflyers.org/)

Offers certification courses for both private and commercial pilots, as well as instrument ratings. Program features include an introductory discovery flight.

Volunteer Aviation
McGhee Tyson Airport
P.O. Box 804
Alcoa, TN 37701
ph.: (865) 970-3090; fax: (865) 977-8901
(http://www.volav.com/)

Flight training includes private and commercial pilot licenses, instrument and multiengine ratings, and flight instructor certification.

Voyager Aviation
7003 Challenger Avenue
Titusville, FL 32780
ph.: (321) 385-2328; fax: (321) 264-0393
(http://voyageraviation.comlhome.html)

The two main courses offered are the professional pilot course, which usually takes four to six months to complete and includes private and commercial pilot certification, with instrument and multiengine ratings. The professional airline transport pilot course has two phases: phase I courses are for professional pilot and certified flight instructor certifications; phase II includes courses for certified/multiengine instructor and airline transport pilot certifications.

Wallace State Community College Flight School
P.O. Box 2000
Hanceville, AL 35077
ph.: (256) 352-8035
(http://www.cneti.com/wsfs/)

Flight training since 1978; offers a complete list of training for both airplane and helicopter, including private and commercial pilot certification, instrument and multiengine ratings, flight and ground instructor certificates, airline transport pilot certification (with both single and multiengine ratings), biennial flight reviews, instrument competency checks, and high-performance checkouts.

Waukegan Wings
2346 W. Beach Road
Waukegan, IL 60087
ph.: (847) 599-9955; fax: (857) 599-9966
(http://www.waukeganwings.com)

Flight school offers a complete list of classes, including those for recreational, private, and commercial pilot certifications; instrument, multiengine, and seaplane ratings; tailwheel and complex sign-offs, and biennial flight reviews.

West Air Aviation
2722 Perimeter Road, Suite 107
North Las Vegas, NV 89032
ph.: (702) 639-6800; fax: (702) 636-0671
(http://www.westairaviation.com/)

Offers flight instruction in both helicopter and fixed-wing aircraft. For airplanes, private pilot license and instrument rating are available; for helicopters, private and commercial pilot ratings are available.

West Bend Air
P.O. Box 409
West Bend, WI 53095
ph.: (262) 334-5603; fax: (262) 334-5662
(http://www.wbair.net/)

Offers training for private pilot license, in addition to advanced ratings and certifications.

Wing & Rotor International
Flagler County Airport
201 Airport Road, Suite 1, SR100
Bunnell, FL 32110
ph.: (904) 437-8359; fax: (904) 437-6000
(http://www.wingandrotor.com)

An airplane and helicopter training center for private and commercial ratings.

Wings International
2635 Cunningham Avenue
San Jose, CA 95148
ph.: (408) 251-6085; fax: (408) 251-8919
(http://www.wingsinternational.com)

Offers courses for private and commercial pilots, for instructor certification, single-engine and multiengine instrument rating, and both advanced and instrument ground instructors; also offers the airline transport pilot license.

Wisconsin Aviation
3606 Corben Court
Madison, WI 53704
ph.: (608) 268-5000; fax: (608) 268-5037
(http://www.wisconsinaviation.com)

Operating since 1981 and offering courses for private pilot, commercial pilot, and airline transport pilot certifications; instrument and multiengine ratings; certified flight instructor, with instrument and multiengine ratings. School also offers several ground schools: private, instrument, commercial; high performance/complex; multiengine and refresher courses; instrument and weathermation refresher courses.

Wright Flyers Aviation
1954 First Avenue
San Antonio, TX 78216
ph.: (210) 820-3800
(http://www.wrightflyers.com/contact frame.htm)

Courses include private and commercial pilot, instrument and multiengine ratings, airline transport pilot, and aerobatics.

Zephyr Aviation
Tacoma Narrows Airport
Gig Harbor, WA 98335
ph.: (253) 851-8083; fax: (253) 851-8433
(http://www.zephyraviation.com)

Offers training for private and commercial pilots, as well as instrument and multiengine ratings.

CANADA

Air Ottowa
Box 350
808 St. Pierre Street
Embrun, Ontario, Canada KOA iWO
ph.: (613) 443-2759
(http://www.conveyor.com/airottawa.html)

Offers single discovery flights, private and commercial licenses, night and instrument ratings.

Aspen Air
Hangar 5, Langley Airport
215-5333 216th Street
Langley, British Columbia, Canada V2Y 2N3
(http://www3.bc.sympatico.calaspenair/default 1E4.html)

Located near Vancouver, Canada; offers classes for recreational pilot permit, in addition to those for commercial and private pilot licenses, instructor and instrument ratings.

Calgary Flight Training Center
Calgary International Airport, Hangar 11
820 MacTavish Road, N.E.
Calgary, Alberta, Canada T2E 7J7
(http://www.calgaryflight.com)

Training programs are for both recreational and professional pilots. Private pilot training includes license, night rating, multiengine endorsement, mountain flying, aerobatics, instrument navigation and rating, and a co-pilot course. Professional pilot training includes commercial pilot license, multiengine endorsement and instrument rating, and preparation for air transport pilot license exam.

Crosswind Aviation
3814 Dundas
London, Ontario, Canada N5V-5C6
ph.: (519) 268-1022
(http://www.crosswindaviation.com/)

A small company offering commercial pilot license.

E-Z Air Helicopter Services
Building 19, City Centre Airport
Suite 203
63 Airport Road
Edmonton, Alberta, Canada
ph.: (780) 453-2058; fax: (780) 453-2080
(http://www.e-zair.coml)

Courses offered for both private and commercial helicopter pilot licenses; advanced courses include those for mountain, instrument, and night ratings. Web site includes information in Japanese for international students from Japan.

Harv's Air Service
Steinbach South Airport, Box 1056
Steinbach, Manitoba, Canada ROA 2A0
ph.: (202) 326-2434; fax: (204) 326-4182
(http://www.harvair.mb.ca/)

Offers on-line ground school and checklists for Canadian and foreign students. Courses are for both private and commercial pilot licenses, with miscellaneous courses for gravel runways, tail draggers, and cold weather experience; also offers training for agriculture and missionary pilots.

Inflight Innovations
Suite 811, 300-8120 Beddington Boulevard, NW
Calgary, Alberta, Canada T3K 2A8
ph.: (403) 230-1951; fax: (403) 230-2784
(http://www.inflightinnovations.comjindex.html)

Offers a preparatory program for cabin crew training, including emergency and safety procedures, evacuation drills, and inflight medical emergencies.

Mount McKay Flying Services
112-305 Hector Dougall Way
Thunder Bay, Ontario, Canada P7E 6M5
ph.: (807) 475-8660; fax: (807) 626-8923
(http://www.mount-mckay.com)

Programs offered include recreational pilot permit, licenses for both private and commercial pilots, instrument and night ratings.

Okanagan Aviation
Vernon Regional Airport
6200 Tronson Road
Vernon, British Columbia, Canada V1H iNS
ph.: (250) 549-5221; fax: (250) 549-5268
(http://www.okanagan-aviation.com)

More than eighteen years experience; offers flight training for private and commercial pilot licenses, and for instructor, multiengine, and night ratings. Another training option is the recreational pilot permit.

Pacific Flying Club
Boundary Bay Airport, Unit 96
4400 72 Street
Delta, British Columbia, Canada V4K 5B3
ph.: (604) 946-0011; fax: (602) 946-0821
(http://www.pacificflying.com)

Operating for thirty-six years; training program includes private pilot ground school, private and commercial pilot licenses, night endorsement, and ratings for multi-engine, instrument, instructor, and multiengine instructor.

Providence Aviation
Providence College

Otterbume, Manitoba, Canada ROA 100
ph.: (204) 433-7488; fax: (204) 433-7158
(http://www.harvair.mb.calprovidence/)

Specializes in the training of missionary and commercial pilots; offers three programs leading to recreational, private, and commercial pilot licenses.

Scotia Flight Centre (1994)
P.O. Box 44
Cambridge, Nova Scotia, Canada BOP 100
ph.: (877) 538-8057; fax: (902) 538-7353
(http://www.scotiaflight.ns.ca/index.htm)

Flight training for recreational permit, private and commercial pilot licenses, night and multiengine ratings, and single/multiengine flight instructor ratings. Assists with financing for student loans.

MEXICO

SEA Mexico
Aeropuerto Dr.
Jorge Jiménez Cantñ, Hangar 8
52930 Atizapán de Zaragoza
Edo. De Mexico
ph.: 53-08-05-52; fax: 53-08-30-52
(http://seamexico.com/portal/)

Offers both private and commercial pilot training.

Ellen Elghobashi

Museums of North America

UNITED STATES

Air Force Flight Test Center Museum
Edwards Air Force Base
405 S. Rosamond Boulevard
Palmdale, CA 93524
ph.: (661) 277-8050
(afftc.edwards.af.mil/trip/)

The birthplace of supersonic flight, where Chuck Yeager broke the sound barrier in 1947, Edwards Air Force Base hosts a museum devoted to flight testing and flight research. A variety of aircraft are stationed both outdoors and indoors. Museum exhibits address the formation of the ancient lakebeds, early homesteading, the first military uses of Edwards, World War II flight testing, high-speed flight, and aircraft hardware, rocket engines, and models.

Air Mobility Command Museum
1301 Heritage Road
Dover Air Force Base, DE 19902
ph.: (302) 677-5938
(www.amcmuseum.org)

The museum preserves military airlift and tanker aircraft and displays memorabilia highlighting the lives of the men and women who flew and supported them.

The Air Museum "Planes of Fame"
7000 Merrill Avenue
Chino, CA 91710
ph.: (909) 597-3722
(www.planesoffame.org/)

The museum displays aircraft spanning the history of flight, from a replica of Octave Chanute's 1896 hang glider through modern spaceflight.

Air Victory Museum
South Jersey Regional Airport
68 Stacy Haines Road
Medford, NJ 08055
ph.: (609) 267-4488
(www.airvictorymuseum.org/)

The museum features a number of aircraft, most on conditional loan from the National Museum of Naval Aviation in Pensacola, Florida, including the A-4, A-7, E-2, F-4, F-14, F-86, F-104, P-51, and the RH-53.

Alaska Aviation Heritage Museum
421 Aircraft Drive
Anchorage, AK 99502
ph.: (907) 248-5325
(home.gci.net/~aahml)

Located on the south shore of the Lake Hood Seaplane Base, the museum features an exhibition of twenty-one historic Alaskan bushplanes, galleries devoted to pioneer and military flight, films, and a gift shop.

American Airpower Heritage Museum
Confederate Air Force Headquarters
Midland International Airport
9600 Wright Drive
Midland, TX 79711
ph.: (915) 567-3009
(www.airpowermuseum.org)

Extensive collection of World War II-era military aircraft, many in flying condition.

American Helicopter Museum
Brandywine Airport
1220 American Boulevard
West Chester, PA 19380
ph.: (610) 436-9600.
(www.helicoptermuseum.org)

An extensive collection of rotorcraft, by manufacturers such as Bell, Boeing, Hughes, Piasecki, and Sikorsky, among others. The museum features the only V-22 Osprey open to public display in the world.

Ames Visitor Center
Moffett Field
Mountain View, CA 94035
ph.: (650) 604-6274
(amesnews.arc.nasa.gov/pages/outreachfolder/visitorcenter/visitorcenter.html)

A public exhibit hall featuring displays on NASA's historic accomplishments and ongoing research. Exhibits include wind tunnel models, a Mercury spacecraft, a Moon rock, space suits, and several research aircraft. Ongoing research programs are highlighted with models and interactive computer software.

Aviation Museum of Kentucky
Blue Grass Airport
Hangar Drive
Lexington, KY 40544
ph.: (859) 231-1219
(www.aviationky.org)

The museum, on 12,000 square feet of display area, also encompasses a fully equipped shop for aviation restoration projects.

Lawrence D. Bell Aircraft Museum
P.O. Box 411
Mentone, IN 46539
ph.: (219) 353-7684
(www.livingweb.com/bell/)

A museum dedicated to the history and development of Bell aircraft, includes exhibits and a UH-1 Huey helicopter that served in the Vietnam War.

Berlin Airlift Historical Foundation
P.O. Box 782
Farmingdale, NJ 07727
ph.: (732) 818-0034
(www.avialantic.com/bahf.html)

This flying museum, inside a restored Douglas C-54 "Spirit of Freedom" cargo aircraft, travels to air shows around the country, with exhibits about the Berlin Airlift of 1948-1949.

Blackbird Airpark
Edwards Air Force Base
Palmdale, CA 93524
ph.: (805) 277-8050
(www.edwards.af.mil/museum/docs_html/
blackbird_airpark.html)

Dedicated in September 1991, the Blackbird Airpark is located on approximately three acres of the Air Force Flight Test Center. It is the world's only display of a Lockheed SR-71A together with its Blackbird predecessor, the A-12, and the once ultra-secret D-21 drone.

Castle Air Museum
Adjacent to Atwater Airport, formerly Castle Air Force Base
Santa Fe Road
Atwater, CA 95301
ph.: (209) 726-2011
(www.elite.net/castle-air/index.htm)

Over forty military aircraft on outdoor display, including B-17 Flying Fortress, B-29 Superfortress, B-52 Stratofortress, and an SR-71 Blackbird spy plane.

Cavanaugh Flight Museum
4572 Claire Chennault
Dallas, TX 75228
ph.: (214) 380-8800
(www.cavanaughflightmuseum.com/)

The museum encompasses nearly 50,000 square feet of display area in four hangars, containing aircraft flown from World War I through the Vietnam War. Exhibits also include aviation-related artwork and artifacts.

Champlin Fighter Museum
Falcon Field
4636 Fighter Aces Drive
Mesa, AZ 85215
ph.: (602) 830-4540
(www.champlinfighter.com)

An international collection of thirty-eight flight-ready fighter aircraft, from the early open-cockpit biplanes of World War I to the powerful jets of the Vietnam War and Operation Desert Storm.

Octave Chanute Aerospace Museum
1011 Pacesetter Drive
Rantoul IL 61866
ph.: (217) 893-1613
(www.aeromuseum.org)

On the grounds of the former Chanute Air Force Base, the museum displays and preserves the proud history of Chanute Air Force Base, the United States Air Force, and Illinois aviation, with more than forty aircraft and missiles on display, including replicas of Charles A. Lindbergh's *Spirit of St. Louis* and Chanute Field's first aircraft, the Curtiss Jenny biplane. The world's only remaining Boeing XB-47 Stratojet prototype is also on exhibit.

College Park Airport Museum
6709 Cpl. Frank Scott Drive
College Park, MD 20740
ph.: (301) 864-6029
(www.avialantic.com/collpark.html)

The airport was established in 1909, when Orville and Wilbur Wright agreed to train Army pilots, and it became the site of the first Army Aviation School in 1911. The museum's collection of aircraft and artifacts reflect the history of the "world's oldest continuously operating airport."

Combat Air Museum
Hangars 602-604, J Street
Forbes Field
Topeka, KS 66620
ph.: (785) 862-3303
(www.combatairmuseum.org/index.htm)

The museum houses a variety of civil and military aviation aircraft and memorabilia, ranging in time from World War I to the space shuttle program.

Cradle of Aviation Museum
Mitchel Field
Garden City, NY 11530
ph.: (516) 572-0411
(www.cradleofaviation.org/)

Billed as the "Centerpiece of the museums at Mitchel Center," the museum's exhibits span the history of aviation, with particular emphasis on the aviation heritage of Long Island.

Curtiss Museum
Route 54
Hammondsport, NY 14840
ph.: (607) 569-2160

The museum is dedicated to the legacy of aircraft designer Glenn H. Curtiss, emphasizing his work from the turn of the century through the 1930's. A full-scale flying reproduction of Curtiss's June Bug and a fully restored Jenny highlight the collection.

EAA Air Adventure Museum
Experimental Aircraft Association
Wittman Field
3000 Poberezny Road
Oshkosh, WI 54902
ph.: (920) 426-4818
(www.eaa.org)

The museum features more than ninety full-size aircraft, ranging from the early days of aviation to modern homebuilt aircraft.

Eighth Air Force Museum
P.O. Box 10
Barksdale Air Force Base
Bossier City, LA 71110
ph.: (318) 456-3067

Chronicles the history of the U.S. Eighth Air Force with a variety of bomber, fighter, training, and transport aircraft.

Evergreen Aviation Museum
3850 Three Mile Lane
McMinnville, OR 97218
ph.: (503) 472-9361
(www.sprucegoose.org)

A 121,000-square-foot facility featuring the famous Hughes Flying Boat, better known as the *Spruce Goose*.

Flying Leatherneck Aviation Museum
Marine Corps Air Station
Miramar, CA
ph.: (858) 577-6125
(www.flyingleathernecks.org/)

The museum houses an inventory of forty historically significant military aircraft, with more than two dozen presently on static display, including the F-4 Phantom II, the F/A-18 Hornet, and a MiG-15.

Flying Tigers Warbird Restoration Museum
231 North Hoagland Boulevard
Kissimmee, FL 34741
ph.: (407) 933-1942
(www.warbirdmuseum.com/)

At this museum-restoration facility, World War II aircraft are refurbished to their former glory and flown for spectators.

Grissom Air Museum
6500 Hoosier Boulevard
Peru, IN 46970
ph.: (765) 688-2654

The museum features military aircraft from World War II through the Gulf War, including the B-17, A-10, F-11F, C-47, B-25, F-100, T-33, B-47, KC-97, C-119, F-105, F-4, O-2, U-3, EC-135, C-1 and UH-1H.

Hill Aerospace Museum
7961 Wardleigh Road
Hill Air Force Base, UT 84056
ph.: (801) 777-6868
(www.hill.af.mil/museum)

Portrays the history of Hill Air Force Base, its tenants, and the assignments of the Ogden Air Logistics Center by collecting, preserving, and displaying historically significant USAF artifacts.

Hiller Aviation Museum
601 Skyway Road
San Carlos, CA 94070
ph.: (650) 654-0200
(www.hiller.org)

The museum, opened in 1998, highlights Northern Californian aviation advances with a collection of vintage and futuristic aircraft that chronicle aviation's past and suggest its future.

International B-24 Memorial Museum
Pueblo Historical Aircraft Society
31001 Magnuson Avenue
Pueblo, CO 81001
ph.: (719) 948-9219
(www.heavybombers.com/pwam/intl_b24.html)

The museum honors the thousands of aircrew members trained in Pueblo and those involved in the design, production, and military deployment of the B-24 Liberator with a collection of B-24 technical and design data, military uniforms, airborne radio equipment, photographs, flight logs and other memorabilia.

International Sport Aviation Museum
Lakeland Linder Regional Airport
Lakeland, FL 33807
ph.: (863) 644-2431
(www.sun-n-fun.org)

A 20,000-square-foot facility situated on 40 acres houses a collection of aircraft and memorabilia, a library and research center, and approximately thirty-five experimental and homebuilt aircraft along with several outdoor displays.

International Women's Air & Space Museum
Burke Lakefront Airport
1501 North Marginal Road
Cleveland, OH 44114
ph.: (216) 623-1111
(www.iwasm.org/)

Opened in 1986, the museum, currently located at Cleveland's Burke Lakefront Airport, collects and preserves memorabilia and historical artifacts relating to women and flight.

Intrepid Sea-Air-Space Museum
Pier 86
Hudson River at 46th Street
New York, NY 10036
ph.: (212) 245-0072
(www.intrepidmuseum.org)

The museum centers on the aircraft carrier USS *Intrepid*, berthed on the Hudson River, and features diverse sea, air, and space exhibits that include antisubmarine, attack, bomber, fighter, and reconnaissance aircraft.

Kalamazoo Aviation History Museum
3101 East Milham Road
Kalamazoo, MI 49002
ph.: (616) 382-6555
(www.airzoo.org)

Better known as the "Air Zoo," and home of the National Guadalcanal Memorial Museum and the Michigan Aviation Hall of Fame, the museum has restored to airworthy condition more than sixty aircraft that played major roles in World War II, the Korean War, the Vietnam War and the Gulf War

Kennedy Space Center Visitor Complex
Kennedy Space Center
Cape Canaveral, FL
ph.: (321) 449-4444
(www.ksc.nasa.gov)

Part of a working launch facility with tours and exhibits on the International Space Station, Launch Complex 39, and the Apollo, the visitor center houses an extensive collection of booster rockets, space capsules, and educational displays.

Lone Star Flight Museum
2002 Terminal Drive
Galveston, TX 77554
ph.: (409) 740-7722
(www.lsfm.org)

Features World War II-era fighters, bombers, trainers, cargo, and observation aircraft.

MAPS Air Museum
Akron-Canton Regional Airport
5359 Massillon Road
Akron, OH 44312
ph.: (330) 896-6332
(www.mapsairmuseum.org)

A collection of vintage military and significant civilian aircraft, preserved in airworthy condition.

March Field Air Museum
P.O. Box 6463
March Air Reserve Base, CA 92518
ph.: (909) 697-6602
(www.pe.net/~marfldmu/)

March Field Air Museum, the P-38 Museum, and the 475th Fighter Group Museum are located at March Air Reserve Base, Riverside, California, and are home to more than fifty historic aircraft and many exhibits relating to the history of March Field, now known as March Air Reserve Base.

Marine Corps Air/Ground Museum
Brown Field
Quantico, VA 22134
ph.: (703) 784-2606

Located at the Marine Corps Combat Development Command, the museum focuses on Marine Corps air-ground team development and its achievements.

Glenn L. Martin Aviation Museum
Martin State Airport
Hangar 5, Suite 531
Middle River, MD 21220
ph.: (410) 682-6122
(www.martinstateairport.com/museum/index.htm)

The museum's collection includes items of local historical significance; industrial models of aircraft and rockets, wind tunnel models, restored and partly restored aircraft, and many original photographs outlining the growth of the Martin Company from its beginnings in Santa Ana, California, to its current standing as the Lockheed Martin Corporation.

Mid-America Air Museum
Liberal Airport
2000 West Second Street
Liberal, KS 67901
ph.: (316) 624-5263
(www.airmuseum.net)

The fifth-largest collection of military and civilian aircraft in the United States, featuring fighters and bombers as well as experimental and general aviation aircraft. Hands-on aviation exhibits educate visitors about the science of flight.

Mid-Atlantic Air Museum
Reading Regional Airport
11 Museum Drive
Reading, PA 19605
ph.: (610) 372-7333
(www.maam.org)

The museum's collection includes more than fifty classic military and civilian aircraft.

Museum of Flight
9404 East Marginal Way South
Seattle, WA 98134
ph.: (206) 767-7373
(www.museumofflight.org)

The museum's extensive collection of civilian and military aviation and aerospace artifacts is the largest and most comprehensive in the West. Aircraft on display include a B-17 Flying Fortress, a P-51 Mustang, and Burt Rutan's VariEze.

Museum of Flying
2772 Donald Douglas Loop North
Santa Monica, CA 90405
ph.: (310) 392-8822
(www.museum of flying.com)

The museum houses a collection of World War II fighter aircraft, most in flight-ready condition, including a P-39 Airacobra, a P-40 Warhawk, a P-47 Thunderbolt, a P-51 Mustang, and British Spitfires and Hurricanes. Also included are the Douglas A-4, DC-2, DC-3, AD-6 Skyraider, A-26, and a 1924 World Cruiser, as well as a Jenny and other early planes.

National Air and Space Museum
Seventh and Independence Avenues, SW
Washington, DC 20560
ph.: (202) 357-2700
(www.nasm.edu)

Part of the Smithsonian Institution, the National Air and Space Museum maintains the world's largest collection of historic aircraft, spacecraft, and aviation memorabilia, which includes the original 1903 Wright *Flyer*, the *Spirit of St. Louis,* and the Apollo 11 Command Module. The museum is also an important center for aviation and spaceflight research.

National Atomic Museum
Kirtland Air Force Base
Albuquerque, NM
ph.: (505) 845-6670
(www.oz.net/~chrisp/natatom.htm)

Operated by the U.S. Department of Energy, the museum contains a large collection of declassified nuclear technology and serves as a repository of educational materials and information on the Atomic Age.

National Model Aviation Museum
5151 East Memorial Drive
Muncie, IN 47302
ph.: (765) 287-1256
(www.modelaircraft.org/Mus/Museum.htm)

The largest collection of model aircraft in the United States.

National Museum of Naval Aviation
Pensacola Naval Air Station
1750 Radford Boulevard

Pensacola, FL 32508
ph.: (904) 452-3543
(www.cityshowcase.com/pensacola/attract/nmna.html)

The museum features more than one hundred naval, Marine Corps, and Coast Guard aircraft, dating from the beginning of U.S. naval aviation to the present, along with photos, films, and other memorabilia.

National Soaring Museum
Harris Hill
51 Soaring Hill Drive
Elmira, NY 14903
ph.: (607) 734-3128
(www.soaringmuseum.org)

On the site of the first U.S. national soaring competition in 1930, the museum is devoted to gliders, sailplanes, and flying wings.

National Warplane Museum
17 Aviation Drive
Horseheads, NY 14845
ph.: (607) 739-8200
(www.warplane.org)

Founded to collect, preserve, interpret and exhibit military aviation memorabilia and to fly military aircraft, the museum includes a B-17 Flying Fortress, an F-14 Tomcat, and an F-15 Eagle in its exhibits.

New England Air Museum
Bradley International Airport
Windsor Locks, CT 06096
ph.: (860) 623-3305
(www.neam.org)
An extensive collection of vintage and modern airplanes, helicopters, experimental and homebuilt aircraft, gliders and ultralights, missiles and rockets, flight simulators, engines, exhibits, and artifacts.

Old Rhinebeck Aerodrome
Norton Road
Rhinebeck, NY 12572
ph.:(845) 752-3200
(www.oldrhinebeck.org)

The aerodrome presents air shows flying original pioneer, World War I, and barnstorming aircraft from 1900 to 1940 and offers barnstorming rides in a 1929 open-cockpit biplane before and after the shows.

Owls Head Transportation Museum
P.O. Box 277
Route 73
Owls Head, ME 04854
ph.: (207) 594-4418
(www.ohtm.org)

A museum celebrating the entirety of transportation history, with more than one hundred pioneer-era aircraft replicas and originals representing the first century of flight, from Sir George Cayley's unmanned glider of 1804 to the legendary Curtiss Jenny of the barnstorming era.

Pacific Coast Air Museum
Santa Rosa Airport
2330 Airport Boulevard
Santa Rosa, CA 95403
ph.: (707) 575-7900
(www.pacificcoastairmuseum.org)

An organization devoted to the acquisition and preservation of contemporary military aircraft, many only recently out of active service, including the F-8U Crusader, the A-6E Intruder, and the A-4E Skyhawk.

Patriots Point Naval and Maritime Museum
40 Patriots Point Road
Mount Pleasant, SC 29464
ph.: (803) 884-2727
(www.cwsmf.org/patriots.htm)

The museum, located on Charleston harbor, features more than twenty aircraft and is home to World War II aircraft carrier USS *Yorktown*, the diesel submarine USS *Clamagore*, the destroyer USS *Laffey*, and the USCG cutter *Ingham*.

Pearson Air Museum
1115 East Fifth Street
Vancouver, WA 98661
ph.: (360) 694-7026
(www.pearsonairmuseum.org)

Located on the grounds of Pearson Field, the birthplace of Pacific Northwest aviation, the museum features a hangar housing numerous permanent and rotating aircraft, including the Curtiss Jenny; a restoration facility; a hands-on children's center; and a theater.

Pima Air and Space Museum
6000 East Valencia Road
Tucson, AZ 85706
ph.: (520) 574-0462
(www.pimaair.org)

Founded in 1976, the museum features a collection of more than 250 aircraft on 80 acres of land.

Pueblo Historical Aircraft Society
31001 Magnuson Avenue
Pueblo, CO 81001
ph.: (719) 948-9219
(www.puebloonline.com/PHAS/)

The museum, on the grounds of the former World War II Pueblo Army Air Base, features numerous military aircraft, including a B-29 Superfortress, an A-26 Invader, and an F-100 Super Sabre.

Redstone Arsenal
Huntsville, AL
ph.: (256) 876-2151
(www.redstone.army.mil)

With a primary focus on rocketry, the museum features an Atlas missile, Saturn IB and V missiles, as well as other assorted missiles and satellites, and space capsules used in the Mercury, Gemini, and Apollo programs.

San Diego Aerospace Museum
2001 Pan American Plaza
Balboa Park
San Diego, CA 92101
ph.: (619) 234-8291
(www.aerospacemuseum.org)

The museum's collection of over sixty-five U.S. and foreign aircraft and spacecraft spans the history of aviation, with particular emphasis on San Diego's numerous contributions to the aerospace industry.

Strategic Air and Space Museum
28210 West Park Highway
Ashland, NE 68003
ph.: (402) 944-3100
(www.strategicairandspace.com/)

The museum preserves the history of the U.S. Strategic Air Command and its role in securing peace while offering an ever-increasing number of exhibits and programs on math, science, engineering, aviation, and space.

Texas Air Museum
8406 Cadmus
San Antonio, TX 78214
ph.: (210) 977-9885
(www.texasairmuseum.org)

The Stinson Chapter of the Texas Air Museum, one of three of the museum's branches, presents the history of flight from the early days of aviation to the present. The museum's collection features rare aircraft, including the world's largest exhibit of German Focke-Wulf FW-190's.

Thunderbirds Museum
4445 Tyndall Avenue
Nellis Air Force Base, NV 89191
ph.: (702) 652-7200
(www.nellis.af.mil)

A behind-the-scenes tour of the U.S. Air Force aerial demonstration squadron's facilities includes a short video presentation of Thunderbird history, a question and answer session, and a walk through the team's museum and hangar, which houses a U.S. Air Force F-16.

Tillamook Naval Air Station Museum
6030 Hangar Road
Tillamook, OR 97141
ph.: (503) 842-1130
(www.TillamookAir.com)

A relatively new museum, located in a World War II blimp hangar, features several airships, including the Cyclo-Crane prototype. The museum also features various civil and military aircraft, most in flight-ready condition, including a P-51 Mustang, an Me-109, and a Spitfire fighter.

Titan Missile Museum
1580 West Duval Mine Road
Sahuarita, AZ
ph.: (602) 574-0646
(www.pimaair.org/titan_01.html)

Turned over to the public by the U.S. Air Force in 1986, the only remaining Titan II missile launch site has been converted into a museum. Hour-long guided tours are led through the Titan missile silo complex.

Travis Air Museum
Building 80
Burgan Boulevard
Travis Air Force Base
Fairfield, CA
ph.: (707) 424-5605

On the grounds of Travis Air Force Base, the museum features photographs, uniforms, and memorabilia detailing the history of the base. The museum's collection of transport aircraft details the growth of airlift aviation.

United States Air Force History and Traditions Museum
Lackland Air Force Base
San Antonio, TX 78236
ph.: (512) 671-3444

Chronicles the history of the U.S. Air Force with a variety of bomber, fighter, reconnaissance, training, and transport aircraft.

United States Air Force Museum
1100 Spaatz Street
Wright-Patterson Air Force Base
Dayton, OH 45433
ph.: (937) 255-3286
(www.wpafb.af.mil/museum/)

A large museum dedicated to the U.S. Air Force and the history of U.S. military aviation, from the early years of powered human flight to the advent of spaceflight.

United States Army Aviation Museum
P.O. Box 620610-0610
Fort Rucker, AL 36362
ph.: (334) 598-2508
(www.armyavnmuseum.org)

More than ninety aircraft, including the world's largest helicopter collection. The museum emphasizes the role of aviation in support of U.S. Army operations.

United States Army Transportation Museum
300 Washington Boulevard
Besson Hall
Fort Eustis, VA 23604
ph.: (804) 878-3603
(www.eustis.army.mil/DPTMSEC/Museum.htm)

The museum is devoted entirely to the history of U.S. Army transportation from colonial days to present, highlighting the importance of logistical support to the Army.

Virginia Aviation Museum
Richmond International Airport
5701 Huntsman Road
Richmond, VA 23250
ph.: (804) 236-3622
(www.smv.org/wvamhome.html)

A division of the Science Museum of Virginia, the Virginia Aviation Museum highlights the golden age of aviation with an extensive collection of vintage flying machines, such as Captain Dick Merrill's 1930's open-cockpit mail plane; a 1929 Ford Trimotor; flight-ready replicas of the Wright brothers' 1900, 1901, and 1902 gliders; and a World War I Spad VII.

War Eagles Air Museum
Santa Teresa Airport
Santa Teresa, NM 88008
ph.: (505) 589-2000

The museum's collection focuses on military aircraft of the World War II and Korean War eras, most of which are maintained in flight-ready condition.

Warhawk Air Museum
Caldwell Industrial Airport
4917 Aviation Way, ID 83605
ph.: (208) 454-2854

The museum preserves World War II history with a collection of fighter planes and memorabilia.

Western Aerospace Museum
North Field, Oakland Airport
8260 Boeing Street
Oakland, CA 94621
ph.: (510) 638-7100

The museum features military and civilian aircraft on the active and historic North Field at Oakland Airport.

Western Museum of Flight
Hawthorne Municipal Airport
12016 Prairie Avenue
Hawthorne, CA 90250
ph.: (310) 332-6228
(www.wmof.com)

Located at historic Jack Northrop Field, the combination museum and restoration facility maintains a collection of completed and in-progress aircraft projects. The museum's collection includes numerous aircraft and target drones; piston and jet aircraft engines; aircraft components, instruments, and accessories; aviation memorabilia; and an extensive model aircraft collection.

Wings of History Air Museum
12777 Murphy Avenue
San Martin, CA 95046
ph.: (408) 683-2290
(www.wingsofhistory.org)

A museum dedicated to the preservation and restoration of antique and unique aircraft and other aviation artifacts.

Wings over the Rockies Aviation and Space Museum
Lowry Campus (formerly Lowry Air Force Base)
Hangar 1
7711 East Academy Boulevard
Denver, CO 80220
ph.: (303) 360-5360
(www.dimensional.com/~worm/)

Opened in 1994 on the former Lowry Air Force Base, the museum seeks to document and preserve Colorado's rich aviation and aerospace heritage with an artifact collection, exhibits, archives, library, workshops, and a collection of more than thirty aircraft, ranging from tiny homebuilt sport planes to the advanced B-1A Lancer supersonic jet bomber.

Wilbur Wright Birthplace
1651 County Road 750 East
Hagerstown, IN
ph.: (317) 332-2495
(www.geocities.com/Heartland/Forest/8737/)

The museum houses a replica of the 1903 Wright *Flyer* and the wind tunnel where the Wrights tested many of their ideas. A multimedia timeline introduces visitors to Wilbur and Orville Wright, their sister Katherine, and other members of the Wright family.

Wright Brothers National Memorial
1401 National Park Drive
Manteo, NC 27954
ph.: (252) 441 7430
(www.nps.gov/wrbr/)

A national park marks the location of the Wright brothers' historic first flight in 1903 at Kill Devil Hills. The visitor center features reproductions of the Wrights' 1902 glider and 1903 *Flyer.*

Yankee Air Museum
Willow Run Airport
Ypsilanti, MI 48198
ph.: (313) 483-4030
(www.eecs.umich.edu/~coalitn/sciedoutreach/exploringsci/tourlisting/yankee.html)

A "working museum," with aircraft restoration and maintenance performed on one of the museum's floors, the Yankee Air Museum features displays of military aircraft dating from World War I to the Gulf War.

CANADA

Aerospace Museum Association of Calgary
4629 McCall Way NE
Calgary, AB T2E 7H1
ph.: (403) 250-3752
(www.asmac.ab.ca/)

Originally a Royal Air Force drill hall, the museum building contains a variety of historical information about Canadian aviation history, both civil and military.

Atlantic Canada Aviation Museum
Halifax International Airport
Enfield, NS
ph.: (902) 873-3773
(www.acam.ednet.ns.ca)

Founded in 1977, the museum moved to its present location in the mid-1980's and has since amassed a collection of more than twenty aircraft reflecting the aviation history of Atlantic Canada.

Canadian Museum of Flight and Transportation
Hangar 3
5333 216th Street
Langley, BC V2Y 2N3
ph.: (604) 535-1115
(www.canadianflight.org)

A museum and restoration site dedicated to the collection and preservation of historical aircraft in Canada houses more than twenty-five aircraft, both static and flying.

Canadian War Museum
General Motors Court
330 Sussex Drive
Ottawa, ON K1A 0M8
ph.: (819) 776-8600
(www.pch.gc.ca/ac-os/war-e.htm)

The museum examines the war and war-related history of Canada and its effect upon Canada and Canadians and documents Canadian military contributions to peacekeeping and the maintenance of national and international security.

Canadian Warplane Heritage Museum
Hamilton International Airport
9280 Airport Road
Mount Hope, ON
ph.: (877) 347-3359
(www.warplane.com)

A living museum featuring the aircraft used by Canadians or Canada's military from the beginning of World War II to the present day.

Greenwood Military Aviation Museum
P.O. Box 786
Greenwood, NS B0P 1N0
ph.: (902) 765-1494
(gmam.ednet.ns.ca)

The museum houses permanent and temporary exhibits reflecting the history of Canadian military units stationed at CFB Greenwood.

Ontario National Aviation Museum
11 Aviation Parkway
Ottawa, ON K1K 4R3
ph.: (613) 993-2010
(www.aviation.nmstc.ca/eng/english_home.html)

A large museum offering a wide variety of programs and exhibits on the history of aviation and aircraft in Canada.

Royal Canadian Air Force Memorial Museum
P.O. Box 1000
Stn. Forces
Astra, ON K0K3W0
ph.: (613) 965-2140
(www.rcafmuseum.on.ca)

An 8-acre air park housing approximately fourteen aircraft, including CP107 Argus, CF100, DC-3 Dakota, MiG-21, CF-5, Hawker Hunter, Bell Kiowa, CT-134 Musketeer, F-86 Sabre, T-33 Silver Star, CF-104 Starfighter, CT-114 Tutor, and CF-101 Voodoo.

Shearwater Aviation Museum
Building 12
P.O. Box 5000
Stn Main.
Shearwater, NS B0J 3A0
ph.: (902) 460-1083
(www3.ns.sympatico.ca/awmuseum)

A museum dedicated to Canadian maritime military aviation.

Western Canada Aviation Museum
Hangar T-2
958 Ferry Road
Winnipeg, MB R3H 0Y8
ph.: (204) 786-5503

The museum emphasizes the important role of aviation in the opening of Western Canada.

Heather Stratton Williams

International Airports

The world's one hundred busiest airports during the year 2000 are listed in descending volume of traffic.

1. William B. Hartsfield Atlanta International Airport (ATL) is located ten miles from downtown Atlanta, Georgia. In 2000, it was the world's busiest airport, serving 80,171,036 passengers. Approximately 2,400 flights fly into and out of Hartsfield Atlanta every day. The 3,750-acre airport serves as the main hub and corporate headquarters for Delta Air Lines.

2. Chicago O'Hare International Airport (ORD) is located eighteen miles from downtown Chicago, Illinois. In 2000, it served 72,135,887 passengers. O'Hare encompasses 7,700 acres and serves as United Air Lines' main hub. O'Hare's three-letter airport code, ORD, reflects the fact that the airport was originally called Orchard Field. The Chicago city council renamed the airport in 1949 in honor of Lieutenant Edward O'Hare, a young U.S. Navy pilot who was killed in World War II.

3. Los Angeles International Airport (LAX) is located fourteen miles to the west of downtown Los Angeles, California. In 2000, it served 68,477,689 passengers. LAX covers 3,500 acres.

4. Heathrow Airport (LHR) is located fifteen miles west of central London, England. The average trip between the airport and central London on the Underground (subway) takes fifty to sixty minutes. In 2000, it served 64,607,185 passengers. Ninety airlines operate an average of 1,250 flights daily into and out of the airport. Heathrow's busiest routes are New York, Paris, Amsterdam, and Dublin. The airport's World Wide Web site notes that some of the strangest items to pass through its Lost and Found office have been a glass eye, a suitcase full of dead fish, and a false leg.

5. Dallas/Fort Worth International Airport (DFW) is located in the cities of Euless, Grapevine, Irving, and Coppell, Texas. The airport is eighteen miles away from downtown Dallas and twenty-three miles from downtown Fort Worth. In 2000, it served 60,687,122 passengers. This mammoth airport, the second largest in the United States and the third largest in the world, covers 29.8 square miles and comprises 18,076 acres. American Airlines maintains its main hub here.

6. Tokyo International Airport (HND), located at Haneda, Japan, is named an international airport even though only one international airline flies there: China Airlines, with flights to Taipei and Honolulu. All other international flights arrive at and depart from Narita (the Tokyo New International Airport). However, Haneda is Tokyo's main domestic travel hub. On average, 632 flights take off from Haneda every day. In 2000, it served 56,402,206 passengers.

7. Frankfurt Airport (FRA) is located twelve kilometers (eight miles) southwest of the center of Frankfurt, Germany. In 2000, it served 49,369,429 passengers. It was Europe's second busiest passenger airport after Heathrow, and Europe's busiest airport for cargo, processing 1.71 million metric tons. Frankfurt Airport is also Germany's single largest workplace, employing approximately 62,000 workers. Frankfurt handles roughly 1,250 flights a day.

8. Charles de Gaulle/Roissy International Airport (CDG) is located twenty-three kilometers (fourteen miles) northeast of downtown Paris, France. In 2000, it served 48,240,137 passengers. It was the third-busiest airport in Europe, after Heathrow and Frankfurt.

9. San Francisco International Airport (SFO) is located fourteen miles south of San Francisco, California. In 2000, it served 41,173,983 passengers. Seventy-four airlines serve SFO, including thirty-four international airlines. The largest two airlines flying into SFO are United, with 51 percent of the market share, and American Airlines, with 6 percent.

10. Amsterdam Airport Schiphol (AMS) is located fifteen kilometers (nine miles) southwest of Amsterdam, the Netherlands. In 2000, it served 39,60,589 passengers. It was also the fourth-busiest European airport, after Heathrow, Frankfurt, and Charles de Gaulle/Roissy.

11. Denver International Airport (DEN) is located twenty-three miles northeast of downtown Denver, Colorado. The airport comprises fifty-three square miles of land, twice the size of Manhattan Island, and is larger than the cities of Boston, Miami, or San Francisco. In 2000, it served 38,748,781 passengers. On average, 1,371 flights pass through this airport every day. United Air Lines maintains one of its hubs here.

12. McCarran International Airport (LAS) is located one mile from the south end of the Las Vegas strip in Las Vegas, Nevada. In 2000, it served 36,856,186 passengers. McCarran International Airport is named after Nevada senator Paul McCarran, who worked to pass the first civil aviation laws in the United States in the 1930's.

13. Kimpo International Airport (SEL) is located seventeen kilometers (eleven miles) to the west of downtown Seoul, South Korea. In 2000, it served 36,727,124 passengers.

14. Minneapolis/St. Paul International Airport (MSP) is located sixteen miles south of downtown Minneapolis and twelve miles south of downtown St. Paul, Minnesota. In 2000, it served 36,688,159 passengers. The airport averages 1,480 flights a day. Northwest Airlines maintains one of its hubs here, and Northwest flights make up almost 77 percent of MSP's total flights.

15. Phoenix Sky Harbor International Airport (PHX) is located in the center of Phoenix, Arizona. In 2000, it served 35,889,933 passengers. Sky Harbor averages 1,300 daily flights and covers 3,000 acres of land.

16. Detroit Metropolitan Wayne County Airport (DTW) is located twenty miles to the southwest of downtown Detroit, Michigan. In 2000, it served 35,535,080 passengers. Detroit Metro Airport averages more than 1,500 landings and takeoffs daily. The airport encompasses approximately 6,700 acres. Northwest Airlines also maintains one of its hubs at DTW.

17. Bush Intercontinental Airport (IAH) is located twenty-three miles north of downtown Houston, Texas. In 2000, it served 35,246,176 passengers. The airport comprises more than 9,000 acres in area. Continental Airlines maintains a hub at Bush Intercontinental, operating five hundred flights daily. When the airport opened in 1969, it was known as Houston Intercontinental Airport. The airport's three-letter designation (IAH) is derived from its original name. The airport was renamed in 1997 in honor of former President George Bush, a longtime Houston resident.

18. Newark International Airport (EWR) is located two miles south of Newark, New Jersey, and about sixteen miles southwest of midtown Manhattan. In 2000, it served 34,194,788 passengers. The airport covers 2,027 acres.

19. Miami International Airport (MIA) is located nine miles west of Miami, Florida. In 2000, Miami served 33,569,625 passengers. The airport comprises 3,230 acres.

20. John F. Kennedy International Airport (JFK) is located in southeastern Queens County, New York, on Jamaica Bay. It is approximately fifteen miles from midtown Manhattan. In 2000, JFK served 32,779,428 passengers. The airport consists of 4,930 acres. The airport was originally named New York International Airport at its dedication in 1948; it was renamed on December 24, 1963, to honor the slain U.S. president.

21. Madrid/Barajas International Airport (MAD) is located in Barajas, Spain, thirteen kilometers (eight miles) northeast of central Madrid. In 2000, Madrid/Barajas served 32,765,820 passengers.

22. Hong Kong International Airport (HKG) is located in Chek Lap Kok, China, forty kilometers (twenty-four miles) from central Hong Kong. The Chek Lap Kok airport replaced the old terminal at Kai Tak in 1998. In 2000, Hong Kong International served 32,746,737 passengers. The airport extends over 1,255 hectares (3,100 acres).

23. Gatwick Airport (LGW) is located twenty-eight miles south of London, England. In 2000, Gatwick served 32,056,942 passengers. Gatwick covers 1,678 acres. Gatwick is the world's busiest single-runway airport. The name Gatwick dates back to 1241, when Richard de Warwick deeded the land on which the airport currently stands to John de Gatwick.

24. Orlando International Airport (MCO) is located nine miles southeast of downtown Orlando, Florida. In 2000, Orlando International served 30,822,580 passengers. Orlando International's total area comprises almost fifteen thousand acres, making it the third-largest airport in the United States. The airport code MCO comes from the former McCoy Air Force Base, where Orlando International now stands.

25. Lambert-St. Louis International Airport (STL) is located thirteen miles northwest of downtown St. Louis, Missouri. In 2000, Lambert-St. Louis served 30,546,698 passengers. Lambert occupies approximately two thousand acres of land. In 1999, Lambert hosted 1,377 daily landings and takeoffs.

26. Bangkok International Airport (BKK) is located approximately twenty-four kilometers (fifteen miles) north of Bangkok, Thailand, in an area called Don Muang. In 2000, Bangkok International served 29,621,898 passengers.

27. Lester B. Pearson International Airport (YYZ) is located sixteen miles northwest of downtown Toronto, Ontario, Canada. In 2000, it served 28,820,326 passengers. The airport covers 4,430 acres and is named after former Canadian prime minister Lester Pearson.

28. Singapore Changi Airport (SIN) is located twenty kilometers (thirteen miles) northeast of Singapore. In 2000, it served 28,618,200 passengers.

29. Seattle/Tacoma International Airport (SEA) is located twelve miles south of downtown Seattle and twenty miles north of Tacoma, Washington. In 2000, it served 28,404,312 passengers. The airport covers 2,500 acres.

30. Logan International Airport (BOS) is located in East Boston, Massachusetts, four miles northeast of downtown Boston. In 2000, it served 27,412,926 passengers. The airport covers 2,400 acres and is named after Edward Lawrence Logan, former lieutenant general of Massachusetts.

31. New Tokyo International Airport (NRT), better known as Narita Airport, is located in the city of Narita, Japan, in Chiba Prefecture, sixty-five kilometers (forty miles) east of central Tokyo. It takes a little over an hour to get to the airport by train from central Tokyo. In 2000, Narita served 27,389,915 passengers.

32. Leonardo da Vinci/Fiumicino International Airport (FCO) is located twenty-six kilometers (sixteen miles) southwest of central Rome, Italy. In 2000, it served 25,921,886 passengers.

33. Orly International Airport (ORY) is located fourteen kilometers (nine miles) south of central Paris, France. In 2000, it served 25,399,111 passengers. The airport covers 3,700 acres.

34. Fiorello LaGuardia International Airport (LGA) is located in the borough of Queens, New York City. It borders Flushing Bay and Bowery Bay. LaGuardia is eight miles from midtown Manhattan. In 2000, it served 25,233,889 passengers. LaGuardia is a fairly small airport, consisting of only 680 acres. It is named after the former mayor of New York City, Fiorello LaGuardia. LaGuardia can also claim another dubious distinction: in 2000, this airport had 61,120 delayed flights, more than any other U.S. airport.

35. Philadelphia International Airport (PHL) is located seven miles from downtown Philadelphia, Pennsylvania. In 2000, it served 24,900,621 passengers. The airport covers 2,302 acres.

36. Sydney Kingsford-Smith International Airport (SYD) is located nine kilometers (six miles) south of the central business district of Sydney, Australia. In 2000, it served 23,553,878 passengers. The airport covers 881 hectares (2,177 acres) and is named after Sir Charles Kingsford-Smith, a famous Australian aviator.

37. Munich International Airport (MUC) is located twenty-eight kilometers (eighteen miles) northeast of downtown Munich, Germany. In 2000, it served 23,125,872 passengers. The airport covers 1,500 hectares (3,700 acres).

38. Charlotte/Douglas International Airport (CLT) is located seven miles west of downtown Charlotte, North Carolina. In 2000, it served 23,073,894 passengers. The airport is named after former Charlotte Mayor Ben Elbert Douglas, Sr.

39. Honolulu International Airport (HNL) is located three miles west of downtown Honolulu, and seven miles from Waikiki, on the island of Oahu, Hawaii. In 2000, it served 22,660,349 passengers. The airport covers 2,200 acres.

40. Zürich International Airport (ZRH) is located twelve kilometers (eight miles) north of downtown Zürich, Switzerland. In 2000, it served 22,649,539 passengers. The airport covers 782 hectares (1,932 acres) and averages 839 takeoffs and landings a day.

41. Cincinnati/Northern Kentucky International Airport (CVG) is located thirteen miles south of Cincinnati, Ohio. In 2000, it served 22,537,525 passengers. Delta Air Lines maintains its second-largest U.S. hub here.

42. Beijing Capital International Airport (PEK) is located twenty-eight kilometers (eighteen miles) northeast of the center of Beijing, China. In 2000, it served 21,659,077 passengers. Its international airport code, PEK, comes from a time when Beijing was transliterated into English as Peking.

43. Brussels International Airport (BRU) is located thirteen kilometers (eight miles) northeast of downtown Brussels, Belgium. In 2000, it served 21,604,478 passengers. The airport covers 3,706 acres.

44. Benito Juárez International Airport (MEX) is located ten kilometers (six miles) east of downtown Mexico City, Mexico. In 2000, it served 21,042,610 passengers. The airport covers 780 hectares (1,927 acres).

45. Milan Malpensa Airport (MXP) is located forty-five kilometers (twenty-nine miles) northeast of central Milan, Italy. In 2000, it served 20,716,815 passengers.

46. Kansai International Airport (KIX) is located fifty kilometers (thirty-one miles) southwest of Osaka, Japan. Even though the airport only opened in 1994, by 2000, it served 20,472,060 passengers.

47. Washington Dulles International Airport (IAD) is located in Loudon and Fairfax Counties, Virginia, approximately twenty-six miles to the west of downtown Washington, D.C. In 2000, it served 19,971,449 passengers. The airport covers 11,000 acres and is named after John Foster Dulles, who served as U.S. secretary of state under Dwight D. Eisenhower.

48. Salt Lake City International Airport (SLC) is located ten miles from downtown Salt Lake City. In 2000, it served 19,900,810 passengers. Delta Air Lines maintains one of its hubs here.

49. Pittsburgh International Airport (PIT) is located sixteen miles northwest of downtown Pittsburgh, Pennsylvania. In 2000, it served 19,813,174 passengers. The airport covers 12,900 acres, making it the fourth-largest U.S. airport. In fact, the airport itself is twice the size of downtown Pittsburgh.

50. Barcelona International Airport (BCN) is located twleve kilometers (eight miles) southwest of central Barcelona, Spain. In 2000, it served 19,797,135 passengers.

51. Baltimore/Washington International Airport (BWI) is located eight miles southwest of Baltimore, Maryland, and thirty miles northeast of Washington, D.C. In 2000, it served 19,602,856 passengers. The airport covers 3,158 acres and hosts approximately eight hundred daily takeoffs and landings.

52. Palma de Mallorca International Airport (PMI) is located eleven kilometers (seven miles) southeast of Palma de Mallorca, Spain. In 2000, it served 19,401,807 passengers.

53. Manchester International Airport (MAN) is located sixteen kilometers (ten miles) from central Manchester, England. In 2000, it served 18,804,322 passengers.

54. Chiang Kai-Shek International Airport (TPE) is located in Tayuan, Taiwan, forty kilometers (twenty-five miles) southwest of central Taipei. In 2000, it served 18,681,418 passengers. The airport covers 1,223 hectares (3,022 acres) and is named after General Chiang Kai-Shek, a Nationalist Army leader who unsuccessfully fought the Communists for control of China. In 1949, he and his Kuomintang party fled to Taiwan.

55. Arlanda Airport (ARN) is located forty-two kilometers (twenty-six miles) north of the center of Stockholm, Sweden. In 2000, it served 18,446,309 passengers.

56. Copenhagen International Airport (CPH) is located in Kastrup, Denmark, a town on the island of Amager, eight kilometers (five miles) southeast of central Copenhagen. In 2000, it served 18,294,387 passengers. The airport covers 11 square kilometers.

57. Melbourne Airport (MEL) is located twenty-two kilometers (fourteen miles) northwest of the city of Melbourne, Australia. In 2000, it served 16,442,312 passengers. The airport covers 2,369 hectares (5,854 acres).

58. Vancouver International Airport (YVR) is located sixteen kilometers (eleven miles) from downtown Vancouver, British Columbia, Canada. In 2000, it served 16,245,209 passengers.

59. Tampa International Airport (TPA) is located six miles west of Tampa, Florida. In 2000, it served 16,041,486 passengers. The airport covers 3,300 acres.

60. Düsseldorf International Airport (DUS) is located eight kilometers (five miles) north of the center of Düsseldorf, Germany. In 2000, it served 16,028,038 passengers.

61. Fort Lauderdale Hollywood International Airport (FLL) is located in Broward County, Florida, five miles from downtown Fort Lauderdale. In 2000, it served 15,856,663 passengers. The airport operates an average of 558 flights daily.

62. Ataturk International Airport (IST) is located twenty-four kilometers (fifteen miles) west of downtown Istanbul, Turkey. In 2000, it served 15,830,526 passengers.

63. San Diego International Airport-Lindbergh Field (SAN) is located two miles north of downtown San Diego, California. In 2000, it served 15,826,221 passengers. It is one of the smallest major airports in the United States, occupying a mere 474 acres. The airport has a single runway.

64. Ronald Reagan Washington National Airport (DCA) is located six miles south of Washington, D.C. In 2000, it served 15,724,613 passengers. The airport sits on 860 acres: 733 on land, and 127 under water. Congress renamed this airport in February, 1998, to honor the former U.S. president.

65. Kuala Lumpur International Airport (KUL) is located fifty kilometers (thirty-one miles) south of central Kuala Lumpur, Malaysia. In 2000, it served 15,648,029 passengers.

66. Chicago Midway Airport (MDW) is located ten miles southwest of downtown Chicago, Illinois. In 2000, it served 15,591,487 passengers.

67. Saõ Paulo Guarulhos International Airport (GRU) is located thirty kilometers (nineteen miles) northeast of the center of Saõ Paulo, Brazil. In 2000, it served 14,218,788 passengers.

68. Oslo Airport Gardermoen (OSL) is located fifty-three kilometers (thirty-three miles) northeast of the center of Oslo, Norway. In 2000, it served 14,214,554 passengers.

69. Dublin Airport (DUB) is located eight miles (eleven kilometers) north of the city center of Dublin, Ireland. In 2000, it served 13,843,528 passengers.

70. Portland International Airport (PDX) is located ten miles northeast of the city of Portland, Oregon. In 2000, it served 13,790,115 passengers. The airport covers 3,229 acres.

71. Cleveland Hopkins International Airport (CLE) is located ten miles southeast of downtown Cleveland, Ohio. In 2000, it served 13,288,353 passengers. Continental and Southwest Airlines each maintain hubs here.

72. San Jose International Airport (SJC) is located two miles northeast of downtown San Jose, California. In 2000, it served 13,096,355 passengers.

73. Ninoy Aquino International Airport (MNL) is located twelve kilometers (eight miles) south of the center of Manila, Philippines. In 2000, it served 12,764,916 passengers. Benigno "Ninoy" Aquino was a Philippine senator. A harsh critic of Ferdinand Marcos's regime, he was assassinated in 1983. His widow, Corazon Aquino, went on to become the nation's first female president.

74. Shanghai Hongqiao International Airport (SHA) is located fifteen kilometers (nine miles) west of the center of Shanghai, China. In 2000, it served 12,354,676 passengers.

75. Dubai International Airport (DXB) is located five kilometers (three miles) southeast of the center of Dubai, United Arab Emirates. In 2000, it served 12,320,660 passengers. Dubai is the busiest airport in the Middle East.

76. Chhatrapati Shivaji International Airport (BOM), formerly called Sahar International Airport, is located thirty kilometers (nineteen miles) north of Mumbai, India, the city formerly called Bombay. The airport has two terminals, twenty-five kilometers (fifteen miles) apart: the international terminal is called Sahar; the domestic terminal is called Santa Cruz. In 2000, it served 12,043,204 passengers.

77. Wien-Schwechat (Vienna) International Airport (VIE) is located eighteen kilometers (eleven miles) southeast of the center of Vienna, Austria. In 2000, it served 11,939,571 passengers.

78. Kansas City International Airport (MCI) is located fifteen miles north of downtown Kansas City, Missouri. In 2000, it served 11,910,654 passengers. The airport covers ten thousand acres. While the airport is sometimes referred to by its acronym, KCI, its international airport code is actually MCI, which stands for Mid-Continent International.

79. London Stansted Airport (STN) is located fifty kilometers (thirty-one miles) northeast of the center of London. In 2000, it served 11,874,894 passengers. Stansted is a single-runway airport.

80. Brisbane Airport (BNE) is located thirteen kilometers (eight miles) northeast of central Brisbane, Australia. In 2000, it served 11,774,135 passengers. The airport covers 2,700 hectares (6,672 acres) and averages 424 landings and takeoffs daily.

81. Memphis International Airport (MEM) is located eight miles south of downtown Memphis, Tennessee. In 2000, it served 11,769,213 passengers. The airport features an Elvis Presley gift shop.

82. Johannesburg International Airport (JNB) is located twenty-four kilometers (fifteen miles) northeast of downtown Johannesburg, South Africa. In 2000, it served 11,680,598 passengers. It is also Africa's busiest airport.

83. Sheremetyevo International Airport (SVO) is located twenty-six kilometers (sixteen miles) northwest of the center of Moscow, Russia. In 2000, it served 10,828,178 passengers. The airport covers 970 hectares (2,397 acres). The international and domestic terminals are separated by a distance of fifteen miles.

84. Oakland International Airport (OAK) is located eight miles from downtown Oakland, California, directly across the bay from San Francisco. In 2000, it served 10,620,798 passengers.

85. King Abdulaziz International Airport (JED) is located thirty kilometers (nineteen miles) south of Jeddah, Saudi Arabia. In 2000, it served 10,603,060 passengers.

86. Soekarno-Hatta International Airport (CGK) is located at Cengkareng, Tangerang, Indonesia, twenty kilometers (thirteen miles) northwest of central Jakarta. In 2000, it served 10,442,993 passengers.

87. Raleigh-Durham International Airport (RDU) is located in Wake County, North Carolina. It lies ten miles northwest of Raleigh, ten miles southeast of Durham, and seventeen miles east of Chapel Hill. In 2000, it served 10,440,561 passengers. The airport spans five thousand acres.

88. Tegel Airport (TXL) is located eight kilometers (five miles) northwest of central Berlin, Germany. In 2000, it served 10,343,630 passengers.

89. Helsinki-Vantaa Airport (HEL) is located nineteen kilometers (twelve miles) north of the center of Helsinki, Finland. In 2000, it served 10,014,873 passengers.

90. Fuhlsbüttel Airport (HAM) is located ten kilometers (six miles) from the center of Hamburg, Germany. In 2000, it served 9,949,269 passengers.

91. New Orleans International Airport (MSY) is located twenty-one miles from New Orleans's central business district. In 2000, it served 9,874,257 passengers. The airline's three-letter designation, MSY, stands for Moisant Stock Yards. John Moisant was an aviation pioneer who crashed near New Orleans. The site of his crash became a cattle stockyard, and eventually the New Orleans International Airport.

92. Pusan Kim Hae International Airport (PUS) is located twenty-seven kilometers (seventeen miles) from

Pusan, in the south of South Korea. In 2000, it served 9,440,244 passengers.

93. Malaga International Airport (AGP) is located eight kilometers (five miles) southwest of the center of Malaga, Spain, and five kilometers (three miles) north of Torremolinos. In 2000, it served 9,438,373 passengers. The airport covers 253 hectares (625 acres).

94. Lisboa International Airport (LIS) is located seven kilometers (four miles) north of the center of Lisbon, Portugal. In 2000, it served 9,395,761 passengers.

95. Nice Côte D'Azur Airport (NCE) is located seven kilometers (four miles) west of the center of Nice, France. In 2000, it served 9,392,408 passengers.

96. Gran Canaria Airport (LPA) is located eighteen kilometers (eleven miles) south of Las Palmas, Gran Canaria Island, Spain. In 2000, it served 9,374,399 passengers.

97. Ben Gurion International Airport (TLV) is located twenty kilometers (twelve miles) southeast of the city of Tel Aviv, Israel, and fifty kilometers (thirty-one miles) west of Jerusalem. In 2000, it served 9,301,604 passengers.

98. Kaohsiung International Airport (KHH) is located nine kilometers (four miles) from the center of Kaohsiung, Taiwan. In 2000, it served 9,138,417 passengers.

99. Cheju International Airport (CJU) is located 4 kilometers (2.5 miles) from the center of the town of Cheju, on Cheju Island, in South Korea. In 2000, it served 9,125,892 passengers.

100. William P. Hobby Airport (HOU) is located seven miles from downtown Houston, Texas. In 2000, it served 9,105,778 passengers. Hobby was Houston's first airport, and served as the base of operations for Howard Hughes's flights. Hughes was responsible for several improvements to the airport, and had its first control tower built, in 1938. In 1967, the airport was renamed in honor of William P. Hobby, a former Texas governor.

Alexandra Ferry

Air Carriers

The statistical and contact information for the following air carriers was current as of late 2001.

Aer Lingus. Aer Lingus was founded in Ireland in 1936 and is considered the flag carrier of that country. They currently fly to more than twenty-nine cities and carry approximately seven million passengers per year. On June 1, 2000, Aer Lingus became a member of the oneworld Alliance, which includes American Airlines, British Airways, Cathay Pacific, and Japan Airlines. *Contact information:* P.O. Box 180, Head Office Building, Dublin Airport, Dublin, Ireland; Ph.: +3 531 886 22 22 or (800) 223-6537 (www.aerlingus.ie).

Aeroflot. Aeroflot is considered the national carrier of Russia. The carrier was reorganized in 1992 with a resolution of the Russian Federation Government, becoming Aeroflot Russian International Airlines. The airline currently flies more than four million passengers to more than 150 cities worldwide. *Contact information:* Lininggradsky Prospect, City Terminal, 12 Block, 37, Moscow 125167, Russian Federation; Ph.: +7 095 155 65 18 (www.aeroflot.com).

Aerolineas Argentinas. Aerolineas Argentinas was founded in Argentina in 1951. In 1959, it became the first airline in South America to operate jet service to the South Atlantic with De Havilland Comet IV's. It was also the first airline to introduce transatlantic service from Argentina to New Zealand in 1980. *Contact information:* Bouchard 547, 9th Floor, Buenos Aires (1106), Argentina; Ph.: +54 1 317 30 00 or 800 333-0276 (www.aerolineas.com.ar/english.htm).

Aeromexico. Aeromexico, one of the two major Mexican air carriers, traces its beginnings to a Mexican carrier that was established in 1934. Aeromexico flies more than eight million passengers per year throughout Mexico and to destinations in the United States, Canada, and Europe. It belongs to the SkyTeam Alliance, which includes Air France and Delta Air Lines. *Contact information:* Avenue Paseo de la Reforma 445, Piro 12 Torre, Colonia Cuauhtenoc, Mexico City 06500, Mexico; Ph.: +525 133 40 05 (www.aeromexico.com).

Air Canada. Air Canada was formed in 1937 to deliver mail between Seattle and Vancouver. It assumed its present name in 1964. The airline was privatized in 1990 and became a member of the Star Alliance, which includes United Air Lines, Lufthansa, SAS, Singapore Airlines, Thai Airways, and Varig, in 1997. The Canadian government recently approved the takeover of Canada's other major airline, Canadian Airlines, by Air Canada. Air Canada carries more than fifteen million passengers to eighty-five cities worldwide. *Contact information:* Air Canada Base 026, Montreal International Airport (Dorval), Quebec, Canada, H4Y 1C2; Ph.: (514) 422-7706 (www.aircanada.ca).

Air China. Air China was founded in 1988. The airline carries more than six million passengers to twenty-nine cities in nineteen countries. It also serves fifty domestic routes. In 1995, Air China was awarded the Five Star Diamond Award by the American Academy of Restaurants and Hospitality Sciences for its safety, courtesy, and high-quality operations. *Contact information:* Jing Xin Mansion, A-2, Dong San Huan Bei Road, Bejing 100027, Peoples's Republic of China; Ph.: +86 10 64 66 35 90 or 900 982 8802.

Air France. Air France is the flag carrier of France. Established in 1933, it is one of the largest airlines in the world in terms of international passengers and international air freight. It flies approximately forty-two million passengers to more than two hundred destinations in ninety-one countries. It is also one of only two airlines in the world to fly the Concorde, a supersonic transport. Air France is a member of the SkyTeam Alliance, which includes Delta Air Lines. The government-owned airline completed its first public offering in 1999. It is based at Charles de Gaulle Airport in Paris. *Contact information:* Délégation a l'Environment, 45, rue de Paris, 95747 ROISSY CDG Cedex, France; Ph.: +33 1 41 56 78 00 (www.airfrance.net).

Air India. Air India was founded in 1932, and it now serves more than forty-four cities worldwide, carrying approximately three million passengers. The symbol of Air India is the turbaned figure of the Maharajah. During the 1991 Gulf War, Air India, in association with Indian Airlines, airlifted more than one million Indian citizens stranded in Amman, Jordan. The operation lasted fifty-nine days and set a *Guinness Book of World Records* record for the largest evacuation of civilians by a scheduled airline. *Contact information:* Hansalaya Building, Fifth Floor, 15 Barakhazmba Road, New Delhi, India 110 001; Ph.: (416) 865-1030 (www.airindia.com).

Air New Zealand. Air New Zealand was founded in New Zealand in 1940. It carries more than 6.5 million passengers to some forty-seven destinations worldwide. In 2000, Air New Zealand achieved full ownership of the Australian carrier Ansett, making the combined Air New Zealand group one of the top twenty airlines in the world. *Contact information:* Quay Tower, 29 Customs Street West, Private Bag 92007, Auckland 1, New Zealand; Ph.: +64 9 336 24 00 (www.airnz.co.nz).

Alaska Airlines. Alaska Airlines was founded in the United States in 1932 and is considered one of the ten major U.S. carriers. It carries more than thirteen million passengers serving forty cities in three countries. It is consistently rated as one of the highest quality airlines in terms of service. Most recently, it was named the best carrier in the United States by readers of *Travel and Leisure* magazine. *Contact information:* P.O. Box 68900, Seattle, WA 98168; Ph.: (206) 433-3200 (www.alaska-air.com).

Alitalia. Alitalia was founded in Italy in 1947 and currently flies more than 20 million passengers to some 130 cities in 60 countries. Its main base of operations centers on the Rome and Milan airports. It has one of the youngest and most efficient aircraft fleets in Europe. A planned merger with the European airline KLM was halted in 2000, and a new alliance with Air France was announced the following year. *Contact information:* Centro Direzionale, Via Alessandro Marchetti 111, Rome, 1-00148, Italy; Ph.: +39 06 656 21 (www.alitalia.it).

All Nippon Airways. All Nippon Airways, or ANA as it is often called, was founded in Japan in 1952 primarily as a carrier of domestic air traffic. It now carries more than forty-three million passengers to sixty-four cities around the world, making it one to the ten largest carriers in the world. In 1999, ANA joined the Star Alliance, which includes United Air Lines, Lufthansa, Air Canada, Thai Airways, Singapore Airlines, and Varig. *Contact information:* Utility Center Building, 3-5-10 Haneda Airport, Ota-Ku, Tokyo 144-0041 Japan; Ph.: (800) 235-9262 (www.ana.co.jp).

Aloha Airlines. Aloha Airlines was founded in 1950. The airline is based in Honolulu, Hawaii, and flies more than five million passengers to twelve cities, mostly within the Hawaiian Islands. Aloha is noted for its excellent service and is the only airline voluntarily to file its on-time statistics with the Bureau of Transportation Statistics. *Contact information:* P.O. Box 30028, Honolulu, HI; Ph.: (808) 836-4113 (www.alohaairlines.com).

America West Airlines. America West was founded in the United States in 1983 and is considered to be one of the ten major airlines in the United States. The airline currently flies more than eighteen million passengers to seventy cities mostly in the western United States. It has a number of alliance agreements with such airlines as Continental, Northwest, and British Airways. *Contact information:* 111 West Rio Salado Parkway, Tempe, AZ, 85281; Ph.: (480) 693-0800 (www.americawest.com).

American Airlines. American Airlines was formed when several smaller airlines, including Robertson Aircraft Corporation whose chief pilot was Charles A. Lindbergh, merged in the 1920's. The name American Airlines was adopted in 1934. American Airlines is considered to be one of the largest airlines in the world in terms of total revenue. The reservation system it founded, SABRE, is also one of the largest in the world. In 2000, SABRE was spun off to become its own company. American Airlines flies more than eighty-six million passengers per year to some 160 cities worldwide. It was a founding member of the oneworld Alliance, along with British Airways, Japan Airlines, and Cathay Pacific. In 2001, American took over most of the assets of Trans World Airways. *Contact information:* P.O. Box 619616, Dallas-Fort Worth Airport, TX 75261; Ph.: (817) 963-1234 (www.aa.com).

Asiana Airlines. Asiana Airlines was founded in South Korea in 1988 and was primarily a domestic carrier of passengers and cargo. Asiana now carries more than nine million passengers to some fifty cities in thirteen countries. They were named the Laurel Airline of 1999 by the magazine *Aviation Week and Space Technology*. Asiana's major alliance is with American Airlines. *Contact information:* Asiana Building, P.O. Box 142, 10-1 2-Ka, Hochyum-dong, Chung-Ku, Seoul, Republic of Korea; Ph.: +822 758 81 14.

Austrian Airlines. Austrian Airlines was founded in Austria in 1957. It carries more than four million passengers to some eighty-four cities worldwide. Formerly a member of the Qualifyer Group alliance, Austrian joined the Star Alliance in March, 2000. Other Star Alliance members include Lufthansa, United, SAS, Singapore Airlines, and Varig. *Contact information:* Fontanastrasse 1, Vienna, A-1107 Austria; Ph.: +43 1 176 60 (www.aua.com).

Braniff International Airlines. Braniff International began in 1928 when brothers Thomas and Paul Braniff organized a combination flying school, aircraft parts supplier, and airline. When the company was sold to the Universal Aviation Corporation, Braniff Airlines became a subsidiary of the new parent company, a predecessor of American Airlines which adopted the name American Airways, in 1930. The Braniff brothers then established a new airline under the Braniff name in late 1930. In 1968, Braniff moved to its new terminal at Dallas Love Field. They remained here until 1974 when they moved to the new Dallas-Fort Worth International Airport. At the time, they were the largest airline to operate from Dallas-Fort Worth, larger than their rival American Airlines. Following airline deregulation in 1978, Braniff embarked on a massive expansion program that eventually led to serious financial problems in the early 1980's. In 1982, Braniff became the first major U.S. airline to file for bankruptcy. The airline resumed operations under new ownership in 1984, but again filed for bankruptcy in 1989. Information on the history of Braniff is available in several publications and on-line at (www.braniffinternational.org).

British Airways. The company that would eventually become British Airways began in the early 1920's with the merger of four British airlines to become Imperial Airways. In 1935, several other airlines merged in an effort to compete with Imperial and took the name British Airways Limited. Both airlines were nationalized in 1939 to form British Overseas Airways Corporation. After the 1972 merger with British European Airways, the company assumed the name British Airways. The company was privatized in 1987 and now flies more than thirty-seven million passengers to some 163 destinations worldwide, making it one of the largest carriers in the world in terms of both passengers and cargo. British Airways is a member of the oneworld Alliance with American Airlines, Cathay Pacific, and Japan Airlines. *Contact information:* Waterside, P.O. Box 365, Harmondsworth, UB7 0GB, UK; Ph.: +44 191 490 79 01 (www.britishairways.com).

British Midland. British Midland began in 1938 as Air Schools, specializing in the training of Royal Air Force pilots. It adopted its current name in 1965, becoming a leader in the European charter market and a highly rated domestic carrier in the United Kingdom. British Midland currently flies to more than thirty-two European destinations and serves the U.S. cities of Washington, D.C., and Chicago. British Midland is now a member of the Star Alliance, which includes United Air Lines, Lufthansa, Air Canada, and SAS, allowing them to serve more than eighty destinations in the United States through code-sharing arrangements. *Contact information:* Donnington Hall, Castle Donington, Derby DE74 2SB; Ph.: (800) 788-0555 (www.flybmi.com).

British West Indies Airways. British West Indies Airways, or BWIA as it is called, was founded in Trinidad and Tobago in 1939, making it the oldest carrier in the Caribbean. BWIA flies more than one million passengers to some seventeen cities worldwide including Miami, New York, Toronto, Frankfurt, and London. *Contact information:* Customer Relations, P.O. Box 604, Port of Spain, Trinidad, W.I.; Ph.: (868) 669-3000 (www.bwee.com).

Canadian Airlines. Canadian Airlines was formed in 1987, when Canadian Pacific and Pacific Western Airlines merged. Canadian Pacific was founded in 1942 and Pacific Western was founded in 1946. The airline was one of the two major carriers in Canada, but was taken over in 1999 by its rival, Air Canada. Before the takeover, Canadian Airlines flew to more than 380 destinations worldwide and was part of the oneworld Alliance, which includes American Airlines, Cathay Pacific, and Japan Airlines.

Cathay Pacific. Cathay Pacific was founded in 1946 by American Roy C. Farrell and Australian Sydney H. de Kantzow. Operations were originally stationed in Shanghai, China, but were moved to Hong Kong in 1948 when one of Hong Kong's leading trading companies, Swire, took a 45 percent share of the company. The airline now flies more than ten million passengers to forty-nine destinations. Cathay is a member of the oneworld Alliance that includes American Airlines, Japan Airlines, British Airways, and Qantas. *Contact information:* 35/F Two Pacific Place, 88 Queensway, Hong Kong; Ph.: +852 27 47 50 00 (www.cathaypacific).

China Airlines. China Airlines was founded in 1959 on the island nation of Taiwan. The airline now flies more than seven million passengers to fifty-one cities in twenty-two countries. Through a series of interline agreements, China Airlines also serves a number of destinations on the Chinese mainland. *Contact information:* 131 Nanking East Road, Sec. 3, Taipei 104, Taiwan; Ph.: +886 27 15 22 33 (www.china-airlines.com).

Comair. Comair was founded in the United States in 1977. The carrier operated a feeder serve for Delta Air Lines for a number of years. They were acquired by Delta Air Lines in 2000 and now operate as a wholly owned subsidiary. Comair is considered to be one of the best-managed regional airlines in the United States. It flies more than five million passengers to ninety-eight cities. *Contact information:* P.O. Box 75021, Cincinnati/ Northern Kentucky International Airport, Cincinnati, OH 45275; Ph.: (606) 767-2550 (www.fly-comair.com).

Continental Airlines. The airline that became Continental Airlines was founded in 1934 as Varney Speed Lines to fly mail from Pueblo to El Paso. The carrier is now the fifth largest in the United States, flying more than forty-six million passengers to 228 destinations worldwide. After nearly a decade of disastrous leadership under Frank Lorenzo, Continental has been recognized as one of the best carriers in the United States. It is a member of the Wings Alliance, which includes Northwest Airlines and KLM. *Contact information:* 1600 Smith Street, Houston, TX 77002; Ph.: (713) 324-5080 (www.contintental.com).

Delta Air Lines. Delta Air Lines was founded in 1924 in Louisiana. The airline, which is now based in Atlanta, Georgia, flies more passengers worldwide than any other airline. Delta Air Lines serves 116 million passengers in 367 cities. With its SkyTeam Alliance partners, Delta operates 6,400 flights a day to more than 450 cities. Other SkyTeam members include Air France and Korean Air. *Contact information:* P.O. Box 20706, Hartfield, Atlanta, GA 30320; Ph.: (404) 715-2600 (www.delta.com).

DHL. DHL was founded in San Francisco, California, in 1969 and is now one of the world's leading international express delivery companies. DHL can deliver documents to more than 635,000 destinations in more than 228 countries. It was one of two companies in the transport sector ranked "above world class" in the INSEAD report "Measuring Competitive Fitness of Global Firms 2001." *Contact information:* Ph.: (800) 225-5345 (www.dhl-usa.com).

Eastern Air Lines. Eastern Air Lines began as Pitcairn Aviation, providing airmail service in the United States. In 1930, the company was sold and renamed Eastern Air Transport. World War I flying ace Eddie Rickenbacker was named president of Eastern Air Lines in 1938 and remained in that position until 1963. Airline deregulation in 1978 was difficult for Eastern, which struggled to reduce its cost and compete in the growing fare wars. Eastern sold a majority share of the company to Frank Lorenzo, owner of the Texas Air Group, which included several previously acquired airlines, such as People Express, Continental, and New York Air. Lorenzo filed to restructure Eastern under federal bankruptcy laws. When a creditor of Eastern filed suit against Eastern Air Lines, the court appointed a trustee to oversee Eastern's remaining assets. There are several interesting books on the demise of Eastern, including *Grounded: Frank Lorenzo and the Destruction of Eastern Air Lines* (1999) by A. Bernstein.

El Al. El Al was founded in Israel in 1948, shortly after the country itself came into existence. The airline now flies more than three million passengers to some fifty cities worldwide and is ranked by the International Air Transport Association as one of the most efficient air carriers in the world. *Contact information:* P.O. Box 41, Ben Gurion International Airport, Tel Aviv, 70100 Israel; Ph.: +972 3 972 14 42 (www.elal.co.il).

Emirates Airline. Emirates Airline was founded in Dubai, United Arab Emirates, in 1985 and is one of the fastest-growing airlines in the world, receiving more than 190 international awards for excellence since its launch. Emirates flies almost six million passengers per year to fifty-five cities worldwide. *Contact information:* P.O. Box 686, Dubai, United Arab Emirates; Ph.: +971 9 295 11 11 (www.emiratesairline.com).

EVA Air. EVA Air was founded in Taiwan in 1989 and now serves more than thirty cities, carrying almost four million passengers. EVA has alliances with a number of other international carriers, including All Nippon Airways, American Airlines, Continental Airlines, British Airways, and Lufthansa. *Contact information:* EVA Air Building, 376 Hsin-nan Road, Sec 1, Luchu, Taoyuan Hsien, Taiwan; Ph.: +886 2 85 00 25 20 (www.evaair.com).

Federal Express. Federal Express, or FedEx, as it is often called, was founded in the United States in 1973 and provides freight, package, and document service throughout the world. Its headquarters are located in Memphis, Tennessee, although the company now have distribution and sorting centers on several continents. FedEx carries more than three million packages daily. *Contact information:* 942 South Shady Grove Road, Memphis, TN 38120; Ph. (901) 395-3460 (www.fedex.com).

Finnair. Finnair was founded in Finland in 1923. The airline carries more than seven million passengers on its international and domestic routes, serving more than sixty-eight destinations. Finnair is considered to be the sixth-oldest airline in the world. *Contact information:* Tietotie 11A, Helsinki-Vantaa Airport, Helsinki FIN-D105 Finland; Ph.: +358 9 818 81 (www.finnair.com).

Gulf Air. Gulf Air was founded in 1950 in Bahrain and is considered the national carrier of Bahrain, Oman, Qatar, and Abu Dhabi, which together form the United Arab Emirates. Gulf Air flies more than five million passengers to seventy-three cities worldwide.

Contact information: P.O. Box 138, Manama, Bahrain; Ph.: +973 32 22 00 (www.gulfairco.com).

Hawaiian Airlines. Hawaiian Airlines was founded in 1929. The airline flies more than six million passengers to fourteen domestic and international destinations and is the only carrier to provide single-carrier service from the western United States to each of the Hawaiian Islands. It is consistently rated one of the best U.S. carriers by travel and leisure magazines. *Contact information:* P.O. Box 30008, Honolulu, HI 96820; Ph.: (808) 835-3700 (www.hawaiianair.com).

Iberia Airlines. Iberia was founded in Spain in 1927, making it one of the world's oldest airlines. It flies to more than ninety-five cities, carrying approximately twenty-four million passengers per year. In 1999, the airline joined the oneworld Alliance, which includes American Airlines, British Airways, and Japan Airlines. *Contact information:* Callee Velagquez 130, Madrid E-28006, Spain; Ph.: +34 91 587 87 87 (www.iberia.com).

Indian Airlines. Indian Airlines was founded in India in 1953 and has one of the largest regional airline systems in Asia. The airline flies more than seven million passengers to seventy-five destinations, including sixteen international cities. *Contact information:* Central Space Control, Indian Airlines Computer Centre, Indira Gandhi International Airport, New Delhi-10037; Ph.: +91 11 5696327 (www.indian-airlines.nic.in).

Japan Airlines. Japan Airlines (JAL) was founded in 1951. JAL carries more than thirty-four million passengers worldwide, making it the fifth-largest air carrier in terms of passengers flown. It is the largest carrier in Asia, serving more than seventy-five cities in twenty-nine countries. JAL is a member of the oneworld Alliance, which includes American Airlines and British Airways. *Contact information:* The JAL Building, Higashi Shinagawa, 4-11, 2-Chome, Shinagawa-Ku, Tokyo 140-8637, Japan; Ph.: +81 3 54 60 31 21 (www.japanair.com).

KLM Royal Dutch Airlines. Commonly known as simply KLM, this carrier was founded in the Netherlands in 1919, making it the oldest continuously operating carrier scheduled airline in the world. Because the Netherlands was the first country to sign an open skies agreement with the United States, KLM has enjoyed antitrust immunity with its alliance partner, Northwest Airlines, for a number of years. This alliance, Wings, is one of the most integrated of all major international alliances. Through its alliance, KLM flies more than fifteen million passengers to five hundred cities worldwide. *Contact information:* P.O. Box 7700, Schipol Amsterdam Airport, NL-1117, Netherlands; Ph.: +31 20 649 9123 (www.klm.nl).

Korean Airlines. Korean Airlines (KAL) was founded in 1969. It serves seventy-seven cities in twenty-nine countries, carrying more than twenty million passengers per year. KAL is also ranked by the International Air Transport Association as the world's second-largest commercial airline cargo operation. KAL is a member of the SkyTeam Alliance, which includes Delta Air Lines and Air France. *Contact information:* 7F, Korean Air Operations Center, 1370 Gonghang-Dong, Kangso-Ku, Seoul, Korea; Ph.: +82 2 656 71 14 (www.koreanair.com).

Kuwait Airways. Kuwait Airways was founded in 1962 and serves more than forty-three cities, enplaning approximately two million passengers per year. The airline resumed operation after its premises and aircraft were destroyed during the 1990-1991 Iraqi invasion of Kuwait. *Contact information:* Kuwait International Airport, P.O. Box 394, 13004 Sfat, Kuwait; Ph.: +965 434 55 55 (www.kuwait-airways.com).

LanChile. LanChile was founded in Chile in 1929 and flies more than three million passengers to fifty-five cities worldwide. In 2000, LanChile joined the oneworld Alliance, which includes American Airlines, British Airways, and Japan Airlines. *Contact information:* Estado 10, Twentieth Floor, Santiago, Chile; Ph.: +562 639 44 11 (www21.lanchile.com).

Lufthansa. Lufthansa was founded in Germany in 1926. Although most flight operation ceased during World War II, the airline resumed flying in 1955. The airline flies more than forty-one million passengers to 349 destinations in ninety-four countries. It also has one of the world's largest cargo operations and was a founding member of the Star Alliance. *Contact information:* Von-Gablenz-Strasse 2-6, Cologne D-50679, Germany; Ph.: +49 221 82 60 (www.lufthansa.com).

Malaysia Airlines. Malaysia Airlines was founded in 1951 and has been voted the best Asian business airline for three consecutive years by *Business Travel World*. The airline flies more than fifteen million passengers to 110 cities worldwide. *Contact information:* Thirty-third Floor, Bangunan MAS, Jalan Sultan Ismail, 50250, Kuala Lumpur, Malaysia; Ph.: +603 21 61 05 55 (www.malaysiaair.com).

Malev. Malev was founded in Hungary in 1946 and is the national carrier of that nation. It serves more than thirty cities, carrying some two million passengers per year. It became a public limited company in 1992. *Contact information:* Roosevelt ter 2, Budapest H-1051, Hungary; Ph.: +36 1 235 35 35 (www.malev.hu).

Mexicana de Aviacion. Mexicana traces its beginnings to the early 1920's, making it one of the oldest carriers in the world. It is now one of the two major carriers of Mexico, primarily serving its fifty-two international destinations from its base in Mexico City. Mexicana is a member of the Star Alliance, which includes United, Lufthansa, and Air Canada. *Contact information:* Xola 535, Col Del Valle, 03100, Mexico City, Mexico; Ph.: (800) 531-7921 (www.mexicana.com).

Northwest Airlines. Northwest Airlines was founded in the United States in 1926. The airline has an extensive route structure to Asia. With its Wings alliance with KLM, it combined its Asian and domestic network with the Atlantic and European network of KLM to serve more than 550 cities and to fly more than fifty-nine million passengers per year. Northwest is one of the ten largest U.S. carriers. *Contact information:* Minneapolis/St. Paul International Airport, 5101 Northwest Drive, St. Paul, MN 55111 (www.nsa.com).

Pan Am. Pan Am traces its origins to early aviation companies founded in the United States in the 1920's. Like many early U.S. airlines, it owes much of its growth to airmail contracts issued by the postmaster of the United States. Pan Am was for many years the main carrier authorized to fly international mail. Pan Am used this position to become the dominant U.S. international carrier. Following the Airline Deregulation Act of 1978, Pan Am began to struggle, as new carriers entered its international routes, and Pan Am attempted to build up its domestic operations. In 1991, Pan Am finally succumbed to its financial pressures and filed for bankruptcy. Two subsequent airlines flying under the Pan Am name have begun operations since that time. The present Pan Am is headquartered in Fort Lauderdale, Florida, and flies to nine cities along the eastern seaboard of the United States

People Express. People Express was the first air carrier established after the 1978 Airline Deregulation Act. People Express was established in 1981 as a low-cost, no-frills carrier along the lines of Southwest Airlines. It rose in four short years to become one of the ten largest U.S. carriers, and explosive growth led to acquisition of Frontier Airlines, Britt Airways, and Provincetown Boston Airlines, before customer complaints and established carrier competition forced the airline to sell out to the Texas Air Group headed by Frank Lorenzo.

Qantas. Qantas was founded in 1920, making it the world's second-oldest airline and the oldest airline in the English-speaking world. Qantas, the national carrier of Australia, flies more than seventeen million passengers per year to 124 destinations worldwide. It is well known for the kangaroo mascot on the tail of its aircraft. *Contact information:* 203 Coward Street, Mascot NSW 2020, Australia; Ph.: +61 2 9691 3636 (www.qantas.com.au).

Sabena Airlines. Sabena was founded in 1923 in Belgium and is considered the national carrier of that country. Sabena flies more than ten million passengers per year primarily to European destinations. Sabena was a founding member of the Qualiflyer Group, which includes Swissair. Swissair owned 49 percent of Sabena. Financial troubles at both Sabena and Swissair placed the carrier's future in jeopardy. Sabena filed for bankruptcy in 2001.

SAS. Scandinavian Airlines, or SAS, as it is commonly known, was founded in 1946. SAS is actually a consortium of three national airlines, SAS Danmark, SAS Norge, and SAS Sverige. The Danish and Norwegian parent companies own two-sevenths of the consortium, while the Swedish parent owns the remaining three-sevenths. SAS flies more than twenty-two million passengers to ninety-two destinations in thirty-three countries. SAS is a member of the Star Alliance, which includes United Airline, Lufthansa, and Air Canada. *Contact information:* Frosundaviks Alle 1, Stockholm S-19587, Sweden; Ph.: +468 797 00 00 (www.scandinavian.net).

Singapore Airlines. Singapore Airlines was originally part of Malaysia Airlines but became a separate company by agreement between the governments of Singapore and Malaysia in 1972. Singapore Airlines flies more than fourteen million passengers to ninety cities in forty countries and has long been considered by business and leisure travelers to be one of the best airlines in the world. Singapore Airlines is a member of the Star Alliance, which includes United and Lufthansa. They recently purchased 49 percent of the British carrier Virgin Atlantic. *Contact information:* P.O. Box 50, Airmail Transit Center, 918101, Singapore; Ph.: +65 542 33 33 (www.singaporeair.com).

Southwest Airlines. Southwest Airlines was founded in 1967 but did not begin flight operations until the end of 1971 due to a series of regulatory and court challenges centering on its right to fly out of Dallas Love Field. Over the years, the low-cost, no-frills airline has expanded to become one of the ten largest air carriers in the United States and one of the most consistently profitable carriers in history. Southwest flies more than sixty-four million passengers to fifty-seven cities in the United States and is known for having one of the best on-time records in the industry. *Contact information:* 2702 Love Field Drive, P.O. Box 36611, Dallas, TX 75235; Ph.: (800) 435-9792 (www.iflyswa.com).

Swissair. Swissair was founded in 1931. The carrier serves more than 200 destinations in Europe and another 330 worldwide, flying more than fourteen million passengers per year. Swissair was a leader in the formation of the Qualiflyer Group alliance, which includes a number of smaller European airlines. Swissair assumed an equity stake in a number of these airlines. Troubles at some of these carriers contributed to financial problems at Swissair, which was reorganized in 2001. *Contact information:* Pstfach, Zurich Airport, Balz Zimmermannstrasse, Kloten CH-8058, Switzerland; Ph.: (800) 221-4750 (www.swissair .com).

TACA. TACA, or Grupo TACA, is a conglomeration of five national and five regional carriers in Central America. It is currently the fourth-largest air carrier in Latin America. TACA serves sixty cities in nineteen countries. *Contact information:* Edificio Caribe, 2 Piso, San Salvador, El Salvador; Ph. 800 535 8780.

TAP Air Portugal. TAP was founded in Portugal in 1945. The airline flies almost five million passengers to forty-two cities. It is a member of the Qualiflyer Group alliance, which includes Swissair and Sabena Airlines. *Contact information:* Eroporto de Lisboa, Apartado 50194 P-1704-801, Lisboa, Portugal; Ph.: +351 21 841 50 00 (www.tap-airportugal.pt).

Thai Airways International. Thai Airways International was founded in 1960 and is considered the national carrier of Thailand. Thai flies more than sixteen million passengers to 105 cities. Thai joined the Star Alliance in 1995. *Contact information:* 89 Vibhavadi Rangsit Road, P.O. Box 1075, Bangkok 10900, Thailand; Ph.: +662 513 01 21 (www.thaiair.com).

Trans World Airlines. Trans World Airlines, or TWA, as it is commonly known, began when Western Air Express and Transcontinental Air Transport merged in 1930 to form Transcontinental and Western Air. TWA began international service in the early 1940's but began to experience financial difficulties in the early 1980's. In 1985, Carl Icahn acquired controlling interest in TWA. In 1988, TWA became a private company. The airline filed for bankruptcy in 1992 and 2001. The majority of its assets were acquired by American Airlines in 2001.

United Air Lines. The company that would become United Air Lines was founded in 1926. United is considered the largest U.S. carrier in terms of revenue passenger miles and is the largest majority employee-owned company in the world. United was a founding member of the Star Alliance, which includes Lufthansa, Air Canada, and Singapore Airlines. United flies more than eighty-seven million passengers to 134 destinations around the world. *Contact information:* P.O. Box 66100, Chicago, IL 60666; Ph.: (800) 241-6522 (www.ual.com).

US Airways. US Airways began as All American Aviation in 1937 and became Allegheny Airlines in 1953. The name was changed to USAirways in 1997. In 1987, the airline merged with Piedmont in the largest U.S. airline merger to date. US Airways is one of the ten largest carriers in the United States, flying more than fifty million passengers to 133 cities worldwide. *Contact information:* 2345 Crystal Drive, Arlington, VA 22227; Ph.: (703) 872-7000 (www.usairways.com).

Varig. Varig was founded in Brazil in 1927 and flies more than eleven million passengers to eighteen countries. The airline joined the Star Alliance in 1997. *Contact information:* Avenue Laminate Silvio de Novonha, Rio de Janeiro 20021-01, Brazil; Ph.: +55 21 814 50 00 (www.varig.com).

Virgin Atlantic. Virgin Atlantic was founded in the United Kingdom in 1984 and has grown to serve more than eighteen destinations flying almost three million passengers per year. Singapore Airlines recently acquired 49 percent of the airline, which has consistently been rated one of the best carriers by business and leisure passengers. *Contact information:* The Office, Crawley Business Quarter, Manor Royal, Crawley, West Sussex RH10 2NU, United Kingdom; Ph.: +44 1293 562 345 (www.virgin-atlantic.com).

Dawna L. Rhoades

Airplane Types

This list of airplanes is organized chronologically under the headings "Pre-1914," "1914-1918," "1919-1939," "1939-1945," and "1945-Present." The entries listed include civilian and military single-engine, twin-engine, and multiengine propeller and jet airplanes.

PRE-1914

Benoit Type XIV two-seat flying boat: Power source 75-horsepower Roberts or 70-horsepower Sturtevant engine driving a pusher propeller. Aircraft was operated by the Airboat Line and provided the world's first scheduled airplane passenger service operated by an airline company, between St. Petersburg and Tampa, Florida.

Curtiss A-1 seaplane: Span 35.33 feet, length 25.75 feet, height 8 feet. Powered by a 50-horsepower Curtiss engine. Tested for the first time by Glenn Curtiss on June 30, 1911. Was a biplane and the first U.S. Navy airplane.

Russki Vityaz (Russian Knight): Span 105 feet, weight 12,130 pounds, crew of seven, and payload of 1,540 pounds. First large airplane designed exclusively as a bomber made its maiden flight in Russia on June 23, 1913.

Short S.39 Triple-Twin biplane: Span 34 feet, length 45 feet. First airplane with two engines and three propellers and the first with a combined pusher-tractor arrangement. Airplane had a single 50-horsepower engine at the back driving a pusher and a single 50-horsepower engine in front driving two propellers. Took off from Eastchurch, United Kingdom, on September 18, 1911.

Wright *Flyer*: Span 40.33 feet, length 21.08 feet. Power source was two contrarotating 8.5-foot propellers driven by a 12-horsepower engine. On December 17, 1903, Orville Wright achieved the world's first manned, sustained, controlled, powered flight in a heavier-than-air machine in Kitty Hawk, North Carolina. Flight lasted about 12 seconds and covered 120 feet.

1914-1918

Albatros B.1 tractor biplane: Span 47.5 feet, length 26 feet, power source 100-horse power engine, maximum speed 62 miles per hour, design range of 400 miles. Aircraft used to set the last international endurance record before World War I, achieved by German pilot R. Bohm. Flight lasted 24 hours and 12 minutes outside of Berlin, Germany, on July 11, 1914.

Albatros D.I single-seat biplane fighter: Power source was one 160-horsepower engine, armed with two forward-firing machine guns. Underwent testing in August, 1916, prior to delivery to the German Air Service.

Breguet 14 bomber: Power source was one 220-horsepower engine. One of the most effective bombers of World War I, this French airplane made its first flight on November 21, 1916. Plane had a maximum weight of 3,400 pounds and could carry a 520-pound bomb load.

Caproni Ca. 1: Heavy bomber used by the Italian Royal Army Air Service. Power source was two 80-horsepower engines on the lower wing of the biplane, each side of the fuselage. One 100-horsepower engine drove a pusher propeller at the rear of the fuselage nacelle. Wingspan was about 73 feet, length 35.75 feet, weight 6,600 pounds. Made its inaugural flight in October, 1914.

Curtiss R-6 twin-float seaplane: The first U.S.-built airplane to operate overseas with American forces. Deployed to the Azores on January 31, 1918, to protect convoys from enemy submarines. Power source was one 360-horsepower engine.

D.H.4 day bomber and fighter reconnaissance biplane: Power source was a variety of engines providing 200 to 400 horsepower, maximum speed up to 140 miles per hour, climb rate of 1,350 feet per minute and endurance of over three hours. Great success with the Royal Flying Corps of the United Kingdom during World War I; made its first flight in August, 1916, at Hendon, United Kingdom.

Gotha G.IV: Power source was two 260-horsepower engines; operating height was 15,000 feet This German bomber could carry 1,100 pounds of bombs. Deployed on a daylight offensive against southern England on May 25, 1917.

Handley Page O/100 bomber: Length 62.83 feet, wingspan 100 feet, maximum loaded weight 14,000 pounds. Power source was two 250-horsepower engines driving four-blade propellers. Made its maiden flight December 17, 1915.

Handley Page V/1500: Power source was four 375-horsepower engines providing a maximum speed of 97 miles per hour. Payload was 7,500 pounds. The largest bomber built by the United Kingdom during World War I.

Junkers J9: All-metal cantilever monoplane fighter from Germany. Power source was one 185-horsepower engine. Maiden flight was made on March 10, 1918.

Martin MB-1 bomber: Length 44.83 feet, wingspan of 71.42 feet, power source was two 400-horsepower engines providing a top speed of 105 miles per hour. Payload was 1,040 pounds, and armament consisted of five defensive machine guns. Inaugural flight of this American airplane was made on August 17, 1918.

Shchetnin M-9 flying boat: Length 29.5 feet, wingspan 52 feet, power source one 150-horsepower engine. Maximum loaded weight of 3,400 pounds. In June, 1916, Russian pilot Jan Jozefovich Nagorski looped this aircraft while trying to escape an attack, the first time that a flying boat conducted such a maneuver.

S.I.A. 9B single-engine bomber: Power source was one 700-horsepower engine, payload was 770 pounds. The most powerful single-engine airplane in operation anywhere in World War I, four of these Italian aircraft conducted a successful bombing raid on the Austro-Hungarian naval base at Pola.

Sopwith Cuckoo: Power source was one 200-horsepower engine. Loaded weight was 3,883 pounds, with a cruising speed of 98 miles per hour. First airplane designed as a torpedo-carrier for operation from the deck of a ship; made its inaugural flight in June, 1917, in the United Kingdom.

Sopwith F.1 Camel: Length 18.75 feet, wingspan 28 feet, power source one 130-horsepower engine, weight fully loaded was 1,454 pounds. Prototype was tested by British Admiralty on February 28, 1917. Between July, 1917, and November, 1918, pilots in Sopwith Camels shot down 1,294 airplanes, a greater total than any other airplane in World War I.

Sopwith Triplane: Three equal-length wings spanning 26.5 feet, power source was a 100-horsepower engine, armed with either one or two Vickers synchronized machine guns (guns that could fire through the arc of the propeller without damaging the latter). Single-seat fighter was cleared for trials on May 28, 1916.

Spad S.VII: Power source was 150-horsepower engine (later models had 200-horsepower engines). One of the most famous and effective fighters of World War I; deliveries of this French airplane began on September 2, 1916.

Spad S.XIII: Power source was one 200- or one 220-horsepower engine providing a maximum speed of 135.5 miles per hour at a height of 10,000 feet. Armament consisted of two Vickers machine guns. This French airplane was one of the fastest fighter aircraft of World War I and entered service in May, 1917.

1919-1939

A.E.G. G.V. twin-engine biplane: Length of 35.42 feet, wingspan 89.5 feet, loaded weight 10,141 pounds. Power source was two 260-horsepower engines. On July 30, 1919, eight people flew to an altitude of 20,013 feet in the open cockpit of this type of German airplane.

Aeromarine 39-B: Length 30.33 feet, wingspan 47 feet, gross weight 2,505 pounds. Power source was one 100-horsepower engine that provided a top speed of 73 miles per hour. On October 26, 1922, an Aeromarine 39-B piloted by Lieutenant Commander Geofrey DeChevalier became the first U.S. Navy airplane to land on an aircraft carrier when it touched down on the USS *Langley.*

Armstrong Whitworth Siskin III: Power source was one 325-horsepower engine that provided a top speed of 134 miles per hour and a service ceiling of 20,500 feet. Armament of this aircraft consisted of twin synchronized Vickers guns. On May 7, 1923, it made its inaugural flight. This was the first British fighter of all-metal construction to enter the Royal Air Force, and it began service in May, 1924.

Avions-Caudron C.61 passenger biplane: Length 45.92 feet, wingspan 79.17 feet, loaded weight of 7,672 pounds. Power source was three 180-horsepower engines. The plane carried eight passengers and two crew and made its first appearance in 1921.

Avro 581 Avian (G-EBOV): Length 24.5 feet, wingspan 28 feet, loaded weight 1,580 pounds. Power source was one 85-horsepower engine that generated a maximum speed of 70 miles per hour. On August 27, 1927, Squadron Leader H. J. Hinkler flew in this British plane from London, United Kingdom, to Riga, Soviet Union, in approximately 11 hours. He thereby covered 1,200 miles in the longest light aircraft (those weighing less than 700 pounds) flight to date.

Beech Model 17R Staggerwing: Length 26.75 feet, wingspan 32 feet. Power source was one 450-horsepower engine that provided a speed of 212 miles per hour and a maximum range of 1,000 miles. This aircraft made its inaugural flight on November 4, 1932, in the United States.

Bf 110C-1: Length 39.58 feet, wingspan 53.33 feet. Power source was two engines that generated a cruising speed of 217 miles per hour at 13,780 feet and a range of 1,070 miles. This cantilevered, low-wing monoplane with a duralumin flush-riveted skin would make its inaugural flight on May 12, 1936. It would prove a valuable night fighter of the German Luftwaffe during World War II.

Blackburn Dart: Length 35.33 feet, wingspan 45.5 feet, power source was one 450-horsepower engine that generated a maximum speed of 107 miles per hour and a range of 285 miles. On July 1, 1926, Flight Lieutenant Boyce made the first night landing aboard an aircraft carrier using this British plane. The Dart had appeared in 1921, entered the Fleet Air Arm of the United Kingdom in 1923 and would remain in use for more than ten years.

Blériot-Spad 33: Length 29.75 feet, wingspan of 38.25 feet, loaded weight of 4,545 pounds with a maximum payload of 1,455 pounds. Power source was one 230-horsepower water-cooled radial engine. The cabin seated four passengers. On December 12, 1920, a prototype of this aircraft made its first flight. The Spad 33 would become one of the most popular French transport planes of the early 1920's and began to make routine flights between London and Paris in 1921.

Boeing Model 40: Length 33.17 feet, wingspan 44.17 feet, maximum weight 6,000 pounds. Power source was one 420-horsepower engine that provided a cruising speed of 105 miles per hour, a ceiling of 14,500 feet and a range of 650 miles.

Boeing Y1B-17: Length 68.33 feet, wingspan 103.75 feet. Power source was four 930-horsepower engines that generated a cruising speed of 217 miles per hour, a service ceiling of 30,600 feet. Its range was 1,377 miles with a bomb load of 10,496 pounds. Gross weight was 42,600 pounds and the crew complement was ten. This American bomber made its first flight on December 2, 1936, and would distinguish itself during World War II. Ultimately 12,731 B-17 bombers would be built.

Bristol Type 105 Bulldog: Power source was one 490-horsepower engine that provided a top speed of 174 miles per hour and a climb time of 14.5 minutes to 20,000 feet. Armament consisted of twin synchronized Vickers machine guns and four 20-pound bombs. This British plane made its inaugural flight on May 17, 1927, and became one of the most famous British fighters of the 1930's.

Curtiss CR biplane: Length 21 feet, height 8.42 feet, wingspan 22.67 feet. Power source was one 425-horsepower engine. On November 3, 1921, Bert Acosta broke the world closed-circuit speed record by flying 176.7 miles per hour in this American plane.

Curtiss CT-1 monoplane: Length 52 feet, wingspan 65 feet, gross weight of 11,208 pounds. Power source was two 350-horsepower engines. Crew consisted of pilot, navigator, and gunner. Armament of this low-wing monoplane was one 1,446-pound torpedo. In March, 1921, this American aircraft made its inaugural flight.

Curtiss Model 50 Robin: Length 25.67 feet, wingspan 41 feet, gross weight 2,440 pounds. Power source was one 185-horsepower engine that generated a cruising speed of 84 miles per hour and a service ceiling between 10,200 feet and 13,000 feet. Range was up to 480 miles. This American plane distinguished itself through a high-wing monoplane configuration and fixed landing gear and proved rugged, reliable, and popular. One of the most successful designs of the day, this plane made its inaugural flight on August 7, 1928.

Curtiss R-6: Length 18.92 feet, height 7.92 feet, gross weight 1,950 pounds. Range was 283 miles. On October 18, 1922, U.S. Army Brigadier General William Mitchell set a world straight-line speed record of 222.96 miles per hour.

Davis-Douglas Cloudster: Length 36.75 feet, wingspan 55.92 feet, gross weight 9,600 pounds. The power source was one 400-horsepower engine, range with two fuel tanks of 660 gallons combined capacity and one 50-gallon oil tank was 2,800 miles. Built to fly nonstop across the continental United States, this airplane made its inaugural flight on February 24, 1921, for 30 minutes. It never did make a nonstop, transcontinental flight.

Dewoitine D1: Parasol monoplane of light metal construction that contained the new metal alloy duralumin and had wings covered with fabric. Power source was one 300-horsepower engine engine providing a top speed of 156 miles per hour, a ceiling close to 28,000 feet, and a landing speed of 50 miles per hour. On November 21, 1921, this French airplane made its inaugural flight.

Dewoitine D.500: Length 25.25 feet, wingspan 39.67 feet, maximum takeoff weight 3,792 pounds. Power source was one 690-horsepower engine that generated a maximum speed of 224 miles per hour. This aircraft made its inaugural flight on June 19, 1932, and would become the first all-metal cantilever monoplane to enter service with the French Air Force.

D.H.66 Hercules (G-BMW): Length 55.5 feet, wingspan 79.5 feet, maximum weight 15,660 pounds. Power source was three 420-horsepower engines. This British plane carried a crew of two, seven passengers and 465 cubic feet of freight. The trimotor transport aircraft made its inaugural flight on September 30, 1926.

Dornier Do-217: Length 59.67 feet, wingspan 63.33 feet. Power source was two 1,580-horsepower engines that generated a cruising speed of 245 miles per hour with a maximum range of 1,430 miles. Maximum bomb load was 8,818 pounds. The prototype of this bomber first flew in August, 1938. Approximately 1,730 Dornier Do-217 bombers would find service in the German air force during World War II.

Douglas Sleeper Transport (DST, eventually known as the DC-3): Length 64.5 feet, wingspan 95 feet, loaded weight 24,000 pounds. Power source was two engines that generated a cruising speed of 192 miles per hour and a ceiling of 20,800 feet. On December 17, 1935, this plane made its first flight in California. As the DC-3, this aircraft would revolutionize air transport in the 1930's and 1940's.

F4F-3: Length 28.75 feet, wingspan 38 feet. Power source was one 1,050-horsepower engine that generated a top speed of 328 miles per hour at 21,000 feet and a range of 845 miles. Its armament consisted of six .50-inch guns. The prototype of this American aircraft first flew on September 2, 1937. The plane entered service in the U.S. Navy in November, 1940. Eventually 7,825 would be built and the plane would distinguish itself in World War II.

Fairey Flycatcher: Power source was one 400-horsepower engine that provided a top speed of 133 miles per hour, an initial climb rate of 1,090 feet per minute and a range of 263 miles. Armament consisted of two Vickers machine guns and four 20-pound bombs. This was the first British airplane built with special strengthening for catapult launches from the decks of aircraft carriers and made its inaugural flight on November 28, 1922.

Fairey Fox: Power source was one 480-horsepower engine that provided a sea-level top speed of 156 miles per hour. This British aircraft was the fastest day bomber of its time and made its first flight, in the United Kingdom, on January 3, 1925.

Fairey Night Bomber: Length 60.75 feet, wingspan 101.75 feet. Power source was two 600-horsepower engines. This airplane would become the first all-metal, low-wing, cantilever monoplane to enter service with the RAF. Its payload was 1,660 pounds of bombs and it had a range of 1,360 miles. It made its inaugural flight on November 25, 1930.

Farman F.50 P twin-engine biplane: Length 39.33 feet, wingspan of 73.33 feet, loaded weight of 6,856 pounds. Power source was two 275-horsepower engines. In July, 1920, the French airline Cie des Grands Express Aeriens began using this airplane on routes linking Paris and London and Paris and Amsterdam.

Farman F.60 Goliath: Length 47 feet, wingspan 86.83 feet, gross weight of 12,786 pounds. Power source was two 260-horsepower engines. On March 29, 1920, this French airplane entered the operation of the airline Cie des Grands Express Aeriens between Paris and London. This type of plane played a central role in the development of European air transport through the 1920's.

Fieseler Fi Storch: Length 32.5 feet, wingspan 46.75 feet. Power source was one 240-horsepower engine that generated a cruising speed of 81 miles per hour. The inaugural flight of this plane would take place in April, 1936, and more than 2,500 would be built for the Luftwaffe, the German air force.

Focke-Wulf Fw-190 VI (D-OPZE): Power source was one 1,660-horsepower engine. Widely regarded as the definitive radial-engined fighter of World War II. A prototype of this German aircraft made its inaugural flight on June 1, 1939. The Fw-190 had good all-around visibility and a wide-track main landing gear.

Fokker F.VII: Length 47.67 feet, wingspan 72.17 feet, gross weight 8,140 pounds. Power source was one 360-horsepower engine. Payload of this Dutch airplane, one of the most famous interwar civil aircraft, was eight passengers. Top speed was 97 miles per hour. The prototype of this plane first flew in April, 1924.

Fokker T-2 monoplane: Length 49.08 feet, wingspan 79.67 feet, gross weight of 10,750 pounds. On April 16-17, 1923, Lieutenant Oakley G. Kelly and John A. Macready flew a distance of 2,516.55 miles over a measured course from Wilbur Wright Field, Ohio. The pilots thereby achieved a new world record after a flight of 36 hours, 4 minutes, and 34 seconds.

GAX triplane: Length 33.58 feet, wingspan 65.5 feet, gross weight 9,740 pounds. Power source was two 435-horsepower engines providing a range of 160 miles. On June 7, 1920, the U.S. Army ordered twenty of these planes from Boeing, and this would be the only triplane to see service with the U.S. Army air forces.

Gloster Gamecock: Length 19.67 feet, wingspan 29.75 feet, gross weight of 2,863 pounds. Power source was one 425-horsepower engine that generated a top speed of 155 miles per hour. The Gamecock was the last wooden biplane fighter to enter service with the Royal Air Force and it made its inaugural flight in February, 1925.

Gloster Grebe: Power source was one 400-horsepower engine that provided a speed of 152 miles per hour and a ceiling of 23,000 feet. Loaded weight was 2,614 pounds, and armament consisted of two Vickers machine guns. The inaugural flight of this plane took place in May, 1923. A Grebe was the first fighter to achieve terminal velocity of 240 miles per hour in a dive.

Haefeli DH-3 biplane: Length 26.42 feet, wingspan 41 feet, loaded weight of 2,292 pounds. Power source was one 150-horsepower engine that provided a top speed of 90 miles per hour. This Swiss-built airplane carried passengers and mail for an experimental period from Zurich to Bern and Lausanne in Switzerland. The military airmail service opened on January 8, 1919, and closed at the end of October, carrying 246 passengers and 20,348 dispatches.

Handley Page W.8b (Hyderabad): Length 59.17 feet, wingspan 75 feet, gross weight 13,590 pounds. Power source was two 454-horsepower engines. This British bomber carried a crew of four, three defensive Lewis machine guns and a bomb load of up to 1,100 pounds. This plane first flew in October, 1923, and would serve the RAF from 1925 until 1934.

Hawker Fury: Length 26.67 feet, wingspan 30 feet, loaded weight of 3,490 pounds. With a top speed of 207 miles per hour, this single-seat interceptor was the first RAF fighter to exceed 200 miles per hour in level flight. It first took to the air on March 25, 1931.

Junkers G.38 monoplane (D-2000): Length 76.08 feet, wingspan 144.33 feet, maximum loaded weight 52,911 pounds. Power source was two 400-horsepower and two 800-horsepower engines. This was the largest aircraft built at the time, and the entire wing was covered in corrugated duralumin sheet. The prototype that first flew in Germany on November 6, 1929, could accommodate thirty passengers.

Junkers Ju-52: Length 60.67 feet, wingspan 95.17 feet. The main cargo hold was 21 feet long, 5.25 feet wide, and 6.25 feet high, providing a volume of 590 cubic feet. Power source was one 800-horsepower engine that was soon replaced with one 600/755-horsepower engine. This single-engine, all-metal aircraft with corrugated skin made its first flight on October 13, 1930. The aircraft could use wheels or floats, and ultimately skis were added to its undercarriage inventory.

Junkers Ju-52/3m: Length 62 feet, wingspan 95.92 feet. Power source was one 525/600-horsepower engine that generated a cruising speed of 152 miles per hour with a range of almost 570 miles. This aircraft was designed as a fifteen- to seventeen-passenger transport aircraft for use as an ambulance, freighter, glider-tug, troop carrier, or bomber. More than 4,800 aircraft of this German type would be built. The first flight of this airplane took place in April, 1932.

Junkers Ju-88: Length 47.25 feet, wingspan 65.58 feet. Power source was two 1,000-horsepower engines that generated a maximum speed of 292 miles per hour at 17,390 feet. The prototype of this German airplane made its debut on December 21, 1936.

Loening PA-1 biplane: Length 19.75 feet, wingspan of 28 feet, gross weight of 2,463 pounds. Power source was one 350-horsepower engine. This aircraft was the first American fighter equipped with an air-cooled radial engine and made its first appearance in March, 1922.

Messerschmitt Bf-109: Power source was one 640-horsepower or 695-horsepower engine that generated 290 miles per hour. This all-metal, low-wing, stressed-skin monoplane made its first flight on May 28, 1935, in Germany and would become the most famous German fighter of all time. It would see extensive service during World War II.

Nieuport 29V (bis): Length 20.33 feet, wingspan 19.67 feet, weight of 2,064 pounds. Power source was one 320-horsepower engine. On October 20, 1920, French aviator Sadi Lecointe became the first man officially to break the 300 kilometers per hour speed barrier when he flew this airplane at a ratified speed of 302.53 kilometers per hour (178.98 miles per hour) for a distance of 3,280 feet.

Nieuport-Delage 29V: Length 20.42 feet, wingspan 19.83 feet, power source was one 280-horsepower engine. Gross weight was 1,838 pounds. In this plane, French aviator Sadi Lacointe became the first pilot to set a new world speed record of the Federation Aeronautique Internationale. On February 7, 1920, he reached a measured speed of 171.14 miles per hour on a course 3,280 feet long.

P-38: Length 37.83 feet, wingspan 52 feet. Power source was two 1,150-horsepower engines that generated a top speed of 395 miles per hour, a climb time of 6.5 minutes to 20,000 feet and a maximum range of 1,390 miles. Armament consisted of one 37-millimeter cannon and four 0.50-inch machine guns. The prototype of this twin-engine, twin-boom aircraft would make its first flight on January 27, 1939. It would enter service in the

United States Army and see extensive use during World War II.

R.II: Length 66.67 feet, wingspan 138.33 feet, power source was four 260-horsepower engines. A single propeller with a diameter of 22.67 feet provided a maximum speed of approximately 81 miles per hour. This German aircraft was the largest airplane ever flown with a single propeller and carried the largest propeller ever used on an airplane.

R2C-1: Length 19.67 feet, wingspan 22 feet, gross weight 2,071 pounds. Power source was one 507-horsepower engine that provided 266 miles per hour. The upper wing of this biplane was lowered to the fuselage so that the pilot looked over the upper surface. On September 9, 1923, this U.S. Navy airplane made its first flight.

Ryan NYP monoplane: Power source was one 237-horsepower engine that generated a top speed of 124 miles per hour. In one such plane, the *Spirit of St. Louis*, Charles A. Lindbergh departed Roosevelt Field, New York, on May 20, 1927, to become the first person to fly solo across the Atlantic Ocean. In 33 hours, 30 minutes, and 28 seconds after his departure, he landed at Le Bourget airfield outside of Paris, France, after a flight of 3,590 miles at an average speed of 107 miles per hour. He thereby set a new long-distance record.

Sablatnig P I: Length 27.67 feet, wingspan 35.92 feet, loaded weight 2,579 pounds. Power source was one 200/220-horsepower engine, providing a cruising speed of 81 miles per hour. This airplane conducted the first long-distance flight after World War I when it flew from Berlin to Copenhagen, Denmark, and Stockholm, Sweden, in April, 1919.

Siemens-Schuckert D.VI. single-seater fighter: Power source was one 160-horsepower engine providing a maximum speed of 137.5 miles per hour. Would have been the fastest fighter aircraft to enter service in Germany had it been constructed in time for World War I. The few pilots who flew it considered it superior to any other German fighter of the First World War. The prototype flew in February, 1919.

Spad Xxbis 6: Length 24 feet, wingspan 31 feet, gross weight 2,888 pounds. Power source was one 300-horsepower engine. On November 4, 1920, the French pilot Bernard de Romanet set a new world air speed record of 192,01 miles per hour.

Spitfire: Length 29.92 feet, wingspan 37.67 feet, weight 5,200 pounds. Power source was one 990-horsepower engine that generated a top speed of 335 miles per hour at 16,800 feet with a service ceiling of 35,400 feet. The prototype of this plane first flew on March 5, 1936. The Spitfire would distinguish itself as a fighter in British service during World War II.

SSW R. VIII: Length of 70.83 feet, wingspan of 157.5 feet, maximum weight of 35,060 pounds. Power source was six 300-horsepower engines that would have provided a maximum speed of 78 miles per hour, a ceiling of 13,124 feet and a range of 559 miles. The German aircraft carried out its first taxi tests on March 1, 1919 but was damaged before its first flight. On June 26, 1919, two days before German delegates signed the Treaty of Versailles, the project was canceled.

Stout ST-1: Length 37 feet, wingspan 60 feet, gross weight 9,817 pounds. Power source was two 300-horsepower engines that provided a range of 385 miles. This was the first all-metal airplane designed for the U.S. Navy and made its inaugural flight on April 25, 1922.

T.S.R.II: Length 36.33 feet, wingspan 45.5 feet. Power source was one 690-horsepower or one 750-horsepower engine. Payload of this British airplane was one 1,610-pound torpedo or 1,500 pounds of bombs. The plane made its first flight on April 17, 1934, and would distinguish itself in convoy protection and fleet protection roles in the Royal Navy during World War II.

Tupolev ANT-4 (TB-1): Length 59 feet, wingspan 94.17 feet, gross weight up to 16,535 pounds. Power source was two 450-horsepower or two 730-horsepower engines. Payload was 6,615 pounds for up to 2.5 hours or 2,205 pounds for 9 hours. This large metal monoplane was one of the most important aircraft to appear from the Soviet Union and made its inaugural flight on November 26, 1925.

Tupolev ANT-6 (TB-3): Length 80 feet, wingspan 129.58 feet, maximum loaded weight of 53,000 pounds. Power source was four 600-horsepower engines. The payload was 4,410 pounds and the range was 600 to 800 miles. This revolutionary heavy Soviet bomber was far ahead of its contempories elsewhere.

Tupolev ANT-14: Length 86.92 feet, wingspan 132 feet, maximum weight 38,646 pounds. The largest landplane of the day, this aircraft could accommodate thirty-six passengers two abreast on either side of a central aisle, the first time that such a configuration was possible in an aircraft. This plane made its inaugural flight on August 14, 1931.

Tupolev ANT-40: Length 66 feet, wingspan 62.33 feet. Power source was two 730-horsepower engines that generated a top speed of about 250 miles per hour and a range between 350 miles and 780 miles. One of the most important Soviet bombers of World War II, this plane made its first flight on October 7, 1934. More than 6,600 SB bombers would be built before production ceased in early 1941.

Vickers Vernon: Power source was two 450-horsepower engines, gross weight 12,500 pounds, endurance was 320 miles, ceiling of 11,700 feet. Payload of this plane, the first troop carrier designed for the British Royal Air Force (RAF), was twelve troops. The first plane of this type was delivered to the RAF on August 31, 1921.

Vickers Virginia: Length 62.25 feet, wingspan 87.67 feet, speed 108 miles per hour, range 985 miles. Payload was 3,000 pounds, usually consisting of 112-pound bombs. The prototype of this British bomber made its inaugural flight on November 24, 1922.

W.8 Handley-Page airliner: Power source was two 450-horsepower engines that could carry sixteen passengers 500 miles at 90 miles per hour. The British Air Ministry insisted that the plane only carry twelve passengers in order to lighten the load and increase the margin of safety. This aircraft could reach 18,000 feet and made its inaugural flight on December 2, 1919.

XB-907: Wingspan 62.17 feet, later changed to 70.58 feet. Power source was two 600-horsepower engines that generated 197 miles per hour. On March 20, 1932, this American aircraft was delivered to the U.S. Army. During the fall, the engines were changed to two 675-horsepower types and a manually operated transparent gun turret was installed in the nose. Speed increased to 207 miles per hour, making this prototype of the B-10 light bomber faster than most contemporary fighters.

XF8C-1: Length 27.92 feet, height 11.67 feet, wingspan 38 feet, gross weight 4,191 pounds. Power source was one 432-horsepower engine and armament consisted of three .30-inch guns. On June 30, 1927, the U.S. Marine Corps placed an initial order for two prototypes of this plane.

1939-1945

Avenger: Speed was 300 miles per hour, loaded range 1,000 miles, ceiling 30,000 feet. The prototype of this monoplane first flew on August 7, 1941, and eventually 9,839 Avengers would be built as the U.S. Navy's standard carrier torpedo bomber of World War II. The airplane would enter service in nine different navies altogether.

Avro Lancaster: Length 69.33 feet, wingspan 102 feet, weight 50,000 pounds. Power source was four Merlin engines. Range was 1,660 miles with a 14,000-pound bomb load or 1,040 miles with a single 22,000-pound bomb. This aircraft made its inaugural flight on January 9, 1941, and would quickly become the most successful bomber of the RAF during World War II.

B-24: Length 63.75 feet, wingspan 110 feet. Power source was four 1,200-horsepower engines that generated a maximum speed of 292 miles per hour, a cruising speed of 228 miles per hour, a ceiling of 30,500 feet, and a range of 2,200 miles. Payload was 8,800 pounds of bombs and ten .50-inch guns. This airplane made its inaugural flight on December 29, 1939. Between 1939 and 1944, 19,256 B-24's would be built for the U.S. and Allied air forces, more than any other American aircraft.

B-25 Mitchell: Length 54.08 feet, wingspan of 67.58 feet. Power source was two 1,700-horsepower engines that generated a top speed of 315 miles per hour at 15,000 feet and a range of 1,350 miles. Payload was 3,000 pounds of bombs. The prototype first flew on August 19, 1940. Almost 11,000 Mitchells were built and the aircraft saw widespread service in both the American and Allied air forces.

B-26 Marauder: Power source was two 1,850-horsepower engines that generated a top speed of 315 miles per hour and a range of 1,000 miles. Payload was 5,800 pounds in bombs. The prototype first flew on November 25, 1940. This aircraft would become a stalwart in the inventory of the U.S. Army Air Corps/Forces.

B-29: Length 99 feet, wingspan 141.25 feet, gross weight 141,000 pounds. Top speed was 358 miles per hour at 25,000 feet, service ceiling was 31,850 feet, and maximum range was 5,830 miles. Armament comprised up to twelve .50-inch machine guns and one 20-millimeter cannon. Maximum bomb load was 20,000 pounds with armament stripped. The prototype first flew on September 21, 1942, and this bomber would enter service with the United States Army Air Corps/Services during World War II.

F4U-5 Corsair: Length 33.33 feet, wingspan 41 feet, gross weight 14,000 pounds. Power source was one 2,000-horsepower engine that generated a top speed of 417 miles per hour at 19,900 feet with a range of 1,015 miles. Armament comprised one .50-inch machine gun and one .30-inch machine gun in each wing and compartments in the wings for ten bomblets. The prototype first flew on May 29, 1940, and eventually 12,571 would be built for the U.S. Navy.

Gloster Meteor F.1: Length 41.25 feet, wingspan 43 feet, gross weight 13,795 pounds. Power source was two 1,700-pound thrust engines that generated a maximum speed of 415 miles per hour. Armament comprised four 20-millimeter cannon. The prototype of this aircraft made its inaugural flight on January 12, 1944. This plane would enter service of the RAF during World War II.

Handley Page Halifax: Length 70.08 feet, wingspan 98.83 feet. Power source was four engines. Maximum bomb load was 13,000 pounds, range was 1,860 miles with a 5,800-pound bomb load. Armament consisted of six .303-inch machine guns with provision for additional guns. The prototype of this plane would make its first flight on October 25, 1939, and eventually 6,176 would be built for the RAF.

Me-262: Power source was two engines with 1,848 pounds of thrust apiece. On July 18, 1942, the first jet-propelled Me-262 flew independently of supplementary propulsion. During World War II, this aircraft would enter service in the German air force as a fighter-bomber.

P-51 (NA-91): Widely considered one of the best fighters of World War II. Armament comprised either four 20-millimeter cannon or four or six .50-inch guns. Range was 1,300 miles with internal fuel and 2,080 miles with external drop tanks. The prototype of this Anglo-American hybrid first flew on May 29, 1942. The extended range of the P-51 meant that it would play a very important role in escorting Allied bombers to their targets in Europe.

Short Stirling: Length 87.25 feet, wingspan 99.08 feet. Power source was four 1,590-horsepower engines that generated a cruising speed of 215 miles per hour at 15,000 feet. The aircraft had a range of 1,930 miles with a 5,000-pound bomb load. A prototype would make its inaugural flight on December 3, 1939. The RAF would receive 2,221 of these aircraft, the only British bomber of World War II designed from the outset with four engines.

Yakovlev I-26 (Yak-26, then designated Yak-1 in December, 1940): Power source was one 1,050-horsepower engine that provided a top speed of 336 miles per hour and a range of 435 miles. Armament comprised one 20-millimeter cannon in the engine and one 12.7-millimeter machine gun in the fuselage as well as mountings for two 220-pound bombs on underwing racks. This aircraft made its maiden flight on January 13, 1940, and the Soviet Union would construct more than 30,000 Yak fighters during World War II.

1945-PRESENT

A-3D: Length 76.33 feet, wingspan 72.5 feet, maximum weight 82,000 pounds. Power source was two 12,400-pound jet engines that generated a top speed of 610 miles per hour at 10,000 feet and a range of 1,050 miles. Payload of this nuclear-capable bomber was 12,000 pounds. The prototype first flew on October 28, 1952. It was the heaviest aircraft to operate from an aircraft carrier and entered U.S. Navy service in 1956.

A-4D: Length 39.42 feet, wingspan 27.5 feet. Power source was one 11,200-pound engine that provided a top speed of 670 miles per hour and a tactical radius of 340 miles with a payload of 4,000 pounds. The prototype first flew June 22, 1954, and the U.S. Navy accepted delivery of its first operational A-4D in November, 1956.

A-6: Length 54.75 feet, wingspan 53 feet. Power source was two 9,300-pound jet engines that provided a cruising speed of 481 miles per hour and a normal range of 1,350 miles. Payload was 18,000 pounds of ordnance underneath the fuselage and the wings. The prototype of this aircraft first flew on April 19, 1960. Used for close air support and interdiction, the A-6 saw extensive service in the U.S. Navy from the early 1960's until the late 1990's, including the Vietnam War and the Gulf War's Operation Desert Storm.

A-7A: Length 46.08 feet, wingspan 38.75 feet. Power source was one 11,350-pound turbofan that generated a top speed of 695 miles per hour at 10,000 feet. Payload exceeded 15,000 pounds of ordnance. The prototype first flew on September 27, 1965. Ultimately 1,491 of these rugged attack bombers would be built, and the type would remain in service with the U.S. Navy and U.S. Marine Corps for more than thirty years.

Airbus A300: Length 175.08 feet, wingspan 147.08 feet. Power source is two 50,000-pound turbofan engines that generate a long-range speed of 526 miles per hour at 31,000 feet and a range of 2,100 to 3,340 miles, depending on the Airbus variant. Seating capacity lies between 269 and 302 passengers in this large-capacity, wide-bodied, short-to-medium-range transport aircraft. The inaugural flight of the Airbus A300 was made on September 28, 1972. This very successful passenger jetliner is available in many configurations and is jointly produced by France, Germany, Italy, and Spain.

Antonov An-22: Length 189.92 feet, wingspan 211.25 feet, gross weight 551,146 pounds. Power source was four 15,000-estimated-horsepower turboprop engines that allowed the plane to lift 221,440 pounds to an altitude of 25,748 in 1967. The world's largest aircraft at the time, the prototype first flew on February 27, 1965. This plane could carry massive loads, and the type served with the Soviet air force as a heavy transport aircraft and with the Soviet airline Aeroflot on strategic cargo routes. Fewer than two hundred of these planes were built.

Avro 698 Vulcan: Length 97.08 feet, wingspan 99 feet. Power source was four 8,000-pound jet engines. This aircraft was the world's first large delta-wing airplane and would enter service with the Royal Air Force (RAF). The first prototype flew on August 30, 1952.

B-2A: Length 69 feet, wingspan 172 feet. Power source is four 19,000-pound turbofan engines. Payload is approximately 50,000 pounds of ordnance, including conventional and nuclear bombs and cruise missiles. The shape of and composite materials employed in the airframe were designed to render the aircraft difficult to observe on radar. This gave rise to the term "stealth technology" to refer to both weapons and weapons platforms difficult for an enemy to detect. A prototype was first publicly displayed on November 22, 1988. This American aircraft would see service in the U.S. Air Force during Operation Desert Storm, as well as in the campaign in Afghanistan following the 2001 terrorist attacks by the al-Qaeda network operating there.

B-36: Length 162.08 feet, wingspan 230 feet, gross weight 328,000 pounds. Power source was six 3,500-horsepower propeller engines that generated a cruising speed of 202 miles per hour and a maximum range of 8,175 miles. Payload was 72,000 pounds of bombs, and armaments comprised twelve 20-millimeter cannons. Crew complement was fifteen. The prototype made its first flight on August 8, 1946. This would become the largest bomber in service of the U.S. Army Air Force/U.S. Air Force and the aircraft with the largest wingspan in operation with any of the U.S. air forces.

B-45: Power source was four 4,000-pound jets that generated a cruising speed of 456 miles per hour and a range of 1,910 miles. Payload of this plane was 20,000 pounds. The prototype first flew on March 17, 1947. The B-45 was the first U.S. all-jet bomber to become operational.

B-47: Power source was six 6,000-pound engines that provided a maximum speed of 617 miles per hour and a range of 4,000 miles. Gross weight was 180,000 pounds. Payload was a 20,000-pound bomb load. Armament consisted of two .50-inch guns, and the crew complement was three. The prototype first flew on December 17, 1947. Eventually Boeing would construct 2,032 B-47's, and Strategic Air Command of the U.S. Air Force would operate this bomber from 1951 through 1967.

B-52: Length 152 feet, wingspan 185 feet, gross weight 390,000 pounds. Power source is eight 8,700-pound jet engines that generate a maximum speed of 556 miles per hour at 40,000 feet, with a range of 5,200 miles. The prototype first flew on October 2, 1952. This heavy strategic bomber would form an essential component of the U.S. nuclear arsenal during the Cold War and would see service in the Vietnam, Korean, and Gulf Wars and in the Afghanistan campaign.

Boeing 707-100: Length 144.5 feet, wingspan 130.83 feet, gross weight 257,000 pounds. Power source was four 12,500-pound turbojet engines that provided a cruising speed of 571 miles per hour. Payload was 124 to 179 passengers and range was 3,075 miles. The prototype of this American passenger jetliner made its inaugural flight on December 20, 1957.

Boeing 727: Length 133.17 feet, wingspan 108 feet, gross weight 152,000 pounds. Power source was three 14,000-pound turbofans that generated a cruising speed of 532 miles per hour and a range of 1,150 miles. Seating capacity was either 129 passengers in a high-density configuration of 94 in a combination of first-class and economy. Approximately 1,832 of these jet airliners would be built, and the prototype first flew on February 9, 1963.

Boeing 747-100: Length 231.33 feet, wingspan 195.67 feet, gross weight 735,000 pounds. Cruising speed ranged between 590 and 625 miles per hour at altitudes between 35,000 and 37,000 feet. Range with a maximum payload was 4,600 miles and with a minimum payload 7,080 miles. Seating capacity was 490 passengers. The prototype first flew on February 9, 1969. The American aircraft was the world's largest commercial airliner.

C-5A: Length 247.83 feet, wingspan 222.67 feet, gross weight 769,000 pounds. This military transport aircraft was the largest and heaviest in the world to date. With a cruising speed of 537 miles per hour at 30,000 feet, the plane could carry a maximum payload of 265,000 pounds over short distances and a 220,000-pound payload up to 3,500 miles. It made its inaugural flight on June 30, 1968, and financial constraints limited the number in service with the U.S. Military Airlift Command to eighty-one.

C-141: Length 145 feet, wingspan 160.08 feet, gross weight 316,600 pounds. Power source was four 21,000-pound engines that allowed the plane to carry 154 troops, 80 litters, or 90,000 pounds of cargo. The prototype made its inaugural flight on December 17, 1963. This airplane would become the first strategic jet transport aircraft for the U.S. Military Air Transport Service.

Dassault Mirage F.1: Length 45.92 feet, wingspan 27.75 feet, gross weight of 24,470 pounds. Power source was a single 11,067-/15,784-pound turbojet engine that provided a top speed of 1,450 miles per hour at 40,000 feet and 835 miles per hour at sea level. Payload was 3,500 pounds of ordnance. The prototype first flew on December 23, 1966. Nearly 1,000 of these single-seat French fighters would be produced by 1992.

Dassault Mirage IIIA: Length 51 feet, wingspan 26.08 feet, gross weight 30,203 pounds. Power source was one 13,228-pound turbojet that generated a maximum speed of Mach 2.2, a speed 2.2 times the speed of sound (which varies, depending on altitude), with a ceiling of 59,055 feet. Combat radius was 391 miles with a payload of 1,765 pounds in ordnance. The prototype first flew on May 12, 1958. Variants of this French fighter appeared as all-weather interceptors, trainers, and fighter-bombers.

Dassault Mirage IVA: Length 77.08 feet, wingspan 38.83 feet. Power source was two 15,432-pound turbojet engines that generated a maximum speed of 1,454 miles per hour at 40,060 feet and a payload of either one 60-kiloton nuclear weapon or 16,005 pounds of stores. The prototype of this French delta-wing strategic bomber first flew on June 17, 1959. The first aircraft joined the French Air Force in 1964.

Douglas C-133: Length 157.5 feet, wingspan 179.67 feet, gross weight 286,000 pounds. Power source was four 6,500-static horsepower engines. This transport aircraft could lift 110,000 pounds of a wide variety of cargo. The prototype first flew on April 23, 1956. The U.S. Military Air Transport Service accepted delivery of the first C-133's in late 1957.

Douglas DC-7: Length 108.92 feet, wingspan 117.5 feet. Power source was four 3,250-horsepower engines. Range was 2,850 miles. The prototype first flew on May 18, 1953. This aircraft was the first truly long-range commercial transport, and a later variant, the DC-7C, could carry ninety-four passengers up to 4,605 miles.

Douglas DC-8: Length 150.5 feet, wingspan 142.42 feet. Power source was four 13,000-pound turbojets that generated a cruising speed of 559 miles per hour. Seating capacity was for 176 passengers. The prototype of this American jetliner first flew on May 30, 1958.

Douglas DC-9: Length 104.42 feet, wingspan 87.5 feet. Power source was one 12,250-pound turbofan that generated a cruising speed of 544 miles per hour and a range of 1,013 miles. Seating capacity was for fifty-six to ninety passengers. The prototype first flew on February 25, 1965. The DC-9 would form an essential element of the U.S. domestic short- and medium-term passenger air traffic for more than thirty years.

Douglas DC-10: Length 181.42 feet, wingspan 165.33 feet, maximum takeoff weight 430,000 pounds. Power source was three 40,000-pound turbofans. Seating capacity ranged between 225 and 270 passengers. The American prototype first flew on August 29, 1970, thereby inaugurating the first new large-capacity, wide-body turbofan airliner after the Boeing 747.

F-4 Phantom II: Length 63 feet, wingspan 38.67 feet. Power source is two 9,300-pound jet engines that generate an average speed of approximately 580 miles per hour and a combat radius between 494 miles and 786 miles. Armaments include missiles mounted underneath the fuselage and both wings, an electric cannon mounted in the nose, and various configurations of either conventional or nuclear bomb loads weighing up to 16,000 pounds. Arguably the most outstanding combat aircraft of the turbojet era, the prototype of this American plane first flew on May 27, 1958. It was used extensively by the U.S. Air Force, U.S. Navy, and the U.S. Marine Corps during the Vietnam War.

F-14A: Swept wingspan 38.17 feet, extended wingspan 64.08 feet, maximum takeoff weight 74,349 pounds. Power source is two 20,600-pound turbofans that generated a maximum speed of Mach 2.34 at 40,000 feet or Mach 1.2 at sea level. The prototype first flew on December 21, 1970. This carrier-based two-seat interceptor is armed with one 20-millimeter cannon and an assortment of air-to-air missiles. The plane also possesses bombing capability and entered service with the U.S. Navy in 1972.

F-15A: Length 63.75 feet, wingspan 42.75 feet, maximum takeoff weight 56,000 pounds. Power source is one 19,000-/25,000-pound turbofan that provides a top dash speed above Mach 2.5, a sustained top speed of Mach 2.3 at 36,000 feet, and supersonic cruise close to the ground. Armament comprises one 20-millimeter cannon and 16,000 pounds of ordnance. The inaugural flight took place on July 27, 1972. This aircraft would enter service with the U.S. Air Force and would distinguish itself during Desert Storm as a fighter-bomber.

F-16: Top speed Mach 2.2 at 40,000 feet and Mach 1.1 at 1,000 feet with a combat radius of 550 miles. The prototype first flew on February 2, 1974. This lightweight air combat fighter can carry 15,200 pounds of ordnance and would distinguish itself in U.S. Air Force service during Desert Storm.

F-86D: Power source was one 5,700-pound engine that generated a top speed of 707 miles per hour, an initial climb rate of 17,000 feet per minute and a ceiling of 54,000 feet. This all-weather interceptor carried armament that included twenty-four 2.75-inch rockets. The prototype first flew on December 22, 1949, and eventually 2,504 F-86's were produced. This jet fighter would distinguish itself in U.S. Air Force service in the Korean War.

F-104: Length 54.75 feet, wingspan 21.92 feet, gross weight 27,853 pounds. Top speed was 1,150 miles per hour at 40,000 feet and climb rate was 54,000 feet per minute. The prototype first flew on February 28, 1954. This tactical day fighter and interceptor was the first aircraft capable of sustained speeds in excess of Mach 2, twice the speed of sound. It joined the U.S. Air Force in 1955.

F-111A: Length 73.5 feet, swept-wing span 31.92 feet, extended wingspan 63 feet, gross weight 92,500 pounds. Power source was two 11,5000-/19,000-pound turbojet engines. The design top speed was 1,650 miles per hour at 40,000 feet and 865 miles per hour at sea level. This bomber was designed to sweep its wings fully forward for slow speeds and back for high-speed travel. The prototype made its inaugural flight on December 21, 1964. The bomber would enter service with the U.S. Air Force.

F/A-18: Length 56 feet, wingspan 37.5 feet, maximum takeoff weight 33,585 pounds in fighter mode and 47,000 pounds in attack mode. Combat radius is 460 miles in fighter mode and 633 miles in attack mode. Power source is two 16,000-pound engines. The prototype flew on November 18, 1978, and this airplane would enter service in the U.S. Navy and the U.S. Marine Corps. It would distinguish itself as a fighter and light attack craft during Desert Storm.

Fokker F.27 Friendship: Length 77.25 feet, wingspan 95.08 feet, maximum weight of 44,996 pounds. Power source was two 2,320-estimated-static-horsepower turboprop engines that generated a cruising speed of 298 miles per hour and a range of 1,197 miles. Payload was forty-four passengers. The prototype first flew on November 24, 1955, and eventually nearly eight hundred of these popular commercial passenger aircraft would be built.

Gloster Meteor F.8: Power source was two 3,600-pound jet engines that provided a maximum speed of 590 miles per hour at sea level with an initial climb rate of 6,950 feet per minute and a range of 980 miles. Four 20-millimeter cannon comprised the armament. On June 29, 1950, this single-seat day interceptor entered service with the RAF, where it would remain the primary air defense fighter for five years. It was first flown on October 12, 1948.

Gulfstream II: Length 79.92 feet, wingspan 68.83 feet. Power source was two 11,450-pound turbofans in rear fuselage pods that generated a cruising speed of 496 miles per hour and a range of 3,680 miles. The prototype flew on December 2, 1966. On May 5, 1968, the type would become the first executive jet to complete a nonstop flight across the Atlantic Ocean, traveling from Peterboro, New Jersey, to Gatwick Airport, London.

Ilyushin I1-62: Length 160.75 feet, wingspan 141.75 feet. Power source was four 23,150-pound turbofan engines. Passenger capacity was 186 persons. This airplane was designed as the Soviet Union's first international jet transport. The prototype first flew in January, 1963.

Lockheed L-1649 Starliner: Length 116.17 feet, wingspan 150 feet, gross weight 160,000 pounds. Power source was four 3,400-horsepower engines that allowed the plane to transport ninety-nine passengers. This American transport airliner made its inaugural flight on October 10, 1956.

MiG-9: Power source was two 1,760-pound engines that generated a maximum speed of 656 miles per hour at 16,405 feet, a range of 684 miles and a ceiling of 42,653 feet. The prototype first flew on April 24, 1946. This fighter was the first Soviet-built jet aircraft that would enter service in the Soviet air force.

MiG-15: Length 32.92 feet, wingspan 33.08 feet, maximum weight 10,692 pounds. Power source was one 5,000-pound jet engine that generated a maximum speed of 652 miles per hour at sea level, a climb rate of 2.3 minutes to 16,400 feet, and a ceiling of 49,869 feet with a range of 882 miles. The prototype of this jet fighter first flew on December 30, 1947. The plane entered service in the air force of the Soviet Union in 1948 and ultimately more than 5,000 single-seat fighters and several thousand two-seat training aircraft would be built before production ceased in 1951.

MiG-17: Length 36.92 feet, wingspan 31.58 feet, maximum loaded weight 13,955 pounds. Power source was one 5,732-/7,451-pound turbojet engine that generated a maximum speed of 711 miles per hour at 9,840 feet and a climb rate of 1.8 minutes to 16,405 feet. The prototype made its first flight on January 17, 1950. By the time that production had ceased at the end of the decade, about 6,000 of these Soviet jet fighters had been built.

MiG-19: Length 41.33 feet, wingspan 30.17 feet. Power source was two 4,079-/6,702-pound turbojets that generated a top speed of 902 miles per hour and an initial climb rate of 22,635 feet per minute. The prototype first flew in October, 1952. This Soviet aircraft was the first truly supersonic fighter outside the United States and it was suitable for ground attack deployment.

MiG-21: Length 51.67 feet, wingspan 23.42 feet, gross weight 22,723 pounds. Various powerplants provided between 12,000 and 14,000 pounds of thrust. The prototype first flew in November, 1955, and ultimately more than 11,000 of these supersonic single-seat fighters would be constructed for the Soviet Union and its client states and allies.

MiG-23: Length 55.08 feet, wingspan 46.75 feet with extended wings, 26.75 feet with wings swept back. Power source was one 27,550-pound engine that provided a maximum speed of approximately 1,550 miles per hour and a maximum combat radius of 808 miles. Flight tests began in 1966, and this air combat fighter would become the mainstay of the air forces of the Soviet Union and its client states as well as Warsaw Pact Nations. The plane would enter Soviet service in 1973. The ground-attack version of the plane was designated MiG-27.

Myasishchyev M-4 Bison: Length 154.83 feet, wingspan 165 feet. Power source was four 19,180-pound jet engines that provided a maximum speed of 621 miles per hour and a range of 6,650 miles. It was flown in 1953, entered the service of the Soviet air force in 1956, and was still operational in the early 1990's.

No. 1 Bell XS-1: Power source was four rocket motors that generated a speed of about 700 miles per hour. On October 14, 1947, U.S. Air Force Major Charles "Chuck" Yeager piloted this aircraft and became the first human being to pass through the sound barrier. A B-29 bomber carried the X-1 to an altitude of 20,000 feet before releasing it. The aircraft rose to an altitude of 45,000 in this historic, 14-minute flight.

P-84 Thunderjet: Top speed 622 miles per hour, range 2,000 miles, bomb load was 2,000 pounds. The prototype of this American aircraft made its inaugural flight on February 28, 1946. Redesignated F-84 in 1948, the plane would become operational in 1951 as the first single-seat fighter-bomber capable of dropping tactical nuclear weapons.

P-86A: Length 37.5 feet, wingspan 37.08 feet, gross weight 16,357 pounds. Power source was one 4,850-pound engine that generated a top speed of 675 miles per hour at 2,500 feet, a ceiling of 48,300 feet, and a range of 783 miles. Armament comprised six .50-inch guns. The prototype flew on October 1, 1947. This was the world's first swept-wing fighter and entered service in the U.S. Air Force in mid-1949.

SAAB-J35A Draken: Length 50.33 feet, wingspan 30.83 feet, gross weight 27,998 pounds. Power source was one 17,262-pound jet engine that provided a top speed of 1,320 miles per hour and a combat radius of 348 miles. The prototype of this double-delta single-seat interceptor first flew on February 15, 1958. The plane joined the Swedish Air Force in February, 1960.

SR-71A: Length 103.83 feet, wingspan 55.58 feet. Power source was two 32,500-pound turbo-ramjets that generated a top speed of Mach 3.35, three times the speed of sound, and an operating ceiling of 80,000 feet. Only thirty-two of these reconnaissance aircraft would be built, and the prototype first flew on December 21, 1964.

Tornado: Length 54.75 feet, wingspan 45.58 feet (extended) 28.17 feet (swept), maximum takeoff weight 58,400 pounds. Power source was two 9,000-/16,000-pound turbofan engines. Armament of this British-German-Italian aircraft comprised one 22.7-millimeter cannon and 19,840 pounds of bombs and missiles. The prototype of this two-seater interceptor, fighter-bomber, and reconnaissance aircraft first flew on August 14, 1974. This plane distinguished itself in Operation Desert Storm.

Tupolev Tu-144: Length 196.83 feet, wingspan 75.42 feet, maximum takeoff weight 330,000 pounds. Power source was four 28,660-/38,580-pound turbofans. It had a design speed of 1,550 miles per hour up to an altitude of 65,600 feet and a maximum range of 4,040 miles. The inaugural flight took place on December 31, 1968. This Soviet plane was the world's first supersonic transport aircraft to fly.

Oliver Griffin

Time Line

1000 B.C.E.: The Chinese invent kites which carried men to scout troops.

1162: Ismail Cevheri, in Constantinople, Turkey, tries to fly using pleated fabric wings. He plummets from the top of a tower and dies.

1250's: The first suggestion of flight by lighter-than-air devices is made by the English philosopher and theologian Roger Bacon.

1300's: Marco Polo witnesses kites carrying humans in China.

1490's-1510's: Leonardo da Vinci, the famed Italian painter, sculptor, and thinker, sketches out several designs for flying machines, including ornithopters, helicopters, and parachutes.

1536: Frenchman Denis Bolor dies trying to fly using wings flapped by a spring mechanism.

1640's: In what is believed by some to be the first successful attempt at gliding flight, the Turkish scientist Hezarfen Ahmet Celebi attempted a flight inspired by Ismail Cevheri and Leonardo da Vinci. Celebi constructed a wing out of rush-work and leaped from the Galata tower in Istanbul into a strong headwind. He was witnessed by the Ottoman Sultan Murat IV and a crowd of citizens below to fly 1 mile across the Bosporus strait, but was later exiled and died at an early age. The incident is not given much historical credence today, but remains as the first eyewitness account of a successful manned flight.

1678: A French locksmith named Besnier tries to fly with wings modeled after the webbed feet of a duck.

1709: Father Bartolomeu de Gusmaõ demonstrates a model hot air balloon to King John V of Portugal.

1783: On June 4, the Montgolfier brothers launch the first successful tethered flight, a balloon propelled by burning a pile of moist wool and old shoes. Three months later, on September 19, their second trial, before King Louis XVI, carries passengers: a rooster, a duck, and a sheep. On November 21, the Montgolfiers construct a hot-air balloon that rises 84 feet into the air, containing human fliers, Jean-François Pilâtre de Rozier and the Marquis François-Laurent d'Arlandes.

1783: On December 1, Jacques-Alexandre-César Charles makes the first solo flight in a hot-air balloon, flying from Paris to Nesle, France.

1784: The French design a model helicopter.

1785: On June 15, De Rozier and a companion become hot-air ballooning's first fatalities, after falling to their deaths when their hybrid hot-air-and-hydrogen balloon ignites over the English Channel.

1785: The first successful crossing of the English Channel by air is made by the French balloonist Jean-Pierre Blanchard and American John Jeffries, using a hydrogen balloon. The flight lasts almost 3 hours.

1793: French armies use tethered balloons to see several miles beyond enemy lines during the French Revolution.

1795: Jean-Pierre Blanchard makes the first balloon flight in America, traveling from Philadelphia, Pennsylvania, to Gloucester County, New Jersey. President George Washington is one of the dignitaries on hand watching the launch of the hydrogen-filled balloon. It was Blanchard's forty-fifth flight, and he charged up to five dollars per person to allow people to observe his takeoff in what is today Independence Square.

1797: Andre Jacques Garnerin completes the first parachute jump, leaping from a balloon approximately 2,000 feet in the air.

1799: Sir George Cayley develops the concept of the fixed-wing aircraft configuration that is still used to this day.

1804: Cayley builds and flies the first fixed-wing glider model.

1809: Marie Madeleine Sophie Blanchard, wife of balloonist Jean-Pierre Blanchard, becomes the first female to die during flight when her hydrogen balloon catches fire amid a fireworks display.

1840: The first photograph is taken of the Moon.

1845: The first photograph is taken of the Sun.

1850: The first photograph is taken of a star.

1852: Henri Giffard successfully attaches a steam engine and propeller to a cigar-shaped balloon to create the first airship.
1861-1864: Balloons are used for reconnaissance during the American Civil War, one of the first effective uses of military air power.
1868: Matthew Boulton obtains a British patent on a design for ailerons as control surfaces.
1870-1871: The French use observation balloons during the Franco-Prussian War.
1880: Mary H. Myers becomes the first American woman to pilot her own balloon.
1884: English engineer Horatio Phillips determines that curved wings work better than flat wings in crude wind tunnel experiments, thereby inventing the airfoil. He also determines that wings with a high aspect ratio work better than stubbier wings.
1887: Samuel Pierpont Langley, director of the Smithsonian Institution, turns his attention to the development of a manned flying apparatus by constructing a large whirling arm 30 feet in radius and capable of speeds of up to 70 mile per hour at the tip.
1891: German Otto Lilienthal helps to develop and popularize hang gliders.
1896: On May 6, Samuel Pierpont Langley makes the first successful unmanned heavier-than-air flight in history, in a 25-pound aerodrome launched from atop a houseboat on the Potomac. Two successful flights were made totaling over 1 mile in flight distance.
1899-1902: The British use balloons and kites for observation purposes during the Boer War.
1900: Influential engineer Octave Chanute advises Orville and Wilbur Wright, Alexander Graham Bell, and Samuel Langley in their aviation projects.
1900: Count Ferdinand von Zeppelin constructs and flies the first dirigible, in Friedrichshafen, Germany.
1903: On December 17, Wilbur and Orville Wright make the first successful powered heavier-than-air flight in their Wright *Flyer* at Kitty Hawk, North Carolina.
1904: Captain Thomas S. Baldwin accomplishes the first circuit flight in a navigable balloon in Oakland, California, on August 3.
1904-1905: During the Russo-Japanese War, the role of balloons leads to later military systems for employing aircraft for reconnaissance and artillery spotting.
1906: On September 13, Alberto Santos-Dumont flies his *14-Bis*, a box-kite canard design, becoming the first to fly an aircraft in Europe.
1907: Paul Cornu makes the first helicopter flight, in France.
1908: Madame Therese Peltier becomes the first woman to fly solo in an airplane.
1908: Orville Wright wins a U.S. Army contract to produce military aircraft.
1909: Louis Blériot makes the first flight across the English Channel.
1910: Aviation pioneer Anthony H. G. Fokker builds his first aircraft, named "The Spider."
1911: Glenn H. Curtiss demonstrates the first amphibian type of aeroplane equipped with wheels and floats.
1911: Earle Ovington carries the first U.S. airmail from Nassau Boulevard Aerodrome, New York, to Mineola, New York.
1911: On December 10, Cal Rodgers completes the first transcontinental flight from Long Island, New York, to Pasadena, California.
1912: Anthony Fokker establishes an airplane factory at Johanneshal, Germany, where he develops the Dr.I. triplane flown by Manfred von Richthofen, the "Red Baron," during World War I.
1913: Igor Sikorsky develops the first passenger airplane.
1913: Roland Garros makes the first crossing of the Mediterranean on September 13.
1914: Airplanes provide vital reconnaissance for the first time in a major conflict during the Battle of the Marne in World War I.
1914: Two British aircraft destroy a German zeppelin in the world's first aircraft bombing raid.
1914: Anthony Fokker develops German pursuit planes during World War I and invents a timing mechanism for the shooting of rear-mounted machine guns through an airplane's propeller blades.
1915: The National Advisory Committee for Aeronautics (NACA) is established by the U.S. government to foster avionics research.

1915: German zeppelin raids on London are the first example of strategic bombing by military aircraft.
1915: Donald W. Douglas joins the Glenn L. Martin Company in Los Angeles, California, as chief engineer.
1916: Boeing is first incorporated by William E. Boeing as the Pacific Aero Products Company to develop the B & W seaplane. The company is renamed the Boeing Airplane Company the following year.
1918: The United States Post Office officially inaugurates airmail service.
1919: On April 28, Leslie Irvin, using a parachute designed by Floyd Smith, makes the first jump from an airplane.
1919: On July 14-15, British Captain John Alcock and Lieutenant Albert Brown make the first nonstop transatlantic flight, from Newfoundland to Ireland.
1919: Robert H. Goddard publishes "A Method for Reaching Extreme Altitudes."
1919: The Koninklijke Luchtvaart Maatschappij (KLM) is incorporated in The Hague, Netherlands.
1920's-1930's: The U.S. government, which controls most of the world's supply of helium, operates four rigid airships for long-range reconnaissance.
1920: With David R. Davis, Donald Douglas forms the Davis Douglas Company near Santa Monica, California.
1920: Anthony Fokker designs the F.II, one of the first passenger transport planes.
1920: The first scheduled KLM flight is made from London to Amsterdam.
1921: The Douglas Company is incorporated.
1921: Bessie Coleman becomes the first African American woman to receive a pilot's license from the Fédération Aéronautique Internationale.
1921: On August 24, the U.S. airship *R-38*, built for high altitudes, maneuvers hard at a low altitude, breaks in half, and explodes.
1921: U.S. Army colonel Billy Mitchell demonstrates the might of air power by sinking a battleship, the most destructive manmade force on Earth at the time, with a single aircraft.
1922: Anthony Fokker moves to the United States, where he eventually builds three more aircraft factories.
1922: The U.S. Navy contracts with the Douglas Company for the DT-2 torpedo bomber, a modified version of which is requested by the U.S. Army Air Service.
1923: On May 3, Lieutenants Oakley Kelly and John Macready complete the first nonstop coast-to-coast airplane flight.
1923: On December 21, the French airship *Dixmude* explodes in flight during a thunderstorm, killing fifty crew members.
1923: Aeroflot is established by the Soviet government as the nation's official airline.
1924: KLM begins scheduled flights between Amsterdam and the Dutch colonies in Indonesia.
1924: The U.S. Post Office Department opens regular day-and-night airmail service between New York and San Francisco.
1924: Four Douglas World Cruiser aircraft leave Santa Monica for an around-the-world flight, which two complete.
1925: The Douglas C-1 military transport, the first military aircraft given the "C" designation for cargo transport, based on the DWC, makes its first flight, and the first Douglas mailplane, the M-1, starts manufacturer's flight trials.
1925: Scientists observe a total eclipse of the sun from above the clouds.
1925: On September 3, the USS *Shenandoah* airship breaks apart in a thunderstorm, killing fourteen of the forty-three crew members.
1926: Allan Loughead (name later changed to Lockheed) establishes the Lockheed Aircraft Company in Hollywood, California, where he and Jack Northrop design the popular and record-setting Vega monoplane.
1926: Western Air Express delivers airmail using a Douglas M-2 on its Salt Lake City-to-Los Angeles route—the airline's first two passengers fly the route for a $90 fare.
1926: Deutsche Luft Hansa Aktiengesellschaft is formed by the merger of Deutsche Aero Lloyd (DAL) and Junkers Luftverkehr and begins scheduled flights.
1926: Robert H. Goddard launches the first liquid-fueled rocket in Auburn, Massachusetts.
1926: Pratt & Whitney Aircraft Company produces its first engine.

1926: U.S. Naval Commander Richard E. Byrd makes the first flight over the North Pole.
1927: On May 27, airmail pilot Charles A. Lindbergh makes the first transatlantic solo flight from Long Island, New York, to Paris, France, in his Ryan aircraft, dubbed the *Spirit of St. Louis*.
1927: The Cessna Aircraft Company is incorporated.
1927: Iberia Airlines is formed and begins regular service between Madrid and Barcelona, Spain.
1928: On May 25, the Italian airship *Italia* loses buoyancy and crashes attempting to reach the North Pole.
1928: Hubert Wilkins and Carl Ben Eiselson make the first trans-Arctic flight.
1928: Charles Kingsford-Smith and Charles Ulm make the first transpacific flight, from California to Australia.
1928: On June 17, Amelia Earhart becomes the first woman to cross the Atlantic.
1928: U.S. Naval Commander Richard E. Byrd, Bert Balchen, Captain Ashley C. McKinley, and Harold I. June make the first flight over the South Pole.
1928: Franz von Opel flies the first rocket-powered plane in Germany, reaching speeds of up to 100 miles per hour.
1928: After building airmail and military aircraft throughout the 1920's, Boeing Airplane Company is merged into the United Aircraft & Transport Corporation (UATC), a group of aircraft manufacturers and airlines.
1928: Cessna produces the first full cantilever-wing light airplane to go into production in the United States.
1928: The Douglas Aircraft Company is organized in November.
1929: The Lockheed Aircraft Company is purchased by the Detroit Aircraft Corporation, which declares bankruptcy three years later.
1929: The *Graf Zeppelin* makes the first around-the-world flight by a dirigible.
1930: On October 5, the British *R-101* airship crashes and burns, killing forty-eight of the fifty-four total passengers and crew.
1930: The Aviation Corporation, a holding company acquiring small aviation companies, is incorporated into American Airways.
1930: Amy Johnson becomes the first woman to solo between England and Australia.
1930: Transcontinental Western Air (TWA) is formed by the merger of Western Air Express (WAE) and Transcontinental Air Transport (TAT) and the new airline inaugurates transcontinental service, with an overnight stop in Kansas City, Missouri.
1931: United Air Lines is incorporated as a management company to coordinate the operations of four original subsidiary airlines, Boeing Air Transport, Pacific Air Transport, Varney Air Lines, and National Air Transport.
1931: Two Swiss airlines, Balair and Ad Astra, merge to form Swissair.
1931: Wiley Post and Harold Gatty make the first around-the-world flight in a single aircraft, the *Winnie Mae*.
1931: Clyde Pangborn and Hugh Herndon make the first nonstop crossing of the Pacific.
1931: Sir Frank Whittle of Britain designs and patents the first jet engine.
1932: Amelia Earhart becomes the first woman to fly solo across the Atlantic.
1932: The Lockheed Corporation is reorganized by a group of investors who improve the company's fortunes throughout the Great Depression with the production of the dual-engine Electra airliner.
1932: Jack Northrop establishes the Northrop Corporation, a Douglas subsidiary, at El Segundo, California.
1933: On April 3, the USS *Akron* airship is driven into the sea by downdrafts in a storm, killing seventy-three of the seventy-six crew members.
1933: From July 15 to 22, Wiley Post makes the first round-the-world solo flight in *Winnie Mae*.
1933: Swissair becomes part of the European night mail network, with flights between Basel, Switzerland, and Frankfurt, Germany.
1933: The first Douglas airliner, the DC-1, makes its first flight.
1933: A group of airlines collectively named the Société Centrale pour l'Exploitation des Lignes Aériennes (S.C.E.L.A.). is renamed Air France.
1933: Deutsche Luft Hansa Aktiengesellschaft is renamed Lufthansa.

1934: President Franklin D. Roosevelt signs the Air Mail Act of 1934, which includes the provision for the appointment of a Federal Aviation commission.

1934: After the cancellation of federal commercial airmail contracts, the U.S. Army Air Corps begins flying the mail in Douglas O-35's and B-7's.

1934: Continental Airlines's predecessor, Varney Speed Lines, makes its first flight, from Pueblo, Colorado, to El Paso, Texas.

1934: Federal antitrust regulations require the splitting of the United Aircraft & Transport Corporation into three separate companies: the United Aircraft Company, the Boeing Airplane Company, and United Air Lines.

1934: American Airways is renamed American Airlines.

1934: Lufthansa makes the first regularly scheduled transoceanic airmail deliveries across the South Atlantic.

1935: On February 12, the fin of the USS *Macon* is ripped off in storm, and the airship loses buoyancy and crashes at sea, killing two of the eighty-three crew members.

1935: The Douglas Sleeper Transport (DST), a predecessor of the DC-3, makes its first flight.

1935: Helen Richey becomes the first woman to be employed as an airline pilot, by Central Airlines.

1935: The first air traffic control center goes into operation at Newark, New Jersey, on December 1.

1935: Boeing's Flying Fortress B-17 bomber, which later plays a crucial role in U.S. success during World War II, is first flown.

1936: American Airlines becomes the first in the nation to fly the Douglas DC-3 for passenger service.

1936: For the third time, the *Detroit News* names the Airmaster the world's most efficient airplane, awarding the trophy to Cessna permanently.

1936: Aer Lingus Teoranta is established by the Irish government.

1937: On May 6, the *Hindenburg*, a hydrogen-filled dirigible, crashes and burns at Lakehurst, New Jersey, killing thirty-six people.

1937: Amelia Earhart disappears on July 2, en route to Howland Island from Lae, New Guinea.

1937: Russian pilots discover the shortest transpolar air route, flying from Russia over the Arctic Ocean to Vancouver, Canada.

1937: Douglas Aircraft Company takes control of its Northrop Corporation subsidiary, which is renamed the following year as the Douglas El Segundo Division.

1937: The name of Varney Speed Lines is changed to Continental Airlines, and the new airline's headquarters are moved from El Paso, Texas, to Denver, Colorado.

1938: Air France becomes the world's third-largest airline network, with one hundred aircraft. Its expansion is subsequently interrupted by World War II.

1939: World War II begins in Europe.

1939: US Airways' predecessor, All American Aviation, begins operations flying airmail to western Pennsylvania and the Ohio Valley.

1939: Engineer James S. McDonnell incorporates the McDonnell Aircraft Corporation in St. Louis, Missouri.

1939: The German Heinkel He-178 becomes the first test aircraft to fly using a jet engine.

1939: Howard Hughes takes ownership control of Trans World Airlines, controlling the airline for the next twenty-five years.

1939: Iberia makes its first international flight, from Madrid and Lisbon, Portugal.

1939: First flight of the VS-300, the first practical helicopter, piloted by Igor Sikorsky.

1939: Two British airlines, Imperial Airways and British Airways, are nationalized to form the British Overseas Airways Corporation (BOAC).

1939: Swissair suspends its operations with the outbreak of World War II; they are later resumed.

1940's: Lockheed begins a long-term association with the U.S. military, providing P-38 Lightning bombers during World War II and establishing the Advanced Development Projects division, or Skunk Works, a top-secret facility for military aircraft development.

1940's: Continental modifies B-17 and B-29 bombers for the United States during World War II.

1940: Germany launches the Battle of Britain over the United Kingdom. The Royal Air Force holds its own.

1940: The Army Air Corps requests from McDonnell a proposal for fighter construction, and a contract to build the XP-67 is awarded the following year.
1940: American becomes the first in the nation in revenue passenger miles flown.
1941: The Tuskegee Airmen, the first African American fighter squadron in the United States armed forces, is formed.
1941: The first successful test flight of the V-2 rocket is made on October 3.
1941: On December 7, the Japanese bomb Pearl Harbor, Hawaii, drawing the United States into World War II.
1941: Larry Bell, entrepreneur and founder of Bell Aircraft Corporation, encourages inventor Arthur Young in helicopter development.
1942: Douglas SBD Dauntless dive-bombers, flying from three U.S. aircraft carriers, sink four enemy carriers on June 4, the first day of the Battle of Midway, the turning point in the Pacific War.
1942: The U.S. Army Air Forces conduct the first U.S. attack on Nazi-occupied Europe on July 4. The mission is flown by six American crews using Douglas DB-7B's (A-20C) provided by the RAF.
1942: Sky Chefs, an American Airlines subsidiary, begins airline catering operations.
1942: Boeing's Superfortress (B-29) bomber, which contributes greatly to the U.S. war effort, is first flown.
1943: U.S. Army Air Forces C-47's, along with British RAF DC-3 Dakotas, begin spectacular night operations for the invasion of Sicily by towing gliders from North Africa across the Mediterranean.
1944: The German Messerschmitt Me-262 becomes the first production aircraft to use jet engines.
1944: Alaska Star Airlines, the result of a series of mergers since 1934, changes its name to Alaska Airlines, and, in the late 1940's, it becomes the largest charter carrier in the world.
1944: V-1 and V-2 rockets launched by Germany during World War II are the first intercontinental ballistic missiles.
1944: German Me-262 and British Meteor are the first military jet aircraft.
1944: More than 1,000 military DC-3 and C-47 aircraft, many towing troop-carrying gliders, airlift more than 20,000 paratroopers and their weapons across the English channel during the first hours of D day, June 6.
1944: On September 14, a Douglas A-20 Havoc makes the first successful flight into a hurricane for scientific data.
1944: Iberia Airlines is nationalized and expands its route network.
1944: American introduces regularly scheduled freight service, the first in the United States.
1945: Bombing of Dresden, Germany, by Allied forces on February 13-14 levels the city.
1945: The B-29 bomber *Enola Gay* drops the first atomic bomb on Hiroshima, Japan, on August 6.
1945: All Lufthansa flights are canceled, and the airline goes into receivership.
1946: During trials aboard the USS *Franklin D. Roosevelt*, the McDonnell FH-1 Phantom makes the first carrier takeoff and landing by an U.S. jet aircraft.
1946: KLM begins transatlantic services to New York.
1946: Iberia begins service to London and Rome and becomes the first airline to fly between Europe and South America, establishing a route from Madrid to Buenos Aires.
1946: The United States and France sign the Five Freedoms Agreement, giving reciprocal rights for each country to operate commercial airlines over the territory of the other.
1946: Air France inaugurates Paris-to-New York service.
1946: SAS, a consortium of three Scandinavian airlines, Swedish Intercontinental Airlines (SILA), Det Danske Luftfartselskap (DDL), and Det Norske Luftfartselskap (DNL), is formed for the purpose of joint transatlantic service.
1946: A new British airline, British European Airways (BEA), is established to handle continental European and domestic British flights. BOAC introduces London-to-New York service.
1946: Arthur Young's Model 47 helicopter becomes the first commercially licensed helicopter in the world, and Bell delivers its first unit to the U.S. Army.
1947: Alitalia makes its first flight, from Turin to Rome.
1947: Air France cooperates with the French Postal Service to establish night-mail service, giving the airline the largest network in the world.

1947: Singapore Airlines' predecessor, Malayan Airways, flies between Singapore and the Malayan cities of Kuala Lumpur, Ipoh, and Penang.

1947: As Swissair becomes the national flag carrier of Switzerland, the airline inaugurates service to New York, with regular scheduled flights beginning two years later.

1947: The official world air speed record is broken on August 25 by U.S. Marine Corps major Marion Carl, flying the Douglas D-558 Skystreak, a high-speed research aircraft, with an average speed of 650.7 miles per hour.

1947: The rocket-powered aircraft Bell X-1 piloted by Chuck Yeager breaks the sound barrier, reaching speeds of 700 miles per hour, just over Mach 1.

1948: Alitalia makes its first intercontinental flight, flying a thirty-six hour, Milan-to-Rome-to-Dakar-to Natal-to-Rio de Janeiro-to-São Paulo-Buenos Aires route.

1948: On June 26, the Berlin airlift begins, by which the United States, Britain, and France attempt to break the Soviet blockade of Berlin.

1949: All American Aviation changes its name to All American Airways and introduces passenger service.

1949: American becomes the first airline with a fleet consisting entirely of postwar pressurized aircraft.

1949: The Berlin airlift ends on September 30.

1950: TWA officially changes its name to Trans World Airlines.

1950-1953: The military use of helicopters for medical evacuation increases during the Korean War, in which 80 percent of helicopters used are of Bell design.

1951: Bell Aircraft creates a separate helicopter division in Fort Worth, Texas, to accommodate the overwhelming demand for production.

1952: Boeing's Stratofortress (B-52) bomber, which will remain the primary U.S. bomber for the next four decades, is first flown.

1952: BOAC flies De Havilland Comet jets on service to Johannesburg, South Africa.

1953: Continental merges with Pioneer Airlines, expanding its services further into Texas and New Mexico.

1953: With an expanded route system, All American again changes its name, to Allegheny Airlines.

1953: A. Scott Crossfield reaches Mach 2 on November 20.

1953: The Douglas DC-7 airliner makes its first flight. With a maximum speed of 400 miles per hour and a cruise speed of 375 miles per hour, it is the largest and most efficient of the DC series yet designed.

1954: Cessna introduces the 310, its first business twin, and production of Cessna's T-37 Air Force jet trainer begins.

1954: After two crashes in one year, BOAC removes De Havilland Comets from service.

1955: Douglas is selected by the Air Force to be the prime contractor for the Thor missile, America's first intermediate-range ballistic missile.

1955: Lufthansa resumes scheduled flights.

1955: The Fokker F-27 Friendship turboprop aircraft makes its first flight.

1956: The Cessna Skyhawk, which becomes the most popular airplane in history, is introduced.

1956: The United States first employs the U-2 spy plane for high-level reconnaissance.

1956: Aeroflot inaugurates regular passenger turbojet service in September, two years ahead of British and American airlines.

1957: On October 4, the Soviet Union launches Sputnik, the first artificial satellite.

1957: On November 3, Sputnik 2 is launched, carrying the dog Laika.

1957: After the death of Larry Bell, Bell Aircraft's helicopter division is reorganized as Bell Helicopter Corporation.

1957: Boeing's first jetliner, the 707, makes its first flight, entering service the following year. The company subsequently develops a series of jetliners that are enormously popular worldwide.

1957: Alitalia merges with Linee Aeree Italiane (LAI) to form a national Italian airline.

1957: World War II pilot Charlie Willis is named chairman and chief executive officer of Alaska Airlines.

1957: With the inauguration of SAS's pioneering Copenhagen-Anchorage-Tokyo polar route, flying time to Japan is reduced from 52 to 32 hours.

1958: The United States launches its first artificial satellite, Explorer 1, on January 31.
1958: NASA becomes operational on October 1 and makes its first launch, of Pioneer 1, on October 11.
1958: The Federal Aviation Administration (FAA) is established in the United States.
1958: Aerlinte Eirann, Aer Lingus's associate company, makes first transatlantic flight from Dublin to New York.
1958: BOAC makes the first transatlantic jet flights, between London and New York.
1959: On September 12, the Soviet Union lands Luna 2, the first artificial object to reach the Moon.
1959: American Airlines becomes the first airline to offer transcontinental jet service, with the Boeing 747.
1959: NASA selects McDonnell Aircraft as prime contractor for Project Mercury, America's first manned orbital spacecraft, and awards Douglas Aircraft a contract to design, test, and produce a new multistage rocket using a modified Thor as the first stage. The new launch vehicle is named Delta.
1960's: With IBM, American develops the Semi-Automated Business Research Environment (SABRE), a real-time data processing system that allows agents to track flight reservations.
1960's: Boeing participates in the U.S. space program by designing and manufacturing Apollo and Saturn rockets and lunar orbiters.
1960: Ed Yost, of Bruning, Nebraska, reintroduces a newly designed hot-air balloon, initiating a renaissance in hot-air ballooning.
1960: Textron purchases several Bell Aircraft companies, including the Bell Helicopter Corporation.
1961: NASA names McDonnell Aircraft as prime contractor for the Gemini Program, the nation's second-generation crewed spaceflight program.
1961: On April 12, Russian Major Yuri Gagarin becomes the first human in space, after his capsule *Vostok 1* makes one full Earth orbit in a flight that lasts less than two hours.
1961: United acquires Capital Airlines and becomes the largest airline in the world.
1961: On May 5, Alan Shepard becomes the first American in space in his Mercury capsule *Freedom 7*.
1961-1975: The military use of helicopters is cemented during the Vietnam War.
1962: On February 20, John Glenn becomes the first American to orbit Earth in the Mercury capsule *Friendship 7*.
1962: On December 14, Mariner 2 makes the first successful planetary flyby, of Venus.
1962: The Soviet Union initiates its space station program, Soyuz.
1962: The South Korean government establishes a new national carrier to replace the former carrier, Korean National Airlines.
1962: TWA begins regularly using Doppler radar navigation systems.
1963: On June 16, Russian cosmonaut Valentina Tereshkova becomes the first woman to solo in space.
1963: In response to national political changes, Malayan Airways is renamed Malaysian Airways.
1963: Continental Airlines moves its headquarters to Los Angeles, California, and transports U.S. troops to Asia during the Vietnam War.
1964: The Fokker F-28 Fellowship jet makes its first flight.
1964: The United States employs missiles with multiple warheads.
1965: Cosmonaut Alexei Leonov takes first walk in space on March 18.
1965: On March 23, the first crewed Gemini Program mission, Gemini 3, is launched with astronauts Virgil "Gus" Grissom and John W. Young.
1965: Ed White makes the first U.S. spacewalk from Gemini IV in June.
1965: Mariner 4 makes the first flyby of Mars on July 14.
1965: SAS introduces its SASCO electronic airline reservations system.
1966: Malaysian Airways' name is again changed, to Malaysia-Singapore Airlines (MSA) to reflect its governmental owners.
1967: On January 27, the Apollo 1 capsule catches fire on the launch pad, killing astronauts Gus Grissom, Roger Chaffee, and Ed White.
1967: Alitalia introduces Arco, a new electronic booking system.
1967: McDonnell and Douglas companies merge to form the McDonnell Douglas Corporation, with headquarters in St. Louis, Missouri.

1968: From October 11 to 12, Apollo 7 makes the first piloted Apollo mission, with astronauts Wally Schirra, Donn Eisele, and Walter Cunningham.
1968: December 21-27: Frank Borman, James A. Lovell, and William Anders become the first humans to orbit the Moon.
1968: The Soviet Union flies the world's first supersonic aircraft, the Tu-144, on December 31.
1968: In relief of Khe Sanh during the Vietnam War, U.S. B-52's carry out the most concentrated bombing raid in military history.
1968: Allegheny merges with Lake Central Airlines, based in Indianapolis.
1968: Swissair renews a prior cooperation agreement with SAS and also includes KLM, to form the KSS Group. The French carrier UTA will join two years later, and the group will be renamed KSSU Consortium.
1969: The Soviet Union docks two crewed spacecraft in orbit, Soyuz 4 and 5, on January 16.
1969: The Concorde supersonic airplane makes its first flight on March 2.
1969: On July 20, Apollo 11 touches down on the Moon with Neil Armstrong and Buzz Aldrin on board.
1969: The Hanjin Group takes over operation of the government-owned Korean Air Lines (KAL).
1969: Continental Airlines inaugurates service to Hawaii.
1969: Alitalia retires its last remaining turboprop aircraft, becoming the first European airline with an all-jet fleet.
1970: The DC-10, Douglas's first jumbojet, makes its first flight.
1970: TWA is the first airline to offer nonsmoking sections on board all of its flights.
1970: The first wide-body jumbojet, Boeing's 747, with twice the passenger capacity of any previous jet, enters service.
1971: Russia's Salyut 1 becomes the first crewed space laboratory.
1971: The United States's Mariner 9 becomes the first mission to orbit another planet (Mars).
1971: Southwest Airlines inaugurates service within Texas, between the cities of Dallas, Houston, and San Antonio.
1972: Allegheny Airlines acquires Mohawk Airlines, based in Utica, New York.
1972: After MSA ceases operations, Malaysia Airlines and Singapore Airlines continue as individual national flag carriers.
1972: NASA announces the space shuttle program, and makes the last Apollo mission to the Moon.
1973: Skylab is launched, although the program ends the following year.
1974: Southwest Airlines carries its one-millionth passenger.
1974: British Airways is formed by the merger of BOAC and BEA.
1974: American introduces one-stop automated check-in service.
1974: Air France flies the first Airbus A300 aircraft.
1975: The United States and the Soviet Union make their first joint space project, the Apollo-Soyuz Test Project.
1976: Cooperating with Air France, British Airways inaugurates supersonic travel on the Concorde.
1976: Air France introduces the Concorde for supersonic travel along the airline's Paris-Dakar-Rio de Janeiro route.
1976: Viking 1 lands on Mars on July 20.
1977: Southwest carries its five-millionth passenger, and its stock is listed on the New York Stock Exchange as "LUV."
1977: A KLM 747 collides with a Pan Am 747 on a runway at Tenerife Airport, Canary Islands, resulting in the worst air disaster of the twentieth century, with 583 casualities.
1977: Aeroflot begins offering supersonic passenger service, which is suspended the following year.
1978: The United States ends government regulation of airline routes and rates.
1979: Allegheny Airlines changes its name to USAir to reflect its continually expanding route network, with new service to Arizona, Texas, Colorado, and Florida.
1979: American moves its headquarters from New York City to Dallas/Fort Worth, Texas.
1980's: Boeing develops both the air-launched cruise missile and the MX intercontinental ballistic missile (ICBM).

1980's: Lockheed develops the F-117A stealth fighter.
1981: The first space shuttle, *Columbia*, is launched on April 12.
1981: American introduces its revolutionary AAAdvantage frequent flier award program and establishes its first hub at Dallas/Fort Worth, Texas, strengthening its hub-and-spoke network throughout the 1980's.
1982: Bell Helicopter is incorporated as a subsidiary of Textron, now officially known as Bell Helicopter Textron.
1982: The space shuttle *Columbia* has its first mission from November 11 to November 16.
1982: McDonnell Douglas devises a new commercial aircraft designation system that combines the "M" of McDonnell and the "D" of Douglas. The designation is first employed on the former DC-9 Super 80, which becomes the MD-80.
1983: Aer Lingus Commuter airline is established.
1983: Continental Airlines reorganizes under Chapter 11 of the Federal Bankruptcy Code.
1983: Straying off course, Korean Air Lines Flight 007 flies into Soviet airspace and is shot down by a Soviet fighter, killing all 269 people on board.
1983: Flying on the seventh space shuttle flight, Sally K. Ride becomes the first American woman in space.
1983: Guy Bluford becomes the first African American astronaut, on the eighth space shuttle flight.
1983: Two new Fokker aircraft are launched to replace the F-27 and the F-28: the Fokker F-50 and the Fokker F-100.
1984: Virgin Records entrepreneur Richard Branson launches Virgin Atlantic Airways, with flights from London to New York.
1984: American Airlines introduces its regional American Eagle network and retires its freight fleet.
1984: Hughes Helicopters merges with McDonnell Douglas.
1985: Cessna merges with General Dynamics Corporation as a wholly owned subsidiary.
1986: Continental Airlines reemerges from Chapter 11 and, a year later, becomes the third-largest U.S. airline, with the consolidation of Frontier, New York Air, and People Express.
1986: On January 28, the space shuttle *Challenger* explodes shortly after liftoff, killing seven astronauts, including the first civilian astronaut.
1986: On December 23, Jeana Yeager and Dick Rutan make the first nonstop flight around the world without refueling, in the experimental *Voyager* aircraft.
1987: The British government privatizes British Airways through a public stock offering.
1987: A bomb planted on a KAL 747 explodes in midair, and the plane crashes into the sea off Burma, killing all 115 people on board.
1987: Virgin Atlantic carries its one-millionth passenger. Its founder, Richard Branson, makes a record-breaking balloon flight across the Atlantic and subsequently launches the Virgin Airship and Balloon Company.
1988: On April 22, *Daedalus* is the first human-powered craft to be flown from the island of Crete to Santorini, in the Mediterranean Sea.
1988: Alaska Airlines begins offering service to Mexico.
1988: USAir acquires Pacific Southwest Airlines of San Diego.
1988: SAS establishes a cooperative agreement with Continental Airlines.
1989: In the largest merger to that date in airline history, USAir joins with Piedmont Airlines, established in 1948.
1989: Swissair enters agreements with Delta Air Lines, SAS, and Singapore Airlines.
1990: Responding to increasing competition in the airline industry, Air France merges with UTA and Air Inter to become the Air France Group, one of the world's largest air transport groups.
1990: After Germany's reunification, Lufthansa resumes flights to Berlin, its first in forty-five years.
1990: Southwest Airlines passes the one-billion-dollar revenue mark, becoming a major airline.
1990: The Hubble Space Telescope is deployed.
1991: A U.N. coalition exhibits a full range of modern military aircraft to defeat Iraq during the Gulf War.
1991: With delivery of its fiftieth MD-80 aircraft, SAS becomes the world's largest MD-operating airline carrier outside the United States.

1991: On January 17, Richard Branson and Per Lindstrand make the first hot-air transpacific flight, in the largest hot-air balloon flown.
1992: General Dynamics sells Cessna to Textron.
1992: Richard Branson sells Virgin Records for $880 million and reinvests the money in Virgin Atlantic.
1992: USAir begins a partnership with the Trump Shuttle, which is renamed USAir Shuttle.
1993: British Airways enters into a partnership with USAir, which is dissolved four years later.
1994: Twelve-year-old Vicki Van Meter becomes the youngest pilot to make a transatlantic flight, in a Cessna 210.
1994: American institutes nonsmoking transatlantic service.
1994: Morris Air merges with Southwest.
1994: United begins the operation of Shuttle by United along the West Coast.
1995: Air France launches the Airbus A340 wide-body aircraft.
1995: The Global Positioning System (GPS) becomes fully operational on April 27.
1995: Virgin Atlantic adopts a nonsmoking policy on all transatlantic and Hong Kong-route flights.
1995: Lockheed merges with the Martin Marietta Corporation.
1995: Southwest introduces "Ticketless Travel," or travel without a paper ticket, systemwide.
1996: Shannon Lucid sets a U.S. record for a continuous space stay, aboard the Mir Space Station.
1997: A KAL flight crashes into a Guam hillside, killing 228 of the 254 people on board.
1997: Lufthansa and SAS join with United Air Lines, Air Canada, and Thai Airways, in the Star Alliance, and all SAS flights are made nonsmoking flights.
1997: McDonnell Douglas merges with the Boeing Company.
1997: USAir officially adopts its new corporate identity by changing its name to US Airways.
1998: John Glenn returns to space at age seventy-seven, becoming the world's oldest astronaut, with a flight on the space shuttle.
1998: Swissair introduces a nonsmoking policy on all European flights.
1998: During a period of reorganization in the aerospace industry, Boeing purchases divisions of Rockwell International involved in aerospace and defense electronics.
1998: Fokker Aircraft declares bankruptcy and is reorganized as Fokker Aviation, which is acquired by Stork.
1998: Lockheed absorbs the defense electronics and systems integration divisions of Loral.
1998: SAS forms an alliance with Lufthansa.
1998: A Swissair flight en route from New York to Geneva crashes off the coast of Nova Scotia, killing all 229 on board.
1998: Alitalia enters into an alliance with KLM Royal Dutch Airlines to expand its service.
1999: The oneworld Alliance, a global network of airlines including British Airways, Aer Lingus, American Airlines, Iberia, Canadian Airlines, Cathay Pacific Airways, and Qantas, is formed.
1999: Swissair makes its first flight with an all-woman cockpit crew.
1999: Bertrand Piccard and Brian Jones make the first nonstop global circumnavigation, in a hybrid hot-air and helium balloon, from March 1 to March 20.
1999: Fokker Aviation is renamed Stork Aerospace Group.
2000: An Air France Concorde jet crashes shortly after takeoff from Paris's Charles de Gaulle Airport, killing all on board and four on the ground. Air France and British Airways suspend their Concorde operations until November, 2001.
2001: On September 11, hijackers crash two commercial airplanes into the World Trade Center in New York City, causing both towers to collapse. A third hijacked plane is crashed into the Pentagon in Washington, D.C. A fourth hijacked plane crashes outside of Pittsburgh, Pennsylvania. More than 3,000 people, both in the air and on the ground, are killed. The airline industry, both in the United States and around the world, suffers economically from the resulting decrease in air travel.

Leslie Ellen Jones

Air Disasters and Notable Crashes

1785: On June 15, Jean-François Pilâtre de Rozier and a companion become hot-air ballooning's first fatalities, after falling to their deaths when their hybrid hot-air-and-hydrogen balloon ignites over the English Channel.

1908: On September 17, during a demonstration flight for the U.S. Army, Orville Wright's plane crashes near Fort Myer, Virginia. Wright suffers several broken bones and Lieutenant Thomas Selfridge is killed; he becomes the first person to die in an airplane accident.

1910: On January 4, French aviation pioneer Leon Délagrange, who piloted the first passenger flight in January, 1908, is killed when the port wing of his Blériot XI collapses.

1910: On July 12, Sir Charles Rolls, cofounder of Rolls-Royce, dies when his French-built Wright biplane collapses during a landing competition at Bournemouth Aviation Week.

1912: On July 1, pioneering American female aviator Harriet Quimby and a friend die when their Blériot falls out of the sky during an air show over Dorchester Bay, south of Boston. Quimby had been the first woman to fly solo across the English Channel.

1913: On August 7, American aviator Samuel Franklin Cody and his passenger die in a crash at Ball Hill near Newbury, Berkshire, England. Cody had made the first registered flight in Great Britain in October, 1908.

1918: On April 21, World War I flying ace Manfred von Richtofen, known as the Red Baron, is killed in action when his Fokker triplane is shot down by Canadian Roy Brown near Morlancourt Ridge. The Red Baron had been responsible for 80 kills in less than two years.

1921: On June 5, pioneering American female aviator Laura Bromwell dies in Garden City, New York, when she loses control of her airplane and crashes from more than 1,000 feet in the air. A month earlier, she had set a new world's record by looping-the-loop 199 times at speeds up to 135 miles per hour.

1923: On December 21, the French airship *Dixmude* explodes in flight during a thunderstorm, killing 50 crew members.

1925: On September 3, the USS *Shenandoah* airship breaks apart in a thunderstorm, killing 14 of the 43 crew members.

1928: On May 1, U.S. representative Thaddeus Sweet of New York is killed in a private plane crash near Whitney Point, New York.

1928: On May 25, Italian explorer Umberto Nobile crashes shortly after crossing the North Pole in his airship, *Italia*.

1928: On June 22, Norwegian explorer Roald Amundsen is lost at sea in the Arctic Ocean while attempting to fly a rescue mission to the *Italia*.

1929: On December 20, U.S. representative William Kaynor of Massachusetts is killed in a private plane crash near Washington, D.C.

1930: On October 5, the British *R-101* airship crashes and burns after hitting a hillside during heavy rain near Beauvais, France, while en route to India. Of the 56 passengers and crew, 48 die, including British air minister Lord Thompson and civil aviation director Sir Sefton Branker.

1931: On March 31, Notre Dame football coach Knute Rockne is one of 8 killed when a Trans Continental & Western Airways Fokker F10A plane flies into a storm and falls into a wheat field near Bazaar, Kansas.

1931: On May 14, Denys Finch Hatton and a servant are killed when their plane stalls and then crashes in a fiery explosion. Hatton, a professional hunter, was the lover of Karen Blixen (Isak Dinesen), the author of *Out of Africa* (1937).

1933: On April 3, the USS *Akron* airship is driven into the sea by downdrafts in a storm, killing 73 of the 76 crew members.

1935: On February 12, the fin of the USS *Macon* is ripped off in storm, and the airship loses buoyancy and crashes at sea, killing 2 of the 83 crew members.

1935: On August 15, a private plane flown by Wiley Post crashes into the water at Walakpi, near Point Barrow, Alaska, just after takeoff. Post, a noted aviator, and his passenger, the famous cowboy and entertainer Will Rogers, are killed.

1936: On December 7, French aviator Jean Mermoz, veteran of twenty-three transatlantic flights including the first from France to South America, is killed along with 5 others when their Latécoère 300 Croix du Sud disappears.

1937: On May 6, the *Hindenburg*, a hydrogen-filled dirigible, crashes and burns at Lakehurst, New Jersey, killing 36 people.
1937: On July 2, American aviator Amelia Earhart and her navigator Fred Noonan disappear on the way from Lae, New Guinea, to Howland Island during an around-the-world flight.
1937: On November 16, the Grand Duke and Duchess of Hess are among 11 people killed when a Sabena Junkers JU-52 airplane crashes near Ostende, Belgium.
1938: On January 11, Captain Edwin Musick, the first pilot for Pan American World Airways (Pan Am), is among 6 people killed when a Pan Am Sikorsky S-42 seaplane explodes when the crew attempts to dump fuel in preparation for an emergency landing in American Samoa.
1938: On August 1, British aircraft designer Frank Barnwell is killed in a plane crash while testing an aeroplane of his own design at the Bristol Civil Airport in England.
1939: On March 18, Boeing's chief engineer Jack Kylstra and 12 others (including a KLM delegation) are killed when their Boeing 307 Stratoliner production prototype breaks up after failing to recover from a spin near Adler, Washington.
1940: On August 31, U.S. senator Ernest Lundeen of Minnesota and 24 others are killed in the crash of a Pennsylvania Central Douglas DC-3 when lightning hits the plane, disorienting the crew.
1941: On January 5, English aviator Amy Johnson is killed during World War II when her transport plane crashes into the River Thames. In 1930, she flew solo from Great Britain to Australia.
1941: On February 21, Sir Frederick Banting, codiscoverer of insulin, is killed in a plane crash.
1941: On February 27, U.S. representative William Byron of Maryland is killed in a private plane crash near Jonesboro, Georgia.
1941: On November 22, German pilot Werner Mölders, the first ace to achieve 100 kills, dies when a Heinkel He-111 loses an engine and crashes in bad weather while attempting to land in Breslau-Gandau, Germany. He had been on his way from Crimea to the state funeral of great aerobatic pilot Ernst Udet.
1942: On January 16, actress Carole Lombard, her mother, her press agent, and 19 other people are killed when their Trans Continental & Western DC-3 crashes near Las Vegas as they are returning from a war bond promotion tour.
1942: On March 21, Carl August Freiherr von Gablenz, the founder of Lufthansa Airlines, is killed in an airplane crash.
1942: On August 25, Prince George of Kent is killed in a plane crash during active war service over Caithness, Scotland.
1943: On January 15, Major Eric Mowbray Knight, author of *Lassie, Come Home*, is one of 35 killed when their Douglas C-54 Skymaster blows up over Dutch Guiana. The plane was on a secret mission to the Casablanca Conference.
1943: On April 18, Admiral Isoroku Yamamoto, the Japanese navy's commander in chief and architect of the Pearl Harbor invasion, is killed when his Mitsubishi G4M1 is shot down by U.S. Air Force P-38s over Bougainville in the Pacific Ocean.
1943: On June 1, British actor Leslie Howard and 16 others are killed when their KLM DC-3 is shot down off the coast of France.
1943: On June 2, Heisman trophy winner Nile Kinnick dies when the motor of his plane failed during a training flight and he had to make an emergency landing off the coast of Venezuela.
1943: On July 4, Wladyslaw Sikorski, Polish prime minister in exile, is killed along with 11 others when their plane crashes into the Mediterranean shortly after taking off from the Gibraltor airport.
1943: On September 21, U.S. representative John William Ditter of Pennsylvania is killed in a private plane crash near Colombia, Pennsylvania.
1944: On April 12, polo player and aviator Tommy Hitchcock dies as he tests a fully fueled, bomb-laden P-51 fighter plane near Salisbury, England.
1944: On July 31, Antoine de Saint-Exupéry, French aviator and author of *The Little Prince* (1943), dies when his P-38 Lightning disappears over the Mediterranean Sea during a reconnaissance mission for the U.S. Air Force.
1944: On August 12, Joseph P. Kennedy, Jr., the oldest son of Joseph Kennedy, is killed when his Navy B-24 Liberator plane explodes over the English Channel.

1944: On September 19, Royal Air Force pilot Guy Gibson, who was awarded the Victoria Cross for leading the Dambuster Raid, dies along with his copilot when their Mosquito crashes over Holland.

1944: On November 11, British air chief marshal Sir Trafford Leigh-Mallory and his wife Dora are killed when their RAF Avro York airliner crashes in mountains west of Grenoble, France, while en route to India, where he was to lead the Allied air forces in Southeast Asia.

1944: On December 15, trombonist and band leader Glenn Miller and 2 others die when their plane disappears in a fog over the English Channel. Miller was entertaining Allied troops during World War II.

1945: On January 2, British admiral Sir Betram Ramsey is among those who die when a Lockheed Hudson climbs, banks, and dives into the ground on taking off from Toussus-le-Noble en route to Brussels, Belgium.

1945: On July 28, a U.S. Army B-25 twin-engine bomber on a routine flight from Bedford, Massachusetts, to Newark, New Jersey, loses its bearings in heavy fog and plunges into the seventy-ninth floor of the Empire State Building in New York City, killing all 3 people on board the plane and another 11 in the skyscraper.

1945: On August 6, Major Richard Ira Bong, the leading U.S. fighter ace during World War II, is killed near Los Angeles while test-flying a Lockheed P-80 jet.

1946: On September 27, English aviator Geoffrey de Havilland, chief test pilot and son of the aircraft manufacturer, is killed while attempting to break the sound barrier. His single-seat DH-108 Swallow swept-wing jet breaks up in midair while in a dive.

1947: On August 23, English aircraft designer Roy Chadwick, Avro's chief designer responsible for the Lancaster bomber, is killed when his Avro Tudor 2 prototype crashes on takeoff during a test flight.

1947: On October 28, Oregon governor Earl Snell and 3 others are killed in a plane crash in wild terrain east of Klamath Falls, Oregon.

1947: On November 22, French general Philippe Leclerc, who led the Allied force which liberated Paris in August, 1944, is among those killed when a military transport crashes in the Sahara.

1948: On January 29, British air marshal Sir Arthur Cunningham, commander of the Royal Air Force in the Western Desert during World War II, is one of 31 who die when a British South American Airways plane crashes near Bermuda while en route to Havana, Cuba. BSAA's founder claims that a known wartime saboteur was seen standing near the plane shortly before takeoff.

1948: On May 13, Kathleen "Kick" Kennedy Hartington, John F. Kennedy's sister, is one of ten people killed when their Skyways de Havilland Dove 1 plane crashes in France's Ardeche mountains during a storm.

1949: On April 20, U.S. representative Robert Coffey of Pennsylvania is killed in the crash of a private plane near Albuquerque, New Mexico.

1949: On May 4, 18 members of the Torino soccer team, 6 trainers, 3 journalists, and 3 crew members are killed when their plane hits a wall surrounding the sanctuary of Superga's Basilica and crashes into a mountain near Turin, Italy.

1949: On November 1, U.S. representative George Bates of Massachusetts and U.S. representative Michael Kennedy of New York are among 56 people killed when a U.S. Air Force P-38 collides with an Eastern Air Lines DC-54B over Arlington, Virginia.

1950: On December 4, Jesse Leroy Brown, the first African American naval aviator, is shot down over Korea.

1952: On January 27, former secretary of war Robert Patterson and 29 others are killed when their airplane hits apartments in Elizabeth, New Jersey. Another 7 people die on the ground.

1953: On June 18, the crash of a U.S. Air Force Globemaster C-124 near Tokyo kills 129 servicemen.

1953: On October 29, American pianist William Kapell dies, along with 18 others, when a British Commonwealth Pacific Airlines Douglas DC-6 crashes as it descended into the San Francisco area.

1956: On June 30, a Trans World Airlines (TWA) Super Constellation and a United Air Lines DC-7 collide over the Grand Canyon, killing 128.

1957: On March 17, Ramon Magsaysay, president of the Philippines, and 2 others die when their airplane crashes into Mt. Manunggal during a campaign trip.

1957: On April 15, popular Mexican singer and actor Pedro Infante dies in a plane crash in Mérida, Yucatán while returning to Mexico City. A family is also killed on the ground.

1958: On March 22, Hollywood producer Mike Todd, his biographer Art Cohn, and the pilot and copilot are killed when their Lockheed Lodestar private plane "The Lucky Liz," named after Todd's wife actress Elizabeth Taylor, crashes in bad weather in the Zuni Mountains of New Mexico.

1958: On August 14, a KLM Super Constellation crashes into the North Atlantic near Ireland, killing 99 people.

1959: On February 23, a small private plane traveling from Clear Lake, Iowa, to Fargo, North Dakota, crashes shortly after takeoff, claiming the lives of the pilot and rock-and-roll performers Buddy Holly, Ritchie Valens, and J. P. "Big Bopper" Richardson.

1959: On March 29, Barthelemy Boganda, the president and founder of the Central African Republic, dies when his plane explodes.

1960: On December 16, United Air Lines Flight 826, a DC-8 carrying 77 passengers and 7 crew members from Chicago's O'Hare International Airport to Idlewild Airport (now JFK), and TWA Flight 266, a Lockheed Super Constellation traveling from Cleveland Airport to LaGuardia Airport with 44 people on board, collide in heavy fog over New York City. The United plane crashes into an apartment building and a church in Brooklyn, killing several people on the ground. In all, 134 people die.

1961: On February 15, the entire U.S. Olympic figure skating team of 18 are among 72 passengers killed when a Belgian Sabena Boeing 707 crashes near Brussels, Belgium.

1961: On September 18, United Nations Secretary-General Dag Hammarskjöld and 15 others die in a plane crash over Rhodesia while on a mission concerning a separatist movement in the Republic of the Congo.

1962: On January 25, Montana governor Donald Nutter is killed when his plane crashes during a snowstorm.

1962: On March 1, 95 people die when an American Airlines 707 crashes at Jamaica Bay, Long Island, as the result of an electrical fault.

1962: On March 4, 111 people die when a British Caledonian Airways DC-7 crashes in Douala, Cameroon, as the result of a jammed elevator.

1962: On March 16, a Flying Tiger Line Lockheed Super Constellation crashes into the Pacific Ocean, killing 107.

1962: On June 3, an Air France 707 crashes during takeoff from Orly, France, killing 130.

1962: On June 22, an Air France 707 crashes into a hill in Pointe-à-Pitre, West Indies, killing 113.

1962: On July 7, an Alitalia DC-8 hits a hill in Bombay, India, killing 94.

1962: On October 7, U.S. representative Clement Miller of California is killed in a private airplane crash near Eureka, California.

1963: On March 5, country singer Patsy Cline dies in a plane crash near Camden, Tennessee.

1963: On November 29, Air Canada Flight 831, a DC-8F, stalls and goes down at St. Thérèse de Blainville, north of Montreal, killing all 111 passengers and 7 crew on board.

1963: On December 8, Pan Am Flight 214, a Boeing 707 traveling from Baltimore to Philadelphia, is struck by lightning and catches on fire. It crashes near Elkton, Maryland, killing all 81 on board.

1964: On February 25, Eastern Air Lines Flight 304, a DC-8 traveling from Mexico City to National Airport in Washington, D.C., crashes into Lake Pontchartrain, near New Orleans, killing all 58 passengers and crew on board.

1964: On June 19, Senator Edward M. Kennedy is severely injured and one of his aides is killed in a private plane crash in Southhamton, Massachusetts, while on the way to the Democratic state convention.

1964: On July 31, country music star Jim Reeves and his manager are killed when their light plane crashes in dense woods near Nashville, Tennessee.

1964: On October 31, astronaut Theodore Freeman is killed when his T-38 jet crashes near Ellington Air Force Base in Houston, Texas.

1965: On May 20, a Pakistan International Airways 707 crashes while landing at an airport in Cairo, Egypt, leaving 124 dead.

1965: On June 25, a Boeing C-135A Stratolifter military transport bound for Okinawa, Japan, from El Toro Marine Corps Air Station in Orange County, California, crashes near the airbase. All 72 Marines and 12 crew members on board are killed.

1965: On November 8, an American Airlines 727 crashes on landing in Cincinnati, killing 58.

1965: On November 11, a United Air Lines 727 crashes on landing in Salt Lake City, killing 41.

1966: On January 24, an Air India 707 hits Mont Blanc in the Alps, killing 117.

1966: On February 1, Nicholas Piantanida dies during his descent after setting a new balloon flight record.

1966: On February 4, an All Nippon Airways 727 crashes on landing in Tokyo Bay, Japan, killing 113.

1966: On February 28, 2 astronauts, Charles Bassett II and Elliot See, Jr., die when their T-38 jet crashes when they attempt an instrument landing at the McDonnell Aircraft field near St. Louis, Missouri.

1966: On March 5, a BOAC Boeing 707 breaks apart in flight and crashes into Mount Fuji in Japan, leaving 124 dead.

1966: On December 24, a Flying Tiger Line Canadair CL-44 crashes into a village in Da Nang, Vietnam, killing 111.

1967: On January 27, the Apollo 1 capsule catches fire on the launch pad, killing astronauts Gus Grissom, Roger Chaffee, and Ed White.

1967: On April 20, a chartered Swiss Globe Britannia Turboprop crashes while landing in Nicosia, Cyprus, killing 126.

1967: On April 24, cosmonaut Vladimir M. Komarov is killed when his Soyuz 1 craft crashes after its parachute lines became tangled during reentry. He becomes the first person to die on a spaceflight.

1967: On December 8, the first African American astronaut, Major Robert Lawrence, Jr., is killed in the crash of his F-104 fighter during a training exercise.

1967: On December 10, soul singer Otis Redding dies in a plane crash in Wisconsin.

1968: On March 24, 61 people die in an Aer Lingus crash in Wexford Harbor, Ireland.

1968: On March 27, the first man in space, Soviet cosmonaut Yuri Gagarin, is killed in the crash of his MiG-15UTI while on a training mission east of Moscow.

1969: On August 31, former heavyweight boxing champion Rocky Marciano is killed in a plane crash near Newton, Iowa.

1970: On February 15, a DC-8 plunges into the Caribbean Sea near Santo Domingo, the Dominican Republic, shortly after takeoff, leaving 102 dead.

1970: On February 21, an explosion occurs in the aft of a Swissair Convair CV-990 shortly after takeoff. The plane, which was on its way to Tel Aviv, Israel, crashes while returning to the airport in Zurich, killing 47.

1970: On July 3, a British charter Dan-Air Comet jet crashes into the sea near Barcelona, Spain, on approach for a landing, killing 112.

1970: On July 5, an Air Canada DC-8 crashes while attempting to land in Toronto, killing 109.

1970: On September 21, 3 people die when their Roziere (helium and hot air) balloon, *Free Life*, is lost in the sea off Newfoundland during an attempted transatlantic flight. No trace of the crew or the balloon is found.

1971: On May 30, World War II hero and actor Audie Murphy dies in a small plane crash in Carroll County, Virginia.

1971: On June 18, a BEA Trident jetliner crashes after takeoff from Heathrow Airport in London. All 118 on board are killed.

1971: On June 30, three cosmonauts are found dead in their Soyuz 11 craft after its automatic landing. The apparent cause of death is loss of pressurization in the spacecraft during reentry.

1971: On July 30, an All Nippon Airways 727 and a Japan Air Force F-86 collide in midair over Morioka, Japan, killing 163.

1971: On September 4, an Alaska Airlines 727 hits a mountain near Juneau, Alaska, killing 111.

1972: On May 5, an Alitalia DC-8 crashes into a mountain near Palermo, Sicily, killing 115.

1972: On June 14, a Japan Airlines DC-8 from Bangkok, Thailand, strikes the banks of the Yamuna River while trying to land in New Delhi, India, killing 86.

1972: On August 14, an onboard fire causes an Ilyushin-62 to crash on takeoff near East Berlin, East Germany, killing 156 people.

1972: On October 13, in Krasnaya Polyana, Soviet Union, an Ilyushin-62 crashes during the landing approach, killing 174.

1972: On October 13, a chartered plane carrying family and members of a soccer team from Uruguay goes down in the Chilean Andes, with 32 of the 45 on board surviving the crash. The survivors are forced to eat those who died. By the time they are rescued seventy-two days later, only 16 people are still alive.

1972: On October 16, House Majority Leader Hale Boggs, of Louisiana, and U.S. representative Nick Begich of Alaska are killed when their plane disappears over Alaska.

1972: On December 3, 155 people die when a Convair-990 crashes on takeoff in the Canary Islands.

1972: On December 8, U.S. representative George Collins of Illinois is among 43 passengers killed when their United Air Lines Boeing 737 crashes in a residential area when it stalls while approaching Chicago's Midway Airport. Two people on the ground also die.

1972: On December 20, a Delta Air Lines Convair-880 taxiing across a runway at Chicago's O'Hare International Airport in bad weather collides with a North Central Airlines DC-9 taking off from the same runway, killing 9 on board the DC-9.

1972: On December 29, an Eastern Air Lines Lockheed L-1011 crashes on landing in Miami, killing 101 of 176 on board.

1972: On December 31, Pittsburgh Pirates outfielder Roberto Clemente is killed in a plane crash while flying to Nicaragua to aid earthquake victims.

1973: On January 22, a Royal Jordanian Airlines Boeing 707 approaching an airport in Kano, Nigeria, crashes in heavy fog, killing 176 people, mostly Muslim pilgrims.

1973: On February 21, a civilian Libyan Arab Airlines Boeing 727 is shot down over the Sinai by Israeli fighters after it strays off course; 108 die and 5 survive.

1973: On April 10, a British airliner carrying tourists to a Swiss fair crashes in Hochwald, Switzerland, during a blizzard, leaving 106 dead.

1973: On July 11, a Varig Airlines Boeing 707 en route to Rio de Janeiro crashes near an airport in Paris, killing 122 of 134 passengers.

1973: On July 31, Delta Air Lines Flight 723, a DC-9 approaching Boston's Logan Airport, strikes a seawall short of the runway and catches on fire, killing 89.

1973: On September 20, singer Jim Croce dies in a plane crash near Natchitoches, Louisiana.

1974: On February 18, one person dies when *Light Heart*, a cluster of ten helium balloons, is lost without a trace during an attempted transatlantic flight.

1974: On March 3, a Turkish Airlines DC-10 crashes shortly after takeoff in Paris when a cargo door opens, killing 346 people.

1974: On April 22, a Pan Am 707 hits a mountain in Bali, Indonesia, killing 107.

1974: On September 8, a TWA 707 explodes and crashes into the Ionian Sea, Greece, as a result of a terrorist bomb, killing 88.

1974: On December 1, TWA Flight 514, a Boeing 727, misses the runway while landing in bad weather in Virginia and crashes into a mountain, killing all 92 on board.

1974: On December 4, 191 people, mostly Muslim pilgrims, die in Colombo, Sri Lanka, when their DC-8 attempts to land in a rainstorm.

1975: On February 14, U.S. representative Jerry Pettis of California dies in a private plane crash near Banning, California.

1975: On April 4, a Galaxy C-58 crashes while making an emergency landing in Saigon, South Vietnam, killing 172 people, 100 of them war orphans.

1975: On June 24, Eastern Air Lines Flight 66, a Boeing 727, crashes into the runway approach lights at JFK International Airport in New York as a result of windshear. Of the 124 on board, 113 die.

1975: On August 3, a Boeing 707 plunges into a mountain near Imzizen, Morocco, killing 188.

1976: On June 27, the hijacking of an Air France plane in Entebbe, Uganda, results in passenger deaths.

1976: On August 3, U.S. representative Jerry Litton of Missouri dies in the crash of a private plane on takeoff.

1976: On September 10, a midair collision between a British Airlines Trident and a DC-9 in Zagreb, Yugoslavia, kills a total of 176 passengers and crew members.

1976: On September 19, 155 are killed when a Boeing 727 crashes into a mountain near Isparta, Turkey.

1977: On March 21, a KLM 747 collides with a Pan Am 747 on a runway at Tenerife Airport, Canary Islands, resulting in the worst air disaster of the twentieth century, with 583 casualities.

1977: On May 16, the landing gear of a New York Airways Sikorsky helicopter fails while the aircraft is parked, with rotors turning, on the rooftop heliport of the Pan Am Building in New York City. Four passengers waiting to board are killed, and a pedestrian dies after being struck by part of the rotor blades.

1977: On August 1, Francis Gary Powers, the American pilot of a U2 spy plane shot down over the Soviet Union in 1960, is killed, along with a cameraman, when his Bell helicopter crashes in Los Angeles while returning from covering a brush fire.

1977: On October 21, singer Ronnie Van Zant and guitarist Steve Gaines of the country rock band Lynyrd Skynyrd are killed in a plane crash near McComb, Mississippi.

1978: On January 1, 213 die when an Air India 747 plunges into the Arabian Sea as a result of instrument failure after taking off from Bombay.

1978: On September 25, Pacific Southwest Airlines (PSA) Flight 182, a Boeing 727, collides in midair over San Diego, California, with a privately owned Cessna 172, killing 144 people, including 37 PSA employees on the plane and 7 people on the ground.

1978: On November 15, an Icelandic Airways DC-8 approaching an airport in Colombo, Sri Lanka, crashes in a thunderstorm, killing 183, mostly Muslim pilgrims.

1978: On December 23, an Alitalia DC-9 crashes into sea near Palermo, Italy, killing 108.

1979: On May 25, American Airlines Flight 191, a DC-10, crashes in a field shortly after takeoff from Chicago's O'Hare International Airport when an engine falls off. All 271 on board the plane are killed, as well as 2 people on the ground.

1979: On August 2, New York Yankees catcher Thurman Munson is killed in the crash of his private plane in Canton, Ohio.

1979: On August 11, 173 die when two Aeroflot Tupolev-134's collide over the Ukraine.

1979: On November 26, a Boeing 707 crashes on takeoff near Jidda, Saudi Arabia, killing 156 passengers and crew members.

1979: On November 28, 257 people on an Air New Zealand sightseeing flight over Mount Erebus in Antarctica are killed when their DC-l0 crashes into the volcano.

1980: On March 18, a Vostok rocket explodes on its launch pad while being refueled, killing 50 at the Plesetsk Space Center in the Soviet Union.

1980: On August 19, a Lockheed TriStar L-1011 makes a successful emergency landing in Riyadh, Saudi Arabia, but a fire kills all 301 on board.

1980: On December 4, Portuguese prime minister Francisco Sá Carneiro, is among those who die in an airplane crash.

1981: On May 24, Ecuador president Jaime Roldos Aguilera is among those who die in an airplane crash.

1981: On July 31, General Omar Torrijos, then leader of Panama, dies in a plane crash.

1981: On December 1, a Yugoslav DC-9 crashes into a mountain near Ajaccio, Corsica, killing 180.

1982: On January 13, Air Florida Flight 90, a Boeing 737, crashes in snowfall following takeoff from Washington National Airport in Washington, D.C. The plane hits a bridge and plunges into the ice-covered Potomac River. Of the 79 passengers and crew members on board, only 5 survive the crash. Seven vehicles on the bridge are struck, killing 4 people.

1982: On July 9, 153 die when a Pan Am Boeing 727 crashes into a residential area in New Orleans after taking off during a thunderstorm.

1982: On July 23, actor Vic Morrow and two child actors are killed when a Bell UH-1B Huey helicopter lands on them during the filming of *The Twilight Zone: The Movie*.

1983: On June 2, a fire in the washroom of Air Canada Flight 797, a DC-9, forces the plane to land in Cincinnati. Eighteen passengers and 5 crew members escape, but 23 passengers die in the fire.

1983: On June 27, famous balloonists Maxie Anderson and Don Ida are killed when their helium balloon crashes in a West German forest during a race.

1983: On July 11, a Boeing 737 hits a mountain near Cuenca, Ecuador, killing 118.

1983: On September 1, a Korean Air Lines (KAL) Flight 007 strays off course and flies into Soviet airspace. It is shot down by a Soviet fighter, killing all 269 on board.

1983: On November 27, mechanical problems bring down an Avianca 747 near Madrid, Spain, killing 183. Eleven people survive.

1983: On December 7, an Aviaco DC-9 taxiing across a runway in Madrid, Spain, collides with an Iberia 727 taking off from the same runway, killing 93.

1985: On February 11, Ben Abruzzo, a member of the first teams to cross the Atlantic Ocean and the Pacific Ocean non-stop in a balloon, is killed when his twin-engine plane crashes shortly after takeoff from Albuquerque, New Mexico.

1985: On February 19, an Iberia 727 crashes in Bilbao, Spain, killing 148.

1985: On June 14, a TWA 727 is hijacked in Greece; the passengers are held in the plane for several days, and one person is killed.

1985: On June 23, Air India Flight 182, a Boeing 747 flying from Montreal to London's Heathrow Airport, crashes into the Atlantic Ocean near Iceland, apparently after a bomb explodes. All 307 passengers and 22 crew members are killed.

1985: On July 13, one member of the U.S. Navy's elite Blue Angels flight demonstration squadron is killed when two of the group's planes collide during an air show in Niagara Falls, New York.

1985: On August 2, Delta Air Lines Flight 191, a Lockheed TriStar, attempts to land in Dallas and crashes as a result of windshear, killing 135 of the 165 on board.

1985: On August 12, in the worst single-plane disaster up to that time, a Boeing 747 crashes into Mount Osutaka, Japan, killing 520 people and injuring 4 others.

1985: On August 25, thirteen-year-old Samantha Smith, her father, and 6 others are killed when their Bar Harbor Airlines Beechcraft 99 crashes while trying to land in Auburn, Maine. Smith was famous for writing a letter to Soviet leader Yuri Andropov and being invited to visit Russia.

1985: On December 12, the crash in Gander, Newfoundland, of a DC-8 shortly after takeoff kills 256 people, including 248 members of the U.S. military.

1986: On January 28, the space shuttle *Challenger* explodes shortly after liftoff, killing 7 astronauts, including Christa McAuliffe, a teacher who was to become the first civilian astronaut.

1986: On March 31, a Mexicana Boeing 727 crashes into a mountain near Mexico City, killing 167.

1986: On April 2, a bomb explodes in a TWA 727, tearing a hole in the fuselage through which 4 passengers are sucked out.

1986: On May 24, astronaut Stephen Thorne dies in a plane crash near Alta Loma, Texas.

1986: On August 31, an Aeromexico DC-9 descending for a landing at Los Angeles International Airport collides with a small Piper Archer that has strayed into restricted airspace. The 82 victims include all 64 passengers and crew members on board the DC-9, the family of 3 in the Piper, and 15 people on the ground in the residential neighborhood of Cerritos.

1986: On October 19, Samora Machel, the first president of Mozambique, and 34 aides are killed when their Tupolev 134A-3 crashes into a hillside in South Africa.

1986: On November 7, 45 people die when a British International Helicopters Chinook crashes into the sea off Sumburgh in the Shetland Islands. The Chinook was ferrying personnel from an offshore oil production platform.

1986: On December 25, hijackers attempt to take over an Iraqi Airways 737 traveling from Baghdad to Amman, Jordan. When security forces intervene, a handgrenade is thrown into the passenger cabin, and another explodes in the cockpit. The plane crashes in Saudi Arabia, killing 63.

1986: On December 31, Ricky Nelson, an actor on the 1950's television show *The Adventures of Ozzie and Harriet* and a popular singer, dies in a New Year's Eve plane crash in Dekalb, Texas.

1987: On May 13, a Polish jetliner crashes near Dobrowka, Poland, after experiencing mechanical problems, killing 183 people.

1987: On August 16, 156 people die when a Northwest Airlines MD-80 plane clips a light pole in a parking lot while taking off in Detroit and crashes into an underpass beneath Interstate 94. Phoenix Suns basketball player Nick Vanos is among the casualities. A four-year-old girl miraculously survives the crash.

1987: On November 26, a South African Airways Boeing 747 goes down in rough seas south of Mauritius, killing 160.

1987: On November 29, a bomb planted on KAL Flight 858, a 707 traveling from Abu Dhabi, United Arab Emirates, to Seoul, South Korea, explodes in midair. The plane crashes into the sea off Burma, killing all 115 on board.

1987: On December 7, David Burke, recently fired by USAir, brings a gun on board PSA Flight 1771 from Los Angeles to San Francisco. He shoots his former boss, the pilots, and then himself, causing the plane to crash near Harmony, California, killing 44 people.

1988: On July 3, all 290 people on board an Iran Air Airbus A-300 are killed when the plane is shot down by U.S. Navy warship *Vincennes* in the Persian Gulf after being misidentified as hostile.

1988: On August 17, Pakistani president Mohammad Zia ul-Haq and U.S. ambassador Arnold Raphel die in a mysterious plane crash.

1988: On August 28, three jets from the Italian Air Force acrobatic team collide in midair during an air show at Ramstein Air Force Base, West Germany. The crash kills 70 people, including the pilots and some spectators on the ground.

1988: On December 21, a terrorist bomb hidden in a cassette recorder destroys Pan Am Flight 103 over Lockerbie, Scotland, killing 259 on board the Boeing 747 and 11 on the ground. The plane was en route to New York from London.

1989: On February 24, 9 people are sucked out the back of a United Air Lines Boeing 747 and fall to their deaths in the Pacific Ocean when a forty-foot hole blows open in the fuselage 100 miles south of Hawaii en route to New Zealand. Another 27 passengers are injured.

1989: On June 7, a Surinam Airways DC-8 carrying 174 passengers and 9 crew members crashes into the jungle near Paramaribo, Suriname, while making a third attempt to land in a thick fog, killing 168 on board.

1989: On June 17, astronaut S. David Griggs dies in the crash of a World War II training plane near Earle, Arkansas.

1989: On July 19, 112 out of 296 on board are killed when United Air Lines Flight 232, a DC-10, crashes at the airport in Sioux City, Iowa, while attempting to land with a disabled hydraulic system.

1989: On August 7, Texas congressman Mickey Leland, the chair of the House Select Committee on Hunger, is killed in a plane crash during a trip to inspect relief efforts in Ethiopia.

1989: On August 13, Representative Larkin Smith of Mississippi is killed when his Cessna 177RG plane crashes near Janice, Mississippi.

1990: On August 27, blues guitarist Stevie Ray Vaughan and 4 others are killed in a helicopter crash in East Troy, Michigan, after playing a Guitar Greats show. Legendary guitarists Eric Clapton and Robert Cray had left on a separate helicopter.

1990: On October 2, a hijacker enters the cockpit of Xiamen Airlines 737 in China and demands to fly to Taiwan or Hong Kong. The captain tries to fool the hijacker by circling for thirty minutes. A struggle takes place during the approach to Guangzhou Airport, and the plane clips a parked China Southwest 707 and then strikes a China Southern 757 waiting for takeoff clearance. In all, 132 people are killed.

1991: On February 1, USAir Flight 1493, a Boeing 737, lands at Los Angeles International Airport and collides with a Skywest Metroliner awaiting takeoff clearance. All 10 passengers and 2 crew members on board the Metroliner and 20 passengers and 2 crew members on board the USAir plane are killed.

1991: On April 4, U.S. senator John Heinz of Pennsylvania dies when his plane collides with a helicopter over a schoolyard in Merion, Pennsylvania. Two children playing outside the school are also killed.

1991: On April 5, former U.S. senator John Tower, golfer Davis Love, Sr., and NASA astronaut Sonny Carter, Jr., are among 23 killed in the crash of an Atlantic Southeast Airlines flight near Brunswick, Georgia.

1991: On May 26, an Austrian Lauda Air Boeing 767, en route to Vienna, crashes into a jungle hilltop shortly after takeoff from Bangkok, Thailand, killing all 223 aboard.

1991: On July 11, Nigeria Airways Flight 2120, a DC-8, crashes in Jidda, Saudi Arabia, while trying to return to the airport after a fire is reported in the landing gear well, killing 261 people.

1991: On October 25, rock promoter Bill Graham dies when his Bell helicopter hits an electrical transmission tower and crashes near Vallejo, California.

1993: On April 1, Winston Cup champion and NASCAR driver Alan Kulwicki and 3 others are killed when their Fairchild SA227-TT private plane goes down near Bristol, Tennessee.

1993: On April 19, South Dakota governor George Mickelson and 7 others are killed when their private plane is damaged and crashes into a silo near Zwingle, Iowa.

1994: On March 22, an Aeroflot Airbus A-310 crashes on its way to Hong Kong, killing 75, after the pilot allows his teenage son to fly the plane.

1994: On April 3, Walt Disney president Frank Wells, documentary filmmaker Beverly Johnson, and the pilot are killed when their helicopter crashes during a ski trip to the remote Ruby Mountains in Nevada. Two others survive.

1994: On April 6, a plane carrying Burundi president Cyprien Ntaryamira and Rwandan president Juvenal Habyarimana is shot down as it nears the Rwandan capital of Kigali.

1994: On April 14, the pilots of two American F-15's mistake two U.S. Army Blackhawk helicopters for Russian-made Iraqi MI-24 helicopters and shoot them down over the "no-fly" zone in Iraq, killing all 26 on board.

1994: On April 26, a China Airlines Airbus A-300 traveling from Taiwan crashes in Japan while approaching Nagoya Airport for landing. Of the 271 people on board, 264 are killed and 7 passengers are seriously injured.

1994: On June 6, a China Northwest Airlines Tupolev-154 crashes near Xian, China, shortly after takeoff, killing all 160 aboard.

1994: On September 8, USAir Flight 427, a Boeing 737, crashes into a wooded ravine in Aliquippa, Pennsylvania, during its approach, killing all 132 on board.

1994: On December 24, the hijacking of an Air France plane in Algiers, Algeria, results in passenger deaths.

1995: On December 20, American Airlines Flight 965, a 757 from Miami to Cali, Colombia, crashes in mountainous terrain. Of the 156 passengers and 8 crew members on board, 4 passengers survive the accident.

1996: On January 8, a Russian-built Antonov-32 cargo plane crashes into the center of Kinshasa, Zaire, killing as many as 350 people and injuring at least 470.

1996: On February 6, a Birgenair Boeing 737 crashes into the Atlantic Ocean off the coast of the Dominican Republic shortly after takeoff, killing 189.

1996: On February 29, a Boeing 737 experiences engine failure and crashes near Arequipa, Peru, killing 123.

1996: On March 22, Colonel Robert Overmyer, an astronaut who commanded one of the last successful flights of the space shuttle *Challenger*, dies when the small plane he is test-flying goes into a spin and crashes near the airport in Duluth, Minnesota.

1996: On April 3, the Air Force passenger jet carrying U.S. Secretary of Commerce Ron Brown, along with 32 others, crashes into the mountains of Bosnia, enroute to Dubrovnik, Croatia, killing all on board.

1996: On April 11, seven-year-old Jessica Dubroff, her father, and a flight instructor are killed when their small plane crashes after takeoff in Cheyenne, Wyoming, during her attempt to become the youngest pilot to fly across the United States.

1996: On May 11, all 110 people on board a ValuJet DC-9 are killed when the plane crashes in the Florida Everglades. Among the dead is San Diego Chargers running back Rodney Culver.

1996: On July 17, TWA Flight 800, a 747 headed to Paris from New York, explodes over the ocean near Long Island, killing 230 people. After a long investigation, the official cause is deemed a spark that ignited fumes in a fuel tank, but many people continue to believe that a missile struck the plane.

1996: On August 29, an Aeroflot plane carrying 140 passengers crashes in Norway.

1996: On November 12, Saudi Arabian Airways Flight 763, a Boeing 747, collides in midair with Kazastan Airlines Flight 1907, an Ilyushin-76, sixty miles west of New Delhi, India. In all, 349 are dead, 312 on the 747 and 37 on the Il-76.

1997: On February 5, two CH-53 Sikorsky transport helicopters shuttling elite troops to Lebanon collide in fog and rain and crash in northern Israel, killing all 73 soldiers on board.

1997: On August 5, KAL Flight 801, a 747, crashes into a hillside in Guam, killing 227 of the 254 on board.

1997: On September 26, Garuda Airlines Flight 152, an Airbus A-300 flying from Jakarta to Medan, Sumatra, crashes near Buah Nabar, Indonesia, where visibility is hampered by dense smoke from forest fires. All 234 passengers and crew are killed.

1997: On October 12, singer-songwriter and actor John Denver is killed when his home-built fiberglass plane plunges into Northern California's Monterey Bay.

1998: On February 2, a DC-9 crashes into a mountain on Mindanao, Philippines, leaving 104 dead.

1998: On February 3, a U.S. Marine surveillance jet on a training flight in the Italian Alps flies too low and accidentally cuts the cable car line of a ski lift, causing all 20 people in the gondola to fall to their deaths.

1998: On February 16, a China Airlines Airbus A-300 returning from Bali with 197 people on board crashes, skids into a residential area, and bursts into flames just short of a runway at Taipei's airport. All 196 passengers and crew are killed, as well as 8 people on the ground.

1998: On April 12, balloonist Alex Ritchie dies in a skydiving accident.

1998: On September 3, Swissair flight SR111, a McDonnell Douglas (Boeing) MD-11 en route from New York to Geneva, is lost off the coast of Peggy's Cove, Nova Scotia, killing 215 passengers and 14 crew members.

1998: On December 11, a Thai Airways Airbus A-310 carrying 146 people crashes into a swamp in southern Thailand as it tries to land in heavy rain. Forty-five people survive the accident, but 101 die.

1999: On July 16, John F. Kennedy, Jr., becomes disoriented while flying his Piper Saratoga at twilight off Martha's Vineyard, Massachusetts. The plane plunges into the Atlantic Ocean, killing Kennedy, his wife Carolyn Bessette Kennedy, and her elder sister Lauren Bessette.

1999: On October 25, golf champion Payne Stewart and 5 others are killed when a private Learjet bound from Florida to Texas crashes in South Dakota after traveling 1,500 miles, most of it while the pilot, copilot, and passengers were apparently unconscious or dead.

1999: On October 31, EgyptAir Flight 990, from New York to Cairo, crashes into the ocean between Long Island, New York, and Martha's Vineyard, with the loss of all 217 people on board. The official investigation concludes that the copilot committed suicide by deliberately diving the plane into the water.

1999: On November 12, a United Nations ATR 42 turboprop carrying officials from the World Food Program crashes near Pristina in Kosovo, killing 24 people.

2000: On January 30, Kenya Airways Flight 431, an Airbus A310 from Nairobi, crashed into the ocean shortly after takeoff from Abidjan, Ivory Coast, killing 170 of 179 on board.

2000: On January 31, Alaska Airlines Flight 261, bound for San Francisco from Puerto Vallarta, Mexico, experiences stabilizer difficulties and crashes in the Pacific Ocean off Point Mugu, California, while preparing to make an emergency landing at Los Angeles International Airport. All 88 on board are killed.

2000: On April 19, 2000, all 131 passengers and crew on board Air Philippines Flight 541 are killed when the Boeing 737 crashes in the southern Philippines.

2000: On July 25, an Air France Concorde strikes metal debris on the runway and crashes shortly after takeoff from Charles de Gaulle Airport in Paris, killing all 109 on board and another 4 people on the ground.

2000: On August 23, Gulf Air Flight GF072, an Airbus A-320, crashes into shallow Persian Gulf waters after circling and trying to land in Bahrain, killing all 143 people on board, including 36 children.

2000: On October 16, Missouri governor and U.S. Senate candidate Mel Carnahan, his son, and an aide are killed when his campaign plane crashes near Hillsboro, Missouri. Carnahan wins the Senate race posthumously, and his wife is appointed to fill his seat until a new election can be held.

2001: On May 22, a small plane carrying astronaut Patricia Hilliard Robertson cartwheels and crashes into trees near Wolfe Air Park in Manvel, Texas. She dies from the resulting burns two days later.

2001: On August 25, R&B singer and actress Aaliyah is killed when her Cessna 402B airplane crashes and explodes on impact after takeoff from the Abaco Island airport in the Bahamas, where she had just completed a music video.

2001: On September 11, teams of terrorists hijack two 767's out of Boston's Logan Airport, American Airlines Flight 11 and United Air Lines Flight 175, and crash them into the Twin Towers of the World Trade Center in New York City, causing both buildings to collapse. A third hijacked plane, American Flight 77, a 757 out of Washington's Dulles Airport, is crashed into the Pentagon in Washington, D.C. A fourth hijacked plane, United Flight 93 out of Newark, New Jersey, crashes in a field near Pittsburgh, Pennsylvania, when passengers storm the cockpit of the 757 in an attempt to overcome the terrorists. In total, more than 3,000 people, from the planes and on the ground, are killed.

2001: On October 4, all 78 crew and passengers are killed on board a Tupolev Tu-154 jet when it explodes and crashes into the Black Sea while Ukrainian forces hold live-fire missile exercises in the Crimean peninsula. Most of the passengers are Russian-born Israelis flying from Tel Aviv to Siberia.

2001: On November 12, American Airlines Flight 587, an Airbus A300 en route from New York to the Dominican Republic, crashes into a residential neighborhood in Queens shortly after takeoff from JFK. All 260 on board are killed.

Tracy Irons-Georges

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