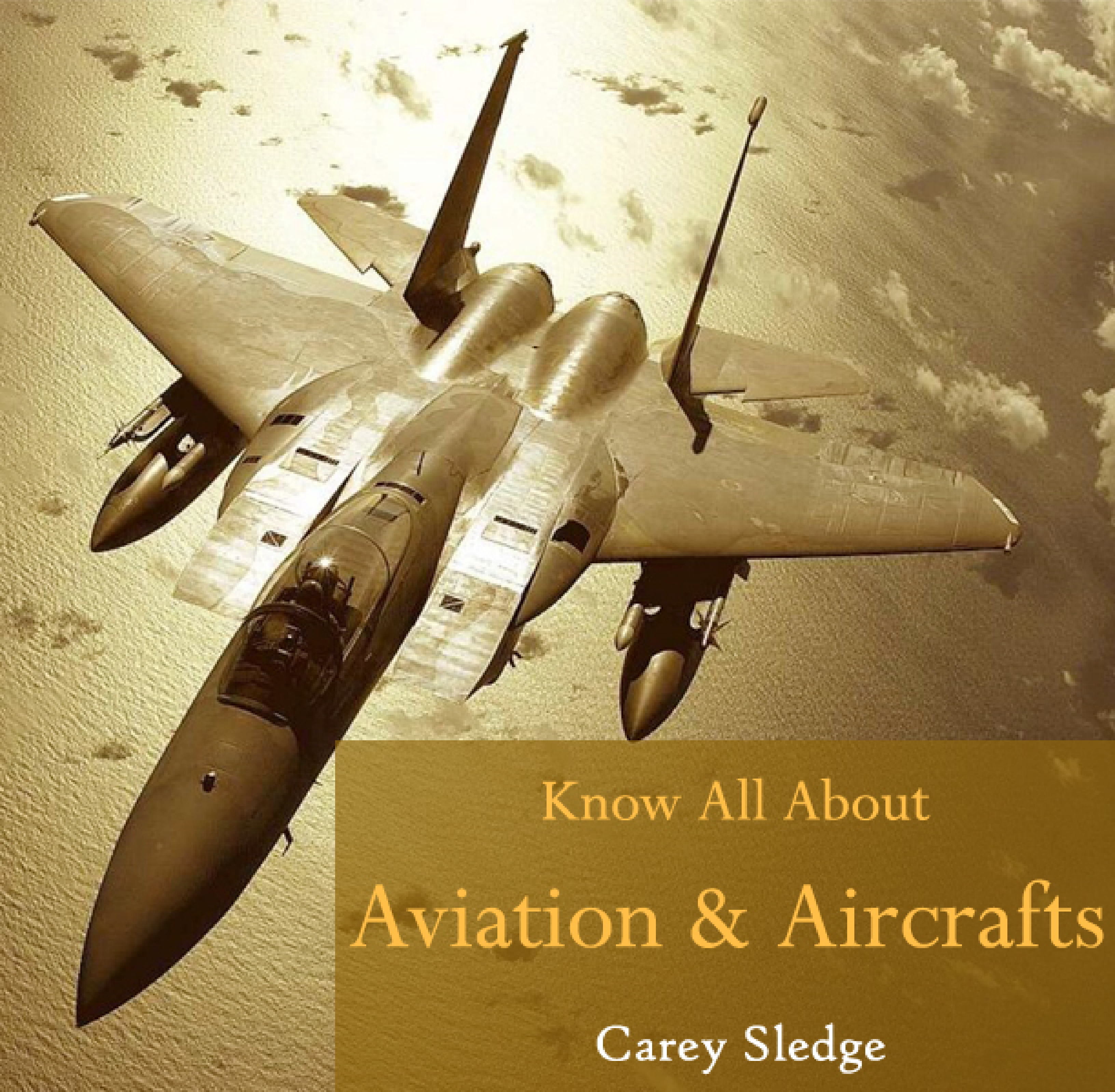

Know All About

Aviation & Aircrafts

Carey Sledge

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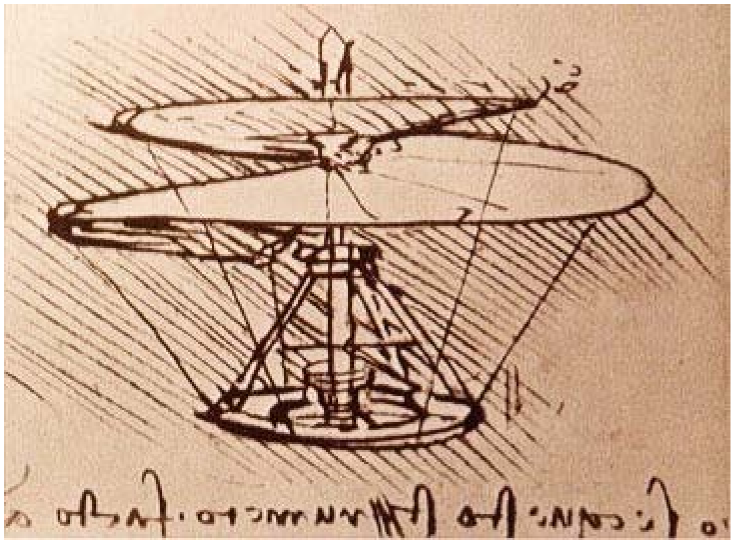
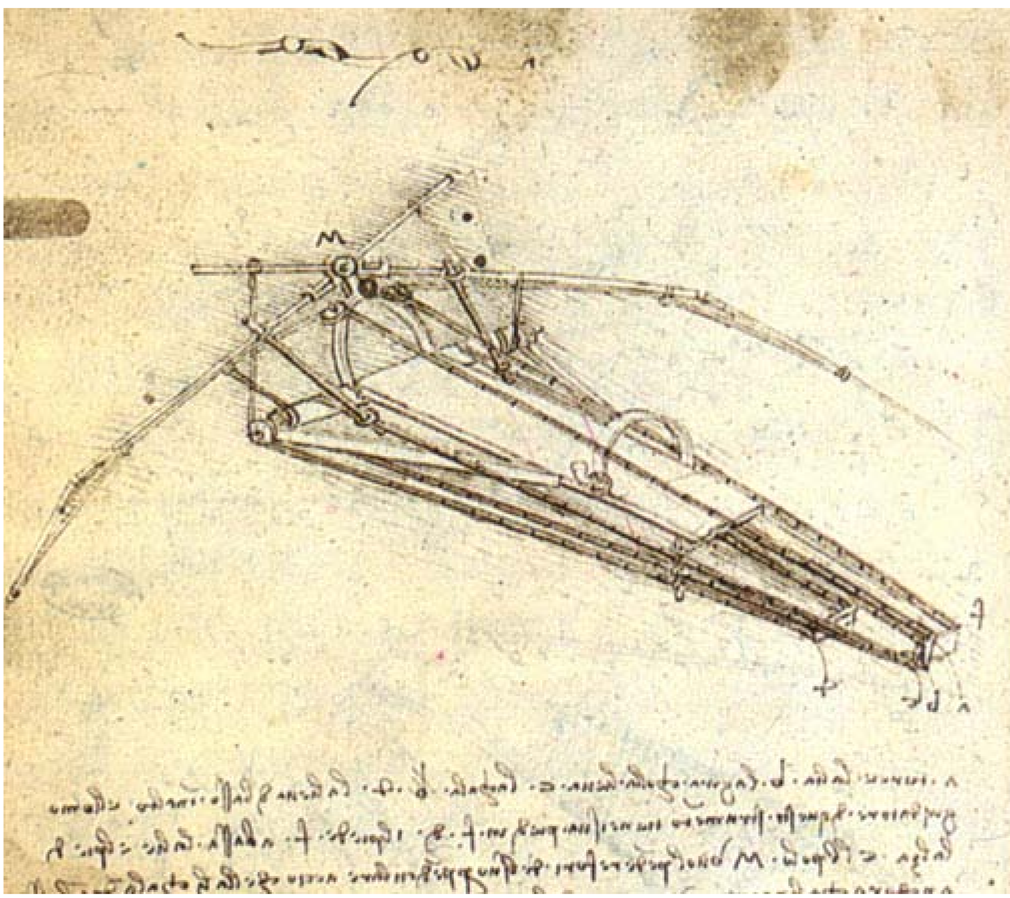
Aviation History

French reconnaissance balloon *L'Intrépide* of 1796, the oldest existing flying device, in the Heeresgeschichtliches Museum, Vienna



Leonardo da Vinci's "aerial screw" design.



Leonardo da Vinci's Ornithopter design.

Aviation history refers to the history of development of mechanical flight—from the earliest attempts in kites and gliders to powered heavier-than-air, supersonic and spaceflights.

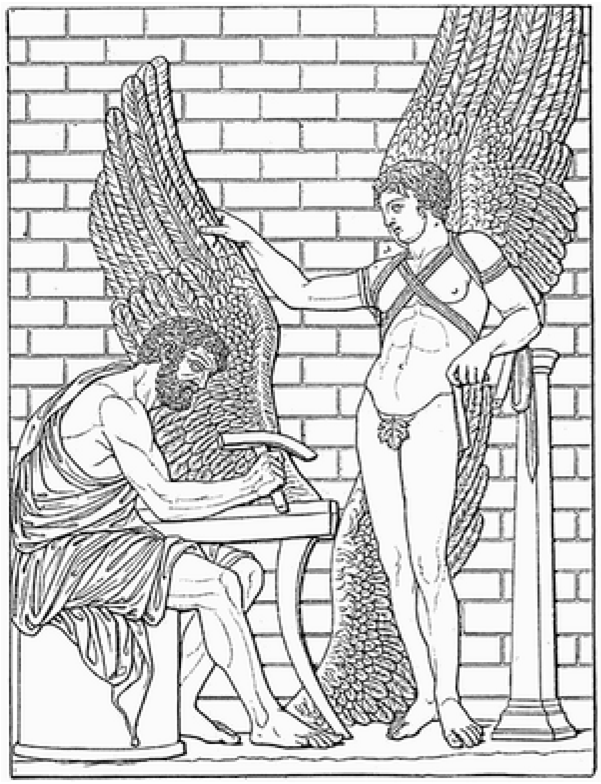
The first form of man-made flying objects were kites. The earliest known record of kite flying is from around 200 B.C. in China, when a General flew a kite over enemy territory to calculate the length of tunnel required to enter the region. Yuan Huangtou, a Chinese prince, survived by tying himself to the kite.

Leonardo da Vinci's (15th c.) dream of flight found expression in several designs, but he did not attempt to demonstrate flight by literally constructing them.

With the efforts to analyze the atmosphere in the 17th and 18th century, gases such as hydrogen were discovered which in turn led to the invention of hydrogen balloons. Various theories in mechanics by physicists during the same period of time—notably fluid dynamics and Newton's laws of motion—led to the foundation of modern aerodynamics. Tethered balloons filled with hot air were used in the first half of the 19th century and saw considerable action in several mid-century wars, most notably the American Civil War, where balloons provided observation during the Battle of Petersburg.

Experiments with gliders laid a groundwork to build heavier-than-air craft, and by the early 20th century advancements in engine technology and aerodynamics made controlled, powered flight possible for the first time.

Mythology



Daedalus working on Icarus' wings. Illustration from a relief in Villa Albani, Rome, 1st-2nd century CE.

Human ambition to fly is illustrated in mythological literature of several cultures; the wings made out of wax and feathers by Daedalus in Greek mythology, or the Pushpaka Vimana of king Ravana in Ramayana, for instance.

Early attempts

Flight automaton in Greece

Around 400 B.C., Archytas, the Greek philosopher, mathematician, astronomer, statesman and strategist, designed and built a bird-shaped, apparently steam powered model named "*The Pigeon*" (Greek: Περιστέρα "Peristera"), which is said to have flown some 200 meters. According to Aulus Gellius, the mechanical bird was suspended on a string or pivot and was powered by a "concealed aura or spirit".

Hot air balloons and kites in China

The Kongming lantern (proto hot air balloon) was known in China from ancient times. Its invention is usually attributed to the general Zhuge Liang (180–234 AD, honorific title *Kongming*), who is said to have used them to scare the enemy troops:

An oil lamp was installed under a large paper bag, and the bag floated in the air due to the lamp heating the air. ... The enemy was frightened by the light in the air, thinking that some divine force was helping him.

However, the device based on a lamp in a paper shell is documented earlier, and according to Joseph Needham, hot-air balloons in China were known from the 3rd century BC.

In the 5th century BCE Lu Ban invented a 'wooden bird' which may have been a large kite, or which may have been an early glider.

During the Yuan dynasty (13th c.) under rulers like Kublai Khan, the rectangular lamps became popular in festivals, when they would attract huge crowds. During the Mongol Empire, the design may have spread along the Silk Route into Central Asia and the Middle East. Almost identical floating lights with a rectangular lamp in thin paper scaffolding are common in Tibetan celebrations and in the Indian festival of lights, Diwali. However, there is no evidence that these were used for human flight.

Gliders in Europe

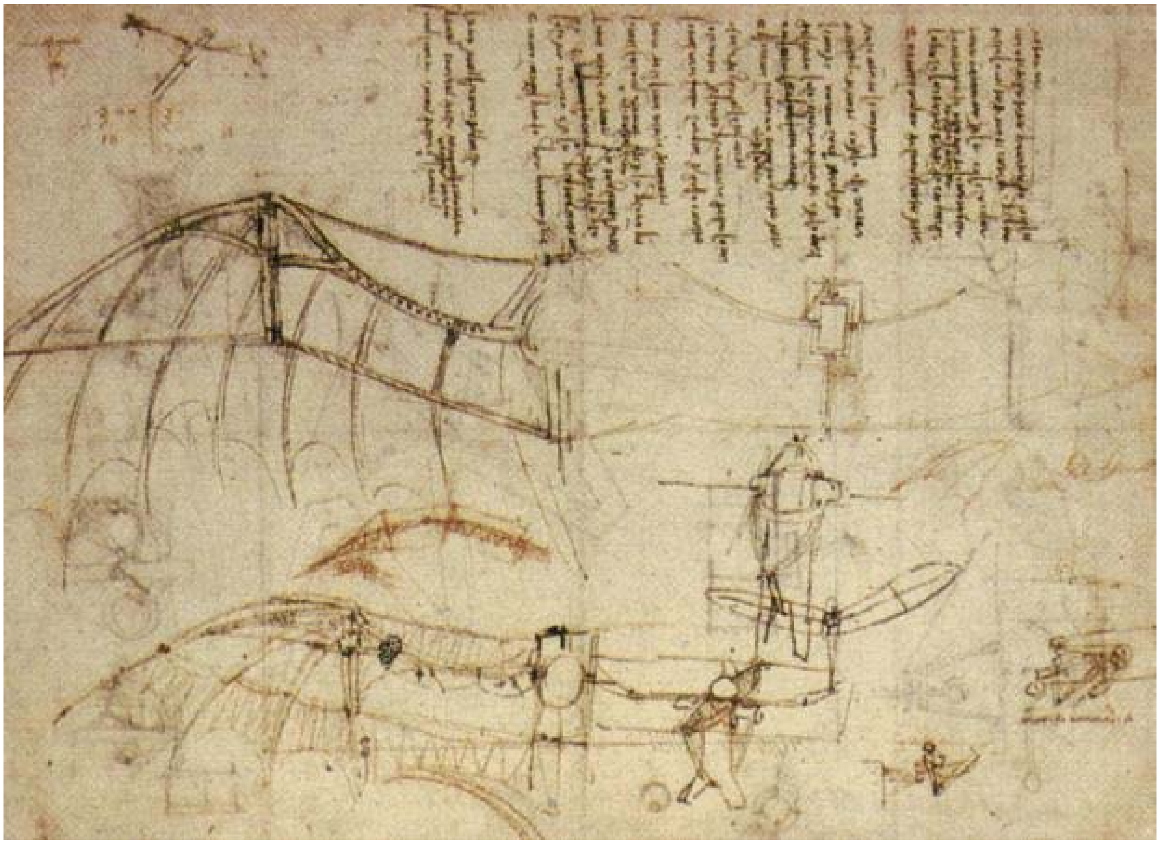
Stained glass window showing Eilmer, installed in Malmesbury Abbey in 1920

In the 9th century, at the age of 65, the Berber polymath Ibn Firnas is said to have flown from the hill Jabal al-'arus by employing a rudimentary glider. While "alighting again on the place whence he had started," he eventually crashed and sustained injury which some contemporary critics attributed to a lack of tail. However, the only source describing the event is from the 17th century.

Between 1000 and 1010, the English Benedictine monk Eilmer of Malmesbury flew for about 200 meters using a glider (circa 1010), but sustained injuries, too. The event is recorded in the work of the eminent medieval historian William of Malmesbury in about

1125. Being a fellow monk in the same abbey, William almost certainly obtained his account directly from people there who knew Eilmer himself.

From Renaissance to the 18th century



Leonardo da Vinci's Ornithopter wings

Some six centuries after Ibn Firnas, Leonardo da Vinci developed a hang glider design in which the inner parts of the wings are fixed, and some control surfaces are provided towards the tips (as in the gliding flight in birds). While his drawings exist and are deemed flightworthy in principle, he himself never flew in it. Based on his drawings, and using materials that would have been available to him, a prototype constructed in the late 20th century was shown to fly. However, his sketchy design was interpreted with modern knowledge of aerodynamic principles, and whether his actual ideas would have flown is not known. A model he built for a test flight in 1496 did not fly, and some other designs, such as the four-person screw-type helicopter have severe flaws.

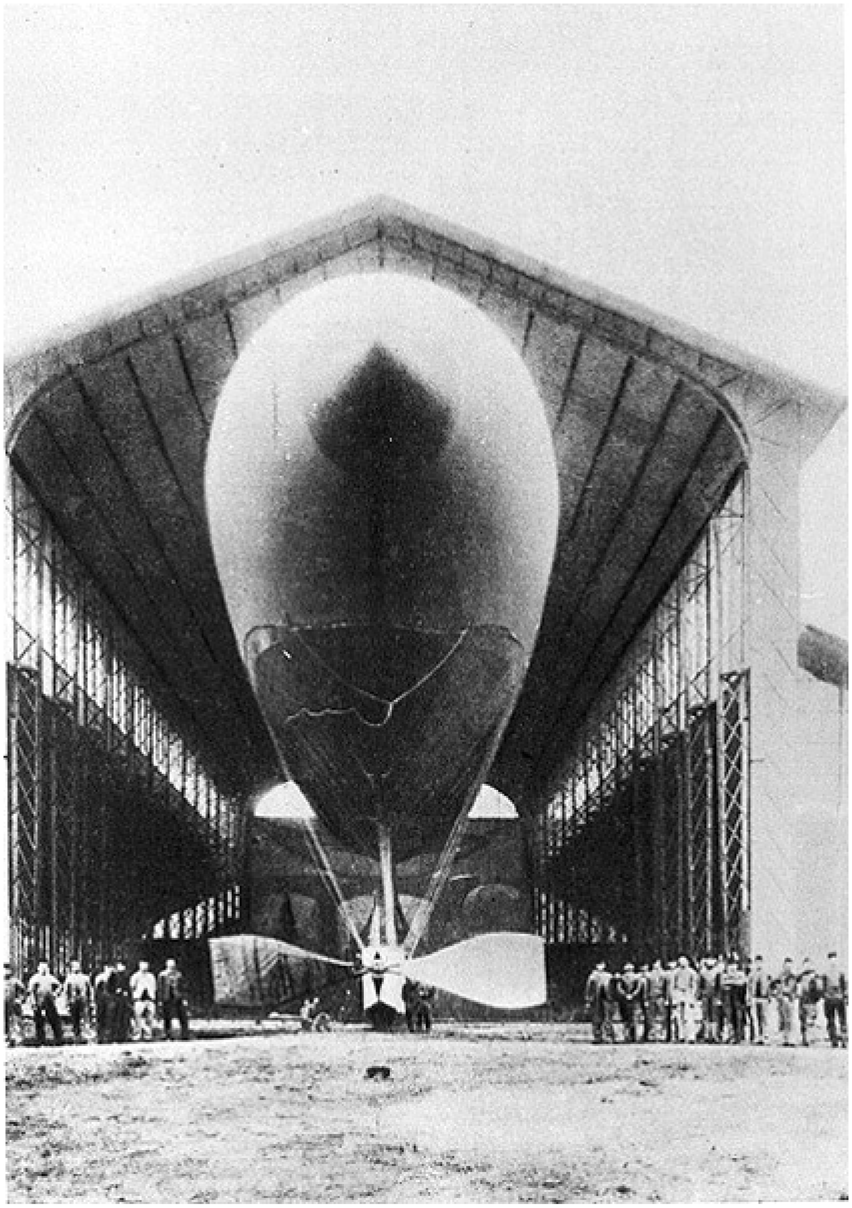
In 1670 Francesco Lana de Terzi published work that suggested lighter than air flight would be possible by having copper foil spheres that contained a vacuum that would be lighter than the displaced air, lift an airship (rather literal from his drawing). While not being completely off the mark, he did fail to realize that the pressure of the surrounding air would smash the spheres.

The small Priekule Lutheran Church in Latvia is related to an old legend about Ikarus of Priekule. For almost two centuries time after time in various printed texts- periodicals and books- there is described a sensational event that happened in the second half of the 17th century (according to another version at the beginning of the 18th century). People of Priekule have been telling their children this legend for many centuries. The blacksmith of Priekule Zviedris (Swede) Johanson (by nationality Swede?) made wings and from the steeple of the church made his first flight. Later the flight was announced as an unforgivable blasphemy. The local Ikarus was announced the Satan's avatar and was burned alive at the stake.

In 1709, Bartolomeu de Gusmão presented a petition to King John V of Portugal, begging a privilege for his invention of an airship, in which he expressed the greatest confidence. The public test of the machine, which was set for June 24, 1709, did not take place. According to contemporary reports, however, Gusmão appears to have made several less ambitious experiments with this machine, descending from eminences. It is certain that Gusmão was working on this principle at the public exhibition he gave before the Court on August 8, 1709, in the hall of the Casa da Índia in Lisbon, when he propelled a ball to the roof by combustion.

Modern flight

Lighter than air



The 1884 *La France*, the first fully controllable airship

Although many people think of human flight as beginning with the aircraft in the early 20th century, in fact people had been flying repeatedly for more than 100 years.

The first generally recognized human flight took place in Paris in 1783. Jean-François Pilâtre de Rozier and François Laurent d'Arlandes went 8 km (5 miles) in a hot air balloon invented by the Montgolfier brothers. The balloon was powered by a wood fire, and was not steerable: that is, it flew wherever the wind took it.

The navigable balloon created by Giffard in 1852

Ballooning became a major "rage" in Europe in the late 18th century, providing the first detailed understanding of the relationship between altitude and the atmosphere.

Work on developing a steerable (or dirigible) balloon (now called an airship) continued sporadically throughout the 19th century. The first powered, controlled, sustained lighter-than-air flight is believed to have taken place in 1852 when Henri Giffard flew 15 miles (24 km) in France, with a steam engine driven craft.

Non-steerable balloons were employed during the American Civil War by the Union Army Balloon Corps.

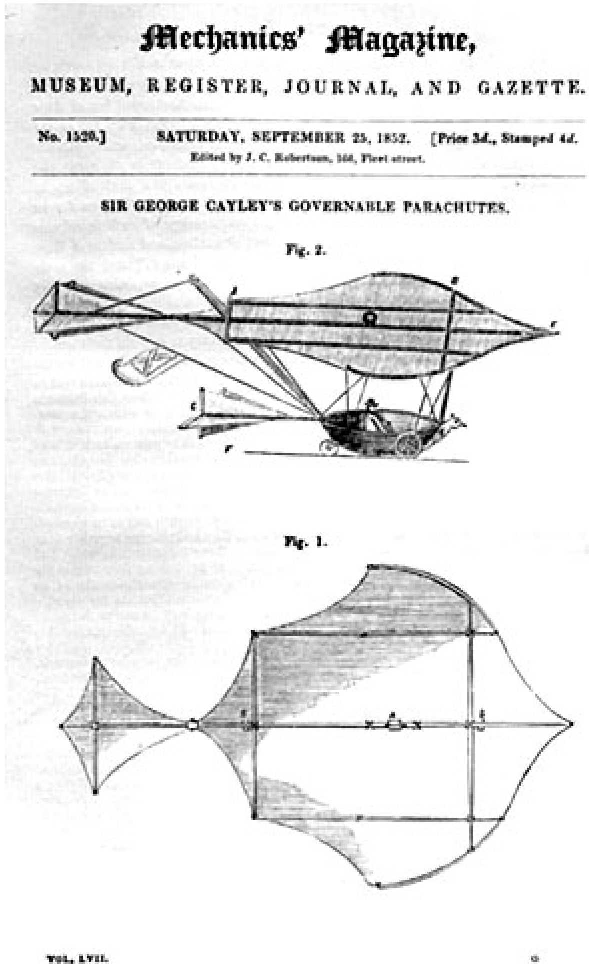
Another advance was made in 1884, when the first fully controllable free-flight was made in a French Army electric-powered airship, La France, by Charles Renard and Arthur Krebs. The 170-foot (52 m) long, 66,000-cubic-foot (1,900 m^3) airship covered 8 km (5 miles) in 23 minutes with the aid of an 8½ horsepower electric motor.

However, these aircraft were generally short-lived and extremely frail. Routine, controlled flights would not come to pass until the advent of the internal combustion engine (see below.)

Although airships were used in both World War I and II, and continue on a limited basis to this day, their development has been largely overshadowed by heavier-than-air craft.

Heavier-than-air

Sustaining the aircraft


Mechanics' Magazine,

MUSEUM, REGISTER, JOURNAL, AND GAZETTE.

No. 1520.] SATURDAY, SEPTEMBER 25, 1852. [Price 3d., Stamped 4d.

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SIR GEORGE CAYLEY'S GOVERNABLE PARACHUTES.

Fig. 2.

Fig. 1.

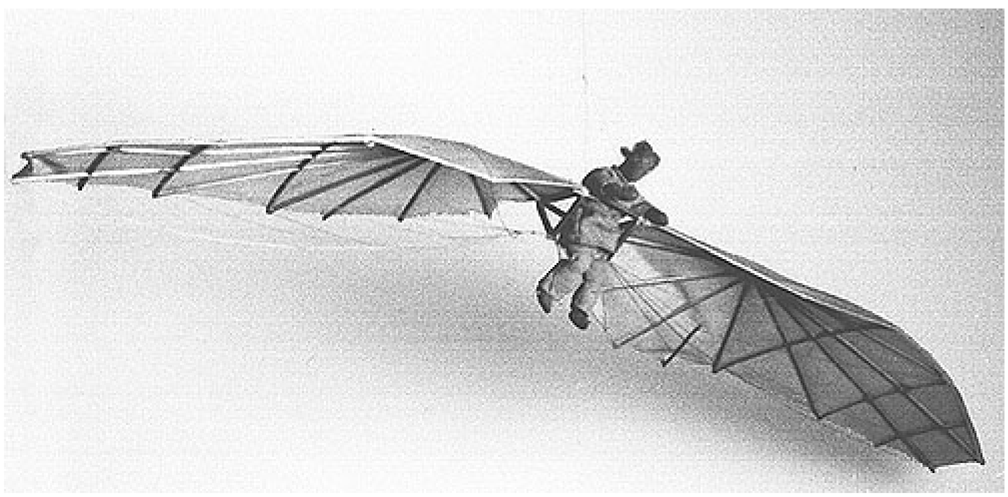
VOL. LVII.

Sir George Cayley's governable parachute

The first published paper on aviation was "Sketch of a Machine for Flying in the Air" by Emanuel Swedenborg published in 1716. This flying machine consisted of a light frame covered with strong canvas and provided with two large oars or wings moving on a horizontal axis, arranged so that the upstroke met with no resistance while the downstroke provided lifting power. Swedenborg knew that the machine would not fly, but suggested it as a start and was confident that the problem would be solved. He said, "It seems easier to talk of such a machine than to put it into actuality, for it requires greater force and less weight than exists in a human body. The science of mechanics might perhaps suggest a means, namely, a strong spiral spring. If these advantages and requisites are observed, perhaps in time to come some one might know how better to utilize our sketch and cause some addition to be made so as to accomplish that which we can only suggest. Yet there are sufficient proofs and examples from nature that such flights can take place without danger, although when the first trials are made you may have to pay for the experience, and not mind an arm or leg." Swedenborg would prove prescient in his observation that powering the aircraft through the air was the crux of flying.

During the last years of the 18th century, Sir George Cayley started the first rigorous study of the physics of flight. In 1799 he exhibited a plan for a glider, which except for planform was completely modern in having a separate tail for control and having the pilot suspended below the center of gravity to provide stability, and flew it as a model in 1804. Over the next five decades Cayley worked on and off on the problem, during which he invented most of basic aerodynamics and introduced such terms as *lift* and *drag*. He used both internal and external combustion engines, fueled by gunpowder. Later Cayley turned his research to building a full-scale version of his design, first flying it unmanned in 1849, and in 1853 his coachman made a short flight at Brompton, near Scarborough in Yorkshire.

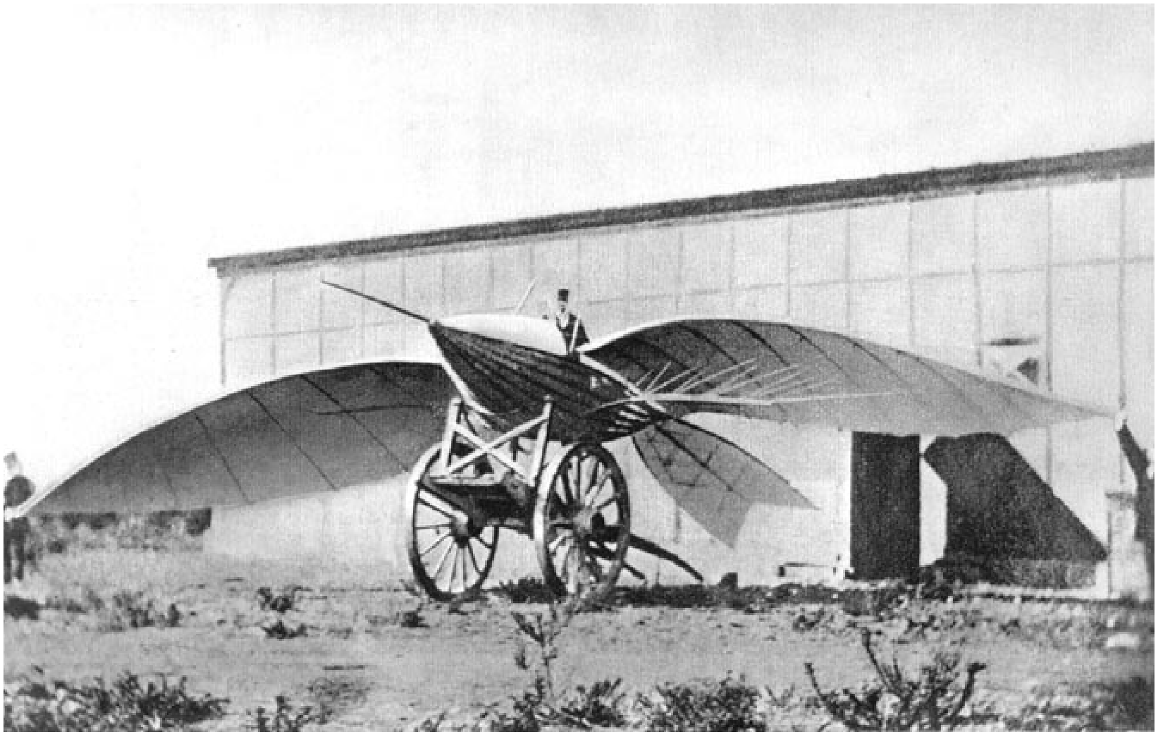
In 1848, John Stringfellow had a successful indoor test flight of a steam-powered model, in Chard, Somerset, England.



Model of Jan Wnęk's glider. Kraków Museum of Ethnography.

In 1866 a Polish peasant, sculptor and carpenter by the name of Jan Wnęk built and flew a controllable glider. Wnęk was illiterate and self-taught, and could only count on his knowledge about nature based on observation of birds' flight and on his own builder and carver skills. Jan Wnęk was firmly strapped to his glider by the chest and hips and controlled his glider by twisting the wing's trailing edge via strings attached to stirrups at his feet. Church records indicate that Jan Wnęk launched from a special ramp on top of the Odporyszów church tower; The tower stood 45 m high and was located on top of a 50 m hill, making a 95 m (311 ft) high launch above the valley below. Jan Wnęk made several public flights of substantial distances between 1866 and 1869, especially during religious festivals, carnivals and New Year celebrations. Wnęk left no known written records or drawings, thus having no impact on aviation progress. Recently, Professor

Tadeusz Seweryn, director of the Kraków Museum of Ethnography, has unearthed church records with descriptions of Jan Wnęk's activities.



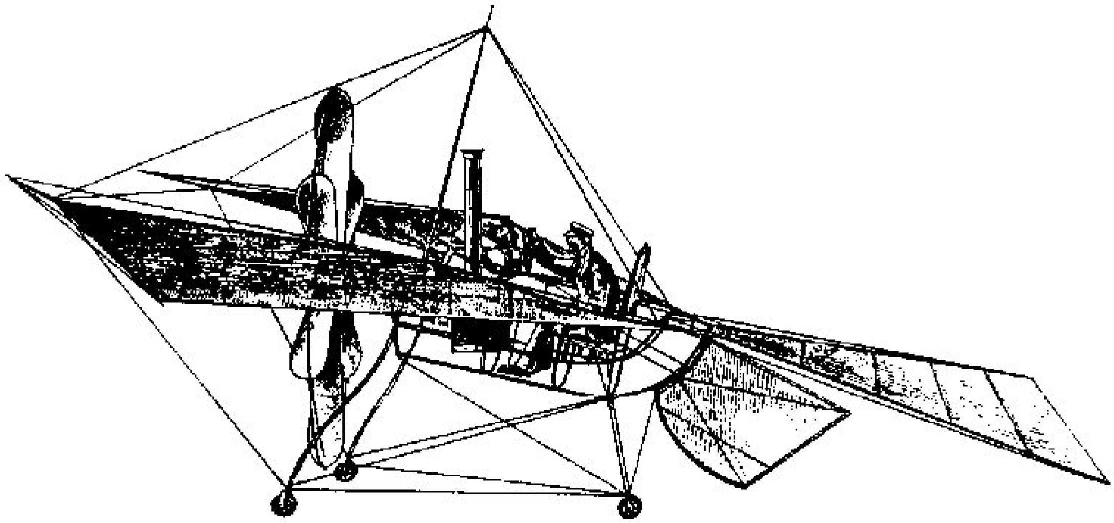
Jean-Marie Le Bris and his flying machine, Albatros II, 1868.

In 1856, Frenchman Jean-Marie Le Bris made the first flight higher than his point of departure, by having his glider *"L'Albatros artificiel"* pulled by a horse on a beach. He reportedly achieved a height of 100 meters, over a distance of 200 meters.

Francis Herbert Wenham built a series of unsuccessful unmanned gliders. He found that the most of the lift from a bird-like wing appeared to be generated at the front edge, and concluded correctly that long, thin wings would be better than the bat-like ones suggested by many, because they would have more leading edge for their weight. Today this measure is known as aspect ratio. He presented a paper on his work to the newly formed Aeronautical Society of Great Britain in 1866, and decided to prove it by building the world's first wind tunnel in 1871. Members of the Society used the tunnel and learned that cambered wings generated considerably more lift than expected by Cayley's Newtonian reasoning, with lift-to-drag ratios of about 5:1 at 15 degrees. This clearly demonstrated the ability to build practical heavier-than-air flying machines; what remained was the problem of controlling the flight and powering them.

Around 1871 Alphonse Pénaud made rubber powered model aircraft. While of little direct practical use they inspired a whole generation of future flight pioneers, including the Wright brothers who were given them as toys as children.

In 1874, Félix du Temple built the "*Monoplane*", a large plane made of aluminium in Brest, France, with a wingspan of 13 meters and a weight of only 80 kilograms (without the driver). Several trials were made with the plane, and it is generally recognized that it achieved lift off under its own power after a ski-jump run, glided for a short time and returned safely to the ground, making it the first successful powered flight in history, although the flight was only a short distance and a short time.



Félix du Temple's 1874 *Monoplane*.

Controlling the flight

The 1880s became a period of intense study, characterized by the "gentleman scientists" who represented most research efforts until the 20th century. Starting in the 1880s advancements were made in construction that led to the first truly practical gliders. Three people in particular were active: Otto Lilienthal, Percy Pilcher and Octave Chanute. One of the first truly modern gliders appears to have been built by John J. Montgomery; it flew in a controlled manner outside of San Diego on August 28, 1883. It was not until many years later that his efforts became well known. Another delta hang-glider had been constructed by Wilhelm Kress as early as 1877 near Vienna.

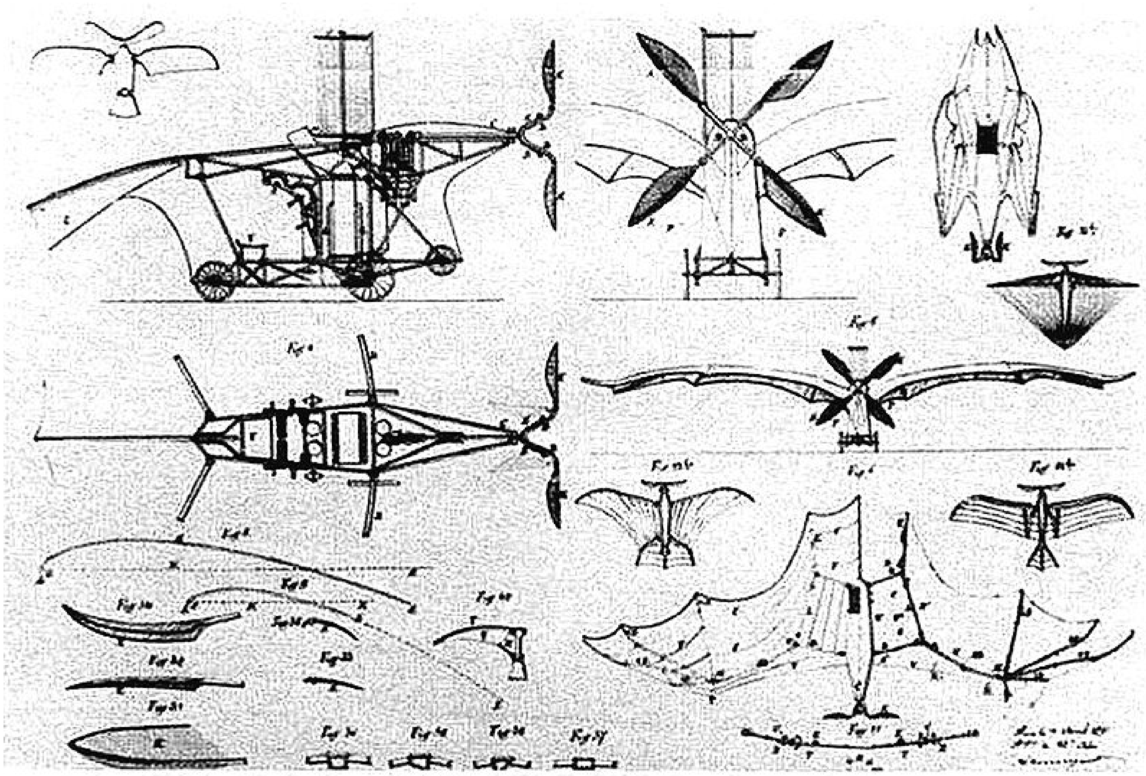
Otto Lilienthal of Germany duplicated Wenham's work and greatly expanded on it in 1874, publishing his research in 1889. He also produced a series of ever-better gliders, and in 1891 was able to make flights of 25 meters or more routinely. He rigorously documented his work, including photographs, and for this reason is one of the best known of the early pioneers. He also promoted the idea of "jumping before you fly", suggesting that researchers should start with gliders and work their way up, instead of simply designing a powered machine on paper and hoping it would work. His type of aircraft is now known as a hang glider.

By the time of his death in 1896 he had made 2500 flights on a number of designs, when a gust of wind broke the wing of his latest design, causing him to fall from a height of roughly 56 feet (17 m), fracturing his spine. He died the next day, with his last words being "small sacrifices must be made". Lilienthal had been working on small engines suitable for powering his designs at the time of his death.

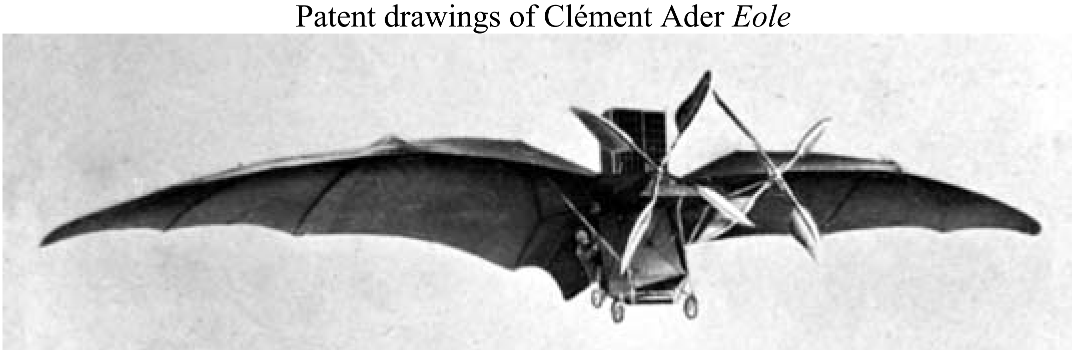
Australian Lawrence Hargrave invented the box kite and dedicated his life to constructing flying machines. In the 1880s he experimented with monoplane models and by 1889 Hargrave had constructed a rotary airplane engine, driven by compressed air.

Picking up where Lilienthal left off, Octave Chanute took up aircraft design after an early retirement, and funded the development of several gliders. In the summer of 1896 his troop flew several of their designs many times at Miller Beach, Indiana, eventually deciding that the best was a biplane design that looks surprisingly modern. Like Lilienthal, he heavily documented his work while photographing it, and was busy corresponding with like-minded hobbyists around the world. Chanute was particularly interested in solving the problem of aerodynamic instability of the aircraft in flight, one which birds corrected for by instant corrections, but one that humans would have to address with stabilizing and control surfaces (or moving center of gravity, as Lilienthal did). The most disconcerting problem was longitudinal instability (divergence), because as the angle of attack of a wing increased, the center of pressure moved forward and made the angle increase more. Without immediate correction, the craft would pitch up and stall. Much more difficult to understand was the mixing of lateral/directional stability and control.

Powering the aircraft



Patent drawings of Clément Ader *Eole*



Clément Ader *Avion III* (1897 photograph).

Throughout this period, a number of attempts were made to produce a true powered aircraft. However the majority of these efforts were doomed to failure, being designed by hobbyists who did not have a full understanding of the problems being discussed by Lilienthal and Chanute.

In France Clément Ader built the steam-powered *Eole* and may have made a 50-meter flight near Paris in 1890, which would be the first self-propelled "long distance" flight in history. Ader then worked on a larger design which took five years to build. In a test for the French military, the *Avion III* reportedly managed to cover 300 meters at a very small height, crashing out of control.

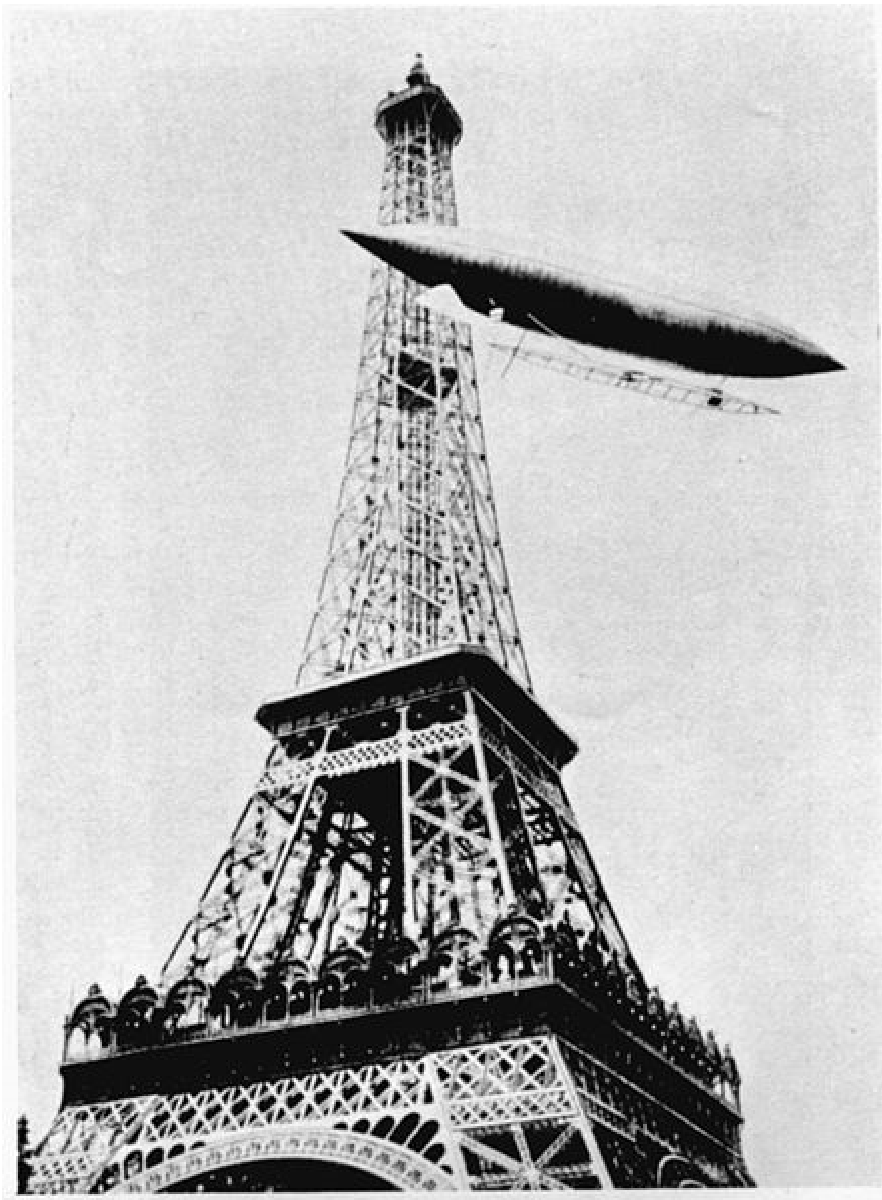
In 1884, Alexander Mozhaysky's monoplane design made what is now considered to be a power assisted take off or 'hop' of 60–100 feet (20–30 meters) near Krasnoye Selo, Russia.

Sir Hiram Maxim studied a series of designs in England, eventually building a monstrous 7,000 pounds (3,200 kg) design with a wingspan of 105 feet (32 m), powered by two advanced low-weight steam engines which delivered 180 hp (134 kW) each. Maxim built it to study the basic problems of construction and power and it remained without controls, and, realizing that it would be unsafe to fly, he instead had a 1,800 feet (550 m) track constructed for test runs. After a number of test runs working out problems, on July 31, 1894 they started a series of runs at increasing power settings. The first two were successful, with the craft "flying" on the rails. In the afternoon the crew of three fired the boilers to full power, and after reaching over 42 mph (68 km/h) about 600 feet (180 m) down the track the machine produced so much lift it pulled itself free of the track and crashed after flying at low altitudes for about 200 feet (61 m). Declining fortunes left him unable to continue his work until the 20th century, when he was able to test a number of smaller designs powered by gasoline.

In the United Kingdom an attempt at heavier-than-air flight was made by the aviation pioneer Percy Pilcher. Pilcher had built several working gliders, *The Bat*, *The Beetle*, *The Gull* and *The Hawk*, which he flew successfully during the mid to late 1890s. In 1899 he constructed a prototype powered aircraft which, recent research has shown, would have been capable of flight. However, he died in a glider accident before he was able to test it, and his plans were forgotten for many years.

The "Pioneer Era" (1900–1914)

Lighter than air



Santos-Dumont's "Number 6" rounding the Eiffel Tower in the process of winning the Deutsch Prize. Photo courtesy of the Smithsonian Institution (SI Neg. No. 85-3941)

The first aircraft to make routine controlled flights were non-rigid airships (later called "blimps".) The most successful early pioneering pilot of this type of aircraft was the Brazilian Alberto Santos-Dumont who effectively combined a balloon with an internal combustion engine. On October 19, 1901 he flew his airship "Number 6" over Paris from the Parc Saint Cloud around the Eiffel Tower and back in under 30 minutes to win the Deutsch de la Meurthe prize. Santos-Dumont went on to design and build several aircraft.

Subsequent controversy surrounding his and others' competing claims with regard to aircraft overshadowed his unparalleled contributions to the development of airships.

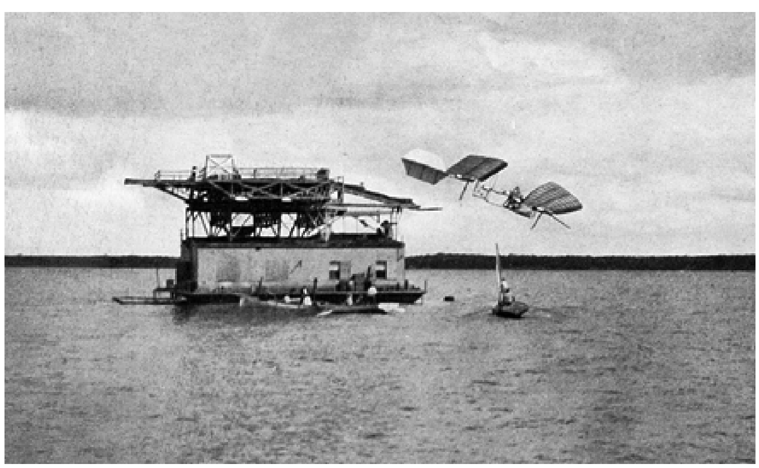
At the same time that non-rigid airships were starting to have some success, rigid airships were also becoming more advanced. Indeed, rigid body dirigibles would be far more capable than fixed wing aircraft in terms of pure cargo carrying capacity for decades. Dirigible design and advancement was brought about by the German count, Ferdinand von Zeppelin.

Construction of the first Zeppelin airship began in 1899 in a floating assembly hall on Lake Constance in the Bay of Manzell, Friedrichshafen. This was intended to ease the starting procedure, as the hall could easily be aligned with the wind. The prototype airship *LZ 1* (LZ for "Luftschiff Zeppelin") had a length of 128 m, was driven by two 14.2 ps (10.6 kW) Daimler engines and balanced by moving a weight between its two nacelles.

The first Zeppelin flight occurred on July 2, 1900. It lasted for only 18 minutes, as LZ 1 was forced to land on the lake after the winding mechanism for the balancing weight had broken. Upon repair, the technology proved its potential in subsequent flights, beating the 6 m/s velocity record of French airship *La France* by 3 m/s, but could not yet convince possible investors. It would be several years before the Count was able to raise enough funds for another try. Indeed, it was not until 1902 when Spanish engineer Leonardo Torres Quevedo developed his own zeppelin airship, with which he solved the serious balance problems the suspending gondola had shown in previous flight attempts.

Heavier than air

Langley



First failure of Langley's manned Aerodrome on the Potomac River, October 7, 1903

After a distinguished career in astronomy and shortly before becoming Secretary of the Smithsonian Institution, Samuel Pierpont Langley started a serious investigation into aerodynamics at what is today the University of Pittsburgh. In 1891 he published *Experiments in Aerodynamics* detailing his research, and then turned to building his designs. On May 6, 1896, Langley's Aerodrome No.5 made the first successful sustained flight of an unpiloted, engine-driven heavier-than-air craft of substantial size. It was launched from a spring-actuated catapult mounted on top of a houseboat on the Potomac River near Quantico, Virginia. Two flights were made that afternoon, one of 1,005 metres (3,297 ft) and a second of 700 metres (2,300 ft), at a speed of approximately 25 miles per hour (40 km/h). On both occasions the Aerodrome No.5 landed in the water as planned, because in order to save weight, it was not equipped with landing gear. On November 28, 1896, another successful flight was made with the Aerodrome No.6. This flight, of 1,460 metres (4,790 ft), was witnessed and photographed by Alexander Graham Bell. The Aerodrome No.6 was actually Aerodrome No.4 greatly modified. So little remained of the original aircraft that it was given the new designation of Aerodrome No.6.

With the success of the Aerodrome No. 5 and its follow-on No. 6, Langley started looking for funding to build a full-scale man-carrying version of his designs. Spurred by the Spanish-American War, the U.S. government granted him $50,000 to develop a man-carrying flying machine for surveillance. Langley planned on building a scaled-up version known as the **Aerodrome A**, and started with the smaller **Quarter-scale Aerodrome**, which flew twice on June 18, 1901, and then again with a newer and more powerful engine in 1903.

With the basic design apparently successfully tested, he then turned to the problem of a suitable engine. He contracted Stephen Balzer to build one, but was disappointed when it delivered only 8 horsepower (6 kW) instead of 12 hp (9 kW) as he expected. Langley's assistant, Charles M. Manly, then reworked the design into a five-cylinder water-cooled radial that delivered 52 horsepower (39 kW) at 950 rpm, a feat that took years to duplicate. Now with both power and a design, Langley put the two together with great hopes.

To his dismay, the resulting aircraft proved to be too fragile. He had apparently overlooked the effects of minimum gauge, and simply scaling up the original small models resulted in a design that was too weak to hold itself together. Two launches in late 1903 both ended with the Aerodrome immediately crashing into the water. The pilot, Manly, was rescued each time.

Langley's attempts to gain further funding failed, and his efforts ended. Nine days after his second abortive launch on December 8, the Wright brothers successfully flew their aptly-named *Flyer*. Glenn Curtiss made several modifications to the Aerodrome and successfully flew it in 1914—the Smithsonian Institution thus continued to assert that Langley's Aerodrome was the first machine "capable of flight".

The Wright Brothers

Following a step by step method, discovering aerodynamic forces then controlling the flight, the brothers built and tested a series of kite and glider designs from 1900 to 1902 before attempting to build a powered design. The gliders worked, but not as well as the Wrights had expected based on the experiments and writings of their 19th century predecessors. Their first glider, launched in 1900, had only about half the lift they anticipated. Their second glider, built the following year, performed even more poorly. Rather than giving up, the Wrights constructed their own wind tunnel and created a number of sophisticated devices to measure lift and drag on the 200 wing designs they tested. As a result, the Wrights corrected earlier mistakes in calculations regarding drag and lift. Their testing and calculating produced a third glider with a larger aspect ratio and true three-axis control. They flew it successfully hundreds of times in 1902, and it performed far better than the previous models. In the end, by establishing their rigorous system of designing, wind-tunnel testing of airfoils and flight testing of full-size prototypes, the Wrights not only built a working aircraft but also helped advance the science of aeronautical engineering.

The Wright Flyer: the first sustained flight with a powered, controlled aircraft.

The Wrights appear to be the first design team to make serious studied attempts to simultaneously solve the power and control problems. Both problems proved difficult, but they never lost interest. They solved the control problem by inventing wing warping for roll control, combined with simultaneous yaw control with a steerable rear rudder. Almost as an afterthought, they designed and built a low-powered internal combustion engine. Relying on their wind tunnel data, they also designed and carved wooden propellers that were more efficient than any before, enabling them to gain adequate performance from their marginal engine power. Although wing-warping was used only briefly during the history of aviation, when used with a rudder it proved to be a key advance in order to control an aircraft. While many aviation pioneers appeared to leave safety largely to chance, the Wrights' design was greatly influenced by the need to teach themselves to fly without unreasonable risk to life and limb, by surviving crashes. This emphasis, as well as marginal engine power, was the reason for low flying speed and for taking off in a head wind. Performance (rather than safety) was also the reason for the rear-heavy design, because the canard could not be highly loaded; anhedral wings were less affected by crosswinds and were consistent with the low yaw stability.

According to the Smithsonian Institution and Fédération Aéronautique Internationale (FAI), the Wrights made the first sustained, controlled, powered heavier-than-air manned flight at Kill Devil Hills, North Carolina, four miles (8 km) south of Kitty Hawk, North Carolina on December 17, 1903.

The first flight by Orville Wright, of 120 feet (37 m) in 12 seconds, was recorded in a famous photograph. In the fourth flight of the same day, Wilbur Wright flew 852 feet (260 m) in 59 seconds. The flights were witnessed by three coastal lifesaving crewmen, a local businessman, and a boy from the village, making these the first public flights and the first well-documented ones.

Orville described the final flight of the day: "The first few hundred feet were up and down, as before, but by the time three hundred feet had been covered, the machine was under much better control. The course for the next four or five hundred feet had but little undulation. However, when out about eight hundred feet the machine began pitching again, and, in one of its darts downward, struck the ground. The distance over the ground was measured to be 852 feet (260 m); the time of the flight was 59 seconds. The frame supporting the front rudder was badly broken, but the main part of the machine was not injured at all. We estimated that the machine could be put in condition for flight again in about a day or two." They flew only about ten feet above the ground as a safety precaution, so they had little room to maneuver, and all four flights in the gusty winds ended in a bumpy and unintended "landing". Modern analysis by Professor Fred E. C. Culick and Henry R. Rex (1985) has demonstrated that the 1903 Wright Flyer was so unstable as to be almost unmanageable by anyone but the Wrights, who had trained themselves in the 1902 glider.

The Wrights continued flying at Huffman Prairie near Dayton, Ohio in 1904–05. After a severe crash on 14 July 1905, they rebuilt the Flyer and made important design changes. They almost doubled the size of the elevator and rudder and moved them about twice the distance from the wings. They added two fixed vertical vanes (called "blinkers") between the elevators, and gave the wings a very slight dihedral. They disconnected the rudder from the wing-warping control, and as in all future aircraft, placed it on a separate control handle. When flights resumed the results were immediate. The serious pitch instability that hampered Flyers I and II was significantly reduced, so repeated minor crashes were eliminated. Flights with the redesigned Flyer III started lasting over 10 minutes, then 20, then 30. Flyer III became the first practical aircraft (though without wheels and needing a launching device), flying consistently under full control and bringing its pilot back to the starting point safely and landing without damage. On 5 October 1905, Wilbur flew 24 miles (39 km) in 39 minutes 23 seconds."

According to the April 1907 issue of the *Scientific American* magazine, the Wright brothers seemed to have the most advanced knowledge of heavier-than-air navigation at the time. Though, the same magazine issue also affirms that no public flight has been made in the United States before its April 1907 issue. Hence, they devised the Scientific American Aeronautic Trophy in order to encourage the development of a heavier-than-air flying machine.

Alberto Santos-Dumont

Alberto Santos-Dumont, the designer of the 14-bis.

The Brazilian inventor Alberto Santos-Dumont made a public flight with the flying machine designated 14-bis on 13 September 1906 in Paris. He used a canard elevator and pronounced wing dihedral, and covered a distance of 60 m (200 ft). Since the plane did not need headwinds or catapults to take off, this flight is considered by some as the first true powered flight. Also, since the earlier attempts of Pearse, Jatho, Watson, and the

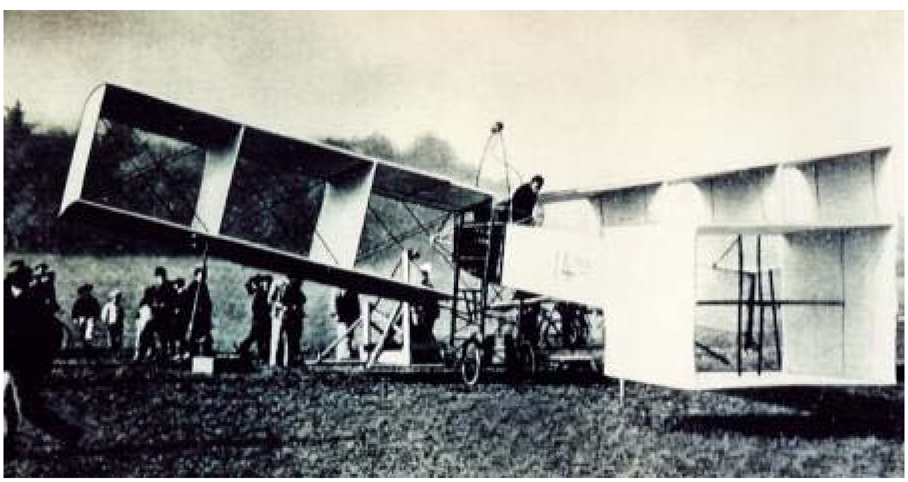
Wright brothers received far less attention from the popular press, Santos-Dumont's flight was more important to society when it happened, especially in Europe and Brazil, despite occurring some years later.

Confusion occasionally still arises over whether the Wright 1903 Flyer I, or the 14-Bis was the first true airplane. In fact, only the Wright Flyer I and its successors met the modern definition of an airplane (i.e., manned, powered, heavier than air, fully controllable around all three axes, and capable of sustained flight). The Wright 1903 Flyer I met this definition on December 17, 1903, taking off under its own power along a level wooden guide rail.

While the Wrights later used a launch catapult for their 1904 and 1905 machines, those Flyers could also take off unassisted given sufficient wind. It should be noted that the Wright 1905 Flyer (also called the Flyer III) flew more than 20 miles (32 km) in October 1905, a full year before the 14-bis made its first flight.

The 14-bis was marginally controllable at best and could only make wallowing hops. This remained true after Santos-Dumont, who was on the right track, installed primitive ailerons in November 1906. Unfortunately, they proved ineffective. On the plus side, Santos-Dumont and other Europeans used wheels whereas the Wrights stuck with skids for too long, which necessitated the use of a catapult in the absence of significant wind.

Santos-Dumont fans usually infer that while the *Wright Flyer* may have been superior in the air, its take-off apparatus made it overly impractical to operate and transport. Alternatively, Wright brothers fans usually point to the implication that the scarcity of usable takeoff fields made the Flyer and "pillar" more practical, needing much less open, smooth and level space than the *14-bis*.



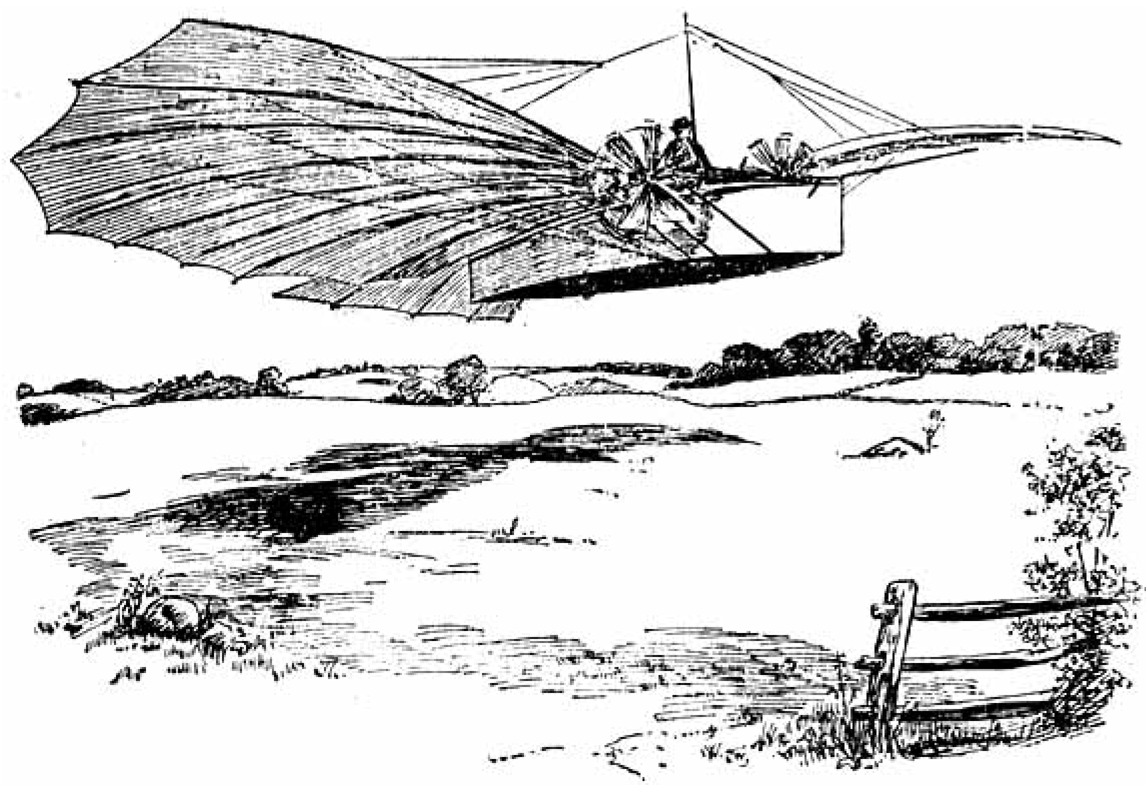
The 14-bis also known as Oiseau de proie (French for "bird of prey").

Opinions may vary on whether the Wright Flyer or the 14-bis was the more practical (and thus the "first") heavier-than-air flying machine. Both designs produced aircraft that made free, manned, powered flights. Which one was "first" or "more practical" is a matter of how those words are defined. No one could contest that the Wrights flew first, that the Flyer was more capable in the air, or that Santos Dumont took off on wheels before the Wrights and earned a variety of prizes and official records in France. Patriotic pride heavily influences opinions of the relative importance and practicality of each aircraft, thus causing debate. U.S. citizens prefer definitions that make the Wrights the "first" to fly, while Brazilians believe that Santos Dumont had the first "real", practical airplane, and that his nationality may have caused his accomplishments to not receive worldwide recognition.

In subsequent years, Santos-Dumont built more aircraft like Demoiselle. He was so enthusiastic about aviation that he released the drawings of Demoiselle for free, thinking that aviation would be the mainstream of a new prosperous era for mankind, and it became the world's first series production aircraft.

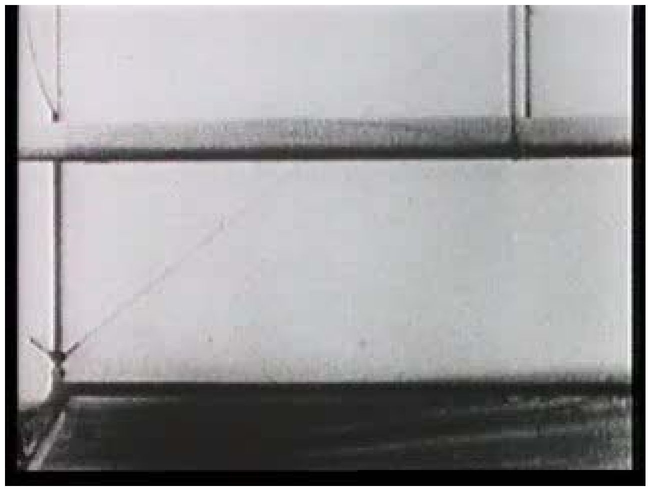
Other early flights & claims of flights

Around the years 1900 to 1910, a number of other inventors made or claimed to have made short flights.



Gustave Whitehead's aircraft was represented in a sketch in the *Bridgeport Herald*.

On August 14, 1901, in Fairfield, Connecticut, Gustave Whitehead reportedly flew his engine-powered No.21 for 800 metres (2,600 ft) at 15 metres (49 ft) height. In January 1902, he claimed to have flown 11 kilometres (6.8 mi) over Long Island Sound in the improved No.22. After 1903, Whitehead faded from public awareness. Three decades later, Whitehead's possible flights emerged from obscurity after the events were featured in a 1935 newspaper article and a 1937 book. Aviation experts debated the topic, and a few decided for Whitehead, while the great majority, such as Charles Harvard Gibbs-Smith, said the flights could not have occurred.



The first in-flight film, made by a camera man flying with Wilbur Wright on 24 April 1909

Lyman Gilmore claimed to have achieved success on 15 May 1902 and is widely credited with the first use of the word "airport."

In New Zealand, South Canterbury farmer and inventor Richard Pearse constructed a monoplane aircraft that he reputedly flew in early 1903. Good evidence exists that on March 31, 1903 Pearse achieved a powered, though poorly controlled, flight of several hundred metres. Pearse himself said that although he had made a powered takeoff, it was at "too low a speed for [his] controls to work".

The first balloon flights took place in Australia in the late 19th century while Bill Wittber and then escapologist Harry Houdini made Australia's first controlled flights in 1910.. Wittber was conducting taxiing tests in a Blériot XI aircraft in March 1910 in South Australia when he suddenly found himself about five feet in the air (Wittber's Hop). He flew about 40 feet (12 m) before landing. South Australia's other aviation firsts include the first flight from England to Australia by brothers Sir Ross and Sir Keith Smith in their Vickers Vimy bomber, the first Arctic flight by South Australian born Sir Hubert Wilkins and the first Australian born astronaut, Andy Thomas.

Karl Jatho from Hanover conducted a short motorized flight in August 1903, just a few months after Pearse. Jatho's wing design and airspeed did not allow his control surfaces to act properly to control the aircraft.

Also in the summer of 1903, eyewitnesses claimed to have seen Preston Watson make his initial flights at Errol, near Dundee in the east of Scotland. Once again, however, lack of photographic or documentary evidence makes the claim difficult to verify. Many claims of flight are complicated by the fact that many early flights were done at such low altitude that they did not clear the ground effect, and by the complexities involved in the differences between unpowered and powered aircraft.

The Wright brothers conducted numerous additional flights (about 150) in 1904 and 1905 from Huffman Prairie in Dayton, Ohio and invited friends and relatives. Newspaper reporters did not pay attention after seeing an unsuccessful flight attempt in May 1904.

Public exhibitions of high altitude flights were made by Daniel Maloney in the John Joseph Montgomery tandem-wing glider in March and April 1905 in the Santa Clara, California area. These flights received national media attention and demonstrated superior control of the design, with launches as high as 4,000 feet (1,200 m) and landings made at predetermined locations.

Two English inventors Henry Farman and John William Dunne were also working separately on powered flying machines. In January 1908, Farman won the Grand Prix d'Aviation by flying a 1 km circle, though by this time several longer flights had already been done. For example, the Wright brothers had made a flight over 39 kilometres (24 mi) in October 1905. Dunne's early work was sponsored by the British military, and tested in great secrecy in Glen Tilt in the Scottish Highlands. His best early design, the D4, flew in December 1908 near Blair Atholl in Perthshire. Dunne's main contribution to early aviation was stability, which was a key problem with the planes designed by the Wright brothers and Samuel Cody.

On 14 May 1908 Wilbur Wright piloted the first two-person fixed-wing flight, with Charlie Furnas as a passenger.

On 8 July 1908 Thérèse Peltier became the first woman to fly as a passenger in an airplane when she made a flight of 656 feet (200 m) with Léon Delagrange in Milan, Italy.

Thomas Selfridge became the first person killed in a powered aircraft on 17 September 1908, when Orville Wright crashed his two-passenger plane during military tests at Fort Myer in Virginia.

The first powered flight in Britain was made in 1908 by American Sam Cody in a plane designed and built with the British Army.

In September 1908, Mrs Edith Berg became the first American woman to fly as a passenger in an airplane when she flew with Wilbur Wright in Le Mans, France.

The first powered flight by a Briton in Britain was made by John Moore-Brabazon (JTC Moore Brabazon) in May 1909 on the Isle of Sheppey (Kent).

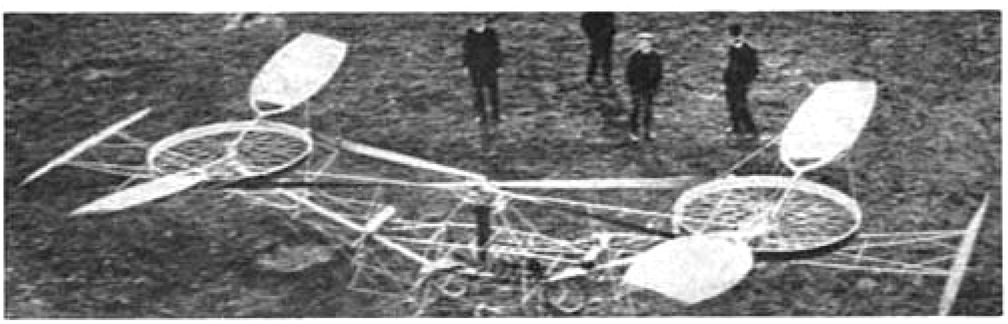
On 25 July 1909 Louis Blériot flew the Blériot XI monoplane across the English Channel winning the Daily Mail aviation prize. His flight from Calais to Dover lasted 37 minutes.

On 22 October 1909 Raymonde de Laroche became the first woman to fly solo in a powered heavier -than-air craft. She was also the first woman in the world to receive a pilot's licence.

Controversy over who gets credit for invention of the aircraft has been fueled by Pearse's and Jatho's essentially non-existent efforts to inform the popular press and by the Wrights' secrecy while their patent was prepared. For example, the Romanian engineer Traian Vuia (1872–1950) has also been claimed to have built the first self-propelled, heavier-than-air aircraft able to take off autonomously, without a headwind and entirely driven by its own power. Vuia piloted the aircraft he designed and built on 18 March 1906 at Montesson, near Paris. None of his flights were longer than 100 feet (30 m) in length. In comparison, in October 1905, the Wright brothers had a sustained flight of 39 minutes and 24.5 miles (39 km), circling over Huffman Prairie.

Helicopter

In 1877, Enrico Forlanini developed an unmanned helicopter powered by a steam engine. It rose to a height of 13 meters, where it remained for some 20 seconds, after a vertical take-off from a park in Milan.



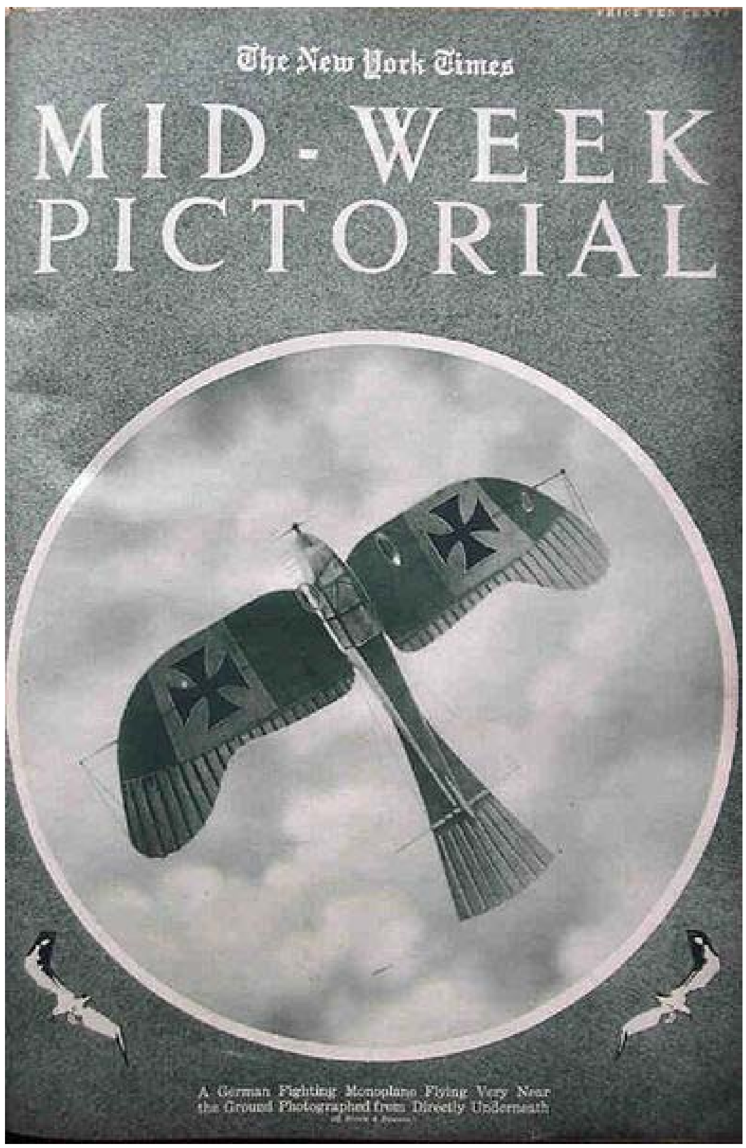
Paul Cornu's helicopter, built in 1907, was the first manned flying machine to have risen from the ground using rotating wings instead of fixed wings.

The first time a manned helicopter is known to have risen off the ground was in 1907 at Lisenux, France. The first successful rotorcraft, however, wasn't a true helicopter, but an autogyro invented by Spanish engineer Juan de la Cierva in 1919. These kind of rotorcrafts were mainly used until the development of modern helicopters, when, for some reason, they became largely neglected, although the idea has since been resurrected several times. Since the first practical helicopter was the Focke Achgelis Fw 61 (Germany, 1936), the autogyro's golden age only lasted around 20 years.

Seaplane

The first powered seaplane was invented in March 1910 by the French engineer Henri Fabre. Its name was *Le Canard* ('the duck'), and took off from the water and flew 800 meters on its first flight on March 28, 1910. These experiments were closely followed by the aircraft pioneers Gabriel and Charles Voisin, who purchased several of the Fabre floats and fitted them to their Canard Voisin airplane. In October 1910, the Canard Voisin became the first seaplane to fly over the river Seine, and in March 1912, the first seaplane to be used militarily from a seaplane carrier, *La Foudre* ('the lightning').

First performances steps under World War I (1914–1918)



German Taube monoplane, illustration from 1917

Almost as soon as they were invented, planes were drafted for military service. The first country to use planes for military purposes was Italy, whose planes made reconnaissance, bombing and shelling correction military flights during the Italian-Turkish war (September 1911 – October 1912), in Libya. First mission (a reconnaissance) happened on the 23rd October 1911. First bombing of enemy columns was the 1st November 1911. Then Bulgaria followed this example. Its planes attacked and reconnoitered the Ottoman positions during the First Balkan War 1912–13. The first war to see major use of planes in offensive, defensive and reconnaissance capabilities was World War I. The Allies and Central Powers both used planes extensively.

While the concept of using the aeroplane as a weapon of war was generally laughed at before World War I, the idea of using it for photography was one that was not lost on any of the major forces. All of the major forces in Europe had light aircraft, typically derived from pre-war sporting designs, attached to their reconnaissance departments. Radiotelephones were also being explored on airplanes, notably the SCR-68, as communication between pilots and ground commander grew more and more important

Combat schemes

It was not long before aircraft were shooting at each other, but the lack of any sort of steady point for the gun was a problem. The French solved this problem when, in late 1914, Roland Garros attached a fixed machine gun to the front of his plane, but while Adolphe Pegoud would become known as the first "ace", getting credit for five victories, before also becoming the first ace to die in action, it was German Luftstreitkräfte Leutnant Kurt Wintgens, who, on July 1, 1915, scored the very first aerial victory by a purpose-built fighter plane, with a synchronized machine gun.

Aviators were styled as modern day knights, doing individual combat with their enemies. Several pilots became famous for their air to air combats, the most well known is Manfred von Richthofen, better known as the **Red Baron**, who shot down 80 planes in air to air combat with several different planes, the most celebrated of which was the Fokker Dr.I. On the Allied side, René Paul Fonck is credited with the most all-time victories at 75, even when later wars are considered.

Because all of the litigations and patent wars fought by the Wright brothers the development of airplanes in USA was hindered and delayed so in WWI practically all pilots, including American pilots, had to use airplanes made in Europe.

Technology and performance advances in aviation's "Golden Age" (1918–1939)

The years between World War I and World War II saw great advancements in aircraft technology. Aeroplanes evolved from low-powered biplanes made from wood and fabric to sleek, high-powered monoplanes made of aluminum, based primarily on the founding work of Hugo Junkers during the World War I period. The age of the great airships came and went.

Flagg biplane from 1933.

After WWI experienced fighter pilots were eager to show off their new skills. Many American pilots became barnstormers, flying into small towns across the country and showing off their flying abilities, as well as taking paying passengers for rides. Eventually the barnstormers grouped into more organized displays. Air shows sprang up around the country, with air races, acrobatic stunts, and feats of air superiority. The air races drove engine and airframe development—the Schneider Trophy, for example, led to a series of ever faster and sleeker monoplane designs culminating in the Supermarine S.6B, a direct forerunner of the Spitfire. With pilots competing for cash prizes, there was an incentive to go faster. Amelia Earhart was perhaps the most famous of those on the barnstorming/air show circuit. She was also the first female pilot to achieve records such as crossing of the Atlantic and Pacific Oceans.

Qantas De Havilland biplane, ca. 1930

Other prizes, for distance and speed records, also drove development forwards. For example on June 14, 1919, Captain John Alcock and Lieutenant Arthur Brown co-piloted a Vickers Vimy non-stop from St. John's, Newfoundland to Clifden, Ireland, winning the £13,000 ($65,000) Northcliffe prize. Eight years later Charles Lindbergh took the Orteig Prize of $25,000 for the first *solo* non-stop crossing of the Atlantic.

Australian Charles Kingsford Smith was the first to fly across the larger Pacific Ocean in the Southern Cross. His crew left Oakland, California to make the first trans-Pacific flight to Australia in three stages. The first (from Oakland to Hawaii) was 2,400 miles, took 27 hours 25 minutes and was uneventful. They then flew to Suva, Fiji 3,100 miles away, taking 34 hours 30 minutes. This was the toughest part of the journey as they flew through a massive lightning storm near the equator. They then flew on to Brisbane in 20 hours, where they landed on 9 June 1928 after approximately 7,400 miles total flight. On arrival, Kingsford Smith was met by a huge crowd of 25,000 at Eagle Farm Airport in his hometown of Brisbane. Accompanying him were Australian aviator Charles Ulm as the relief pilot, and the Americans James Warner and Captain Harry Lyon (who were the radio operator, navigator and engineer). With Ulm, Kingsford Smith later continued his journey being the first in 1929 to circumnavigate the world, crossing the equator twice.

The first lighter-than-air crossings of the Atlantic were made by airship in July 1919 by His Majesty's Airship R34 and crew when they flew from East Lothian, Scotland to Long Island, New York and then back to Pulham, England. By 1929, airship technology had advanced to the point that the first round-the-world flight was completed by the *Graf Zeppelin* in September and in October, the same aircraft inaugurated the first commercial transatlantic service. However the age of the dirigible ended following the destruction by fire of the zeppelin *Hindenburg* just before landing at Lakehurst, New Jersey on May 6, 1937, killing 35 of the 97 people aboard. Previous spectacular airship accidents, from the *Wingfoot Express* disaster (1919) to the loss of the *Akron* (1933) and the *Macon* (1935) had already cast doubt on airship safety; following the destruction of the Hindenburg, the remaining airship making international flights, the *Graf Zeppelin* was retired (June 1937); its replacement, the dirigible *Graf Zeppelin II*, made a number of flights, primarily over Germany, from 1938 to 1939, but was grounded when Germany began World War II. Both remaining German zeppelins were scrapped in 1940 to supply metal for the German Luftwaffe; the last American zeppelin, the *Los Angeles*, which had not flown since 1932, was dismantled in late 1939.

Meanwhile in Germany, who was restricted by the Treaty of Versailles in its development of powered aircraft, instead developed gliding as a sport, especially at the Wasserkuppe, during the 1920s. In its various forms, this activity now has over 400,000 participants.

In 1929 Jimmy Doolittle developed instrument flight.

1929 also saw the first flight of by far the largest plane ever built until then: the Dornier Do X with a wing span of 48 m. On its 70th test flight on October 21 there were 169 people on board, a record that was not broken for 20 years.

In the 1930s development of the jet engine began in Germany and in England. In England Frank Whittle patented a design for a jet engine in 1930 and towards the end of the decade began developing an engine. In Germany Hans von Ohain patented his version of a jet engine in 1936 and began developing a similar engine. The two men were unaware of the other's work, and both Germany and Britain would go on to develop jet aircraft by the end of World War II.

Progress goes on and massive production, World War II (1939–1945)

World War II saw a drastic increase in the pace of aircraft development and production. All countries involved in the war stepped up development and production of aircraft and flight based weapon delivery systems, such as the first long range bomber. Also air combat tactics and doctrines changed, large scale strategic bombing campaigns were launched, Fighter escorts introduced and the more flexible aircraft and weapons allowed more precise attacks on small targets for effective ground support. New technologies like radar also allowed more coordinated and controlled deployment of fighter aircraft.

Me 262, world first operational jet fighter

The **first functional jetplane** was the Heinkel He 178 (Germany), flown by Erich Warsitz in 1939, followed by the worlds first operational fighter aircraft, the Me 262, in July 1942 and worlds first jet powered bomber, the Arado Ar 234, in June 1943. British developments, like the Gloster Meteor, followed afterwards, but saw only brief use in World War II. The first cruise missile (V-1), the first ballistic missile (V-2), the first (and to date only) operational rocket powered combat aircraft Me 163 and the first vertical take-off manned point-defense interceptor Bachem Ba 349 were also developed by Germany. However, jet fighters had only limited impact due to their late introduction, fuel shortages, the lack of experienced pilots and the declining war industry of Germany.

But not only airplanes, helicopters too saw rapid development in the Second World War. With the introduction of the Focke Achgelis Fa 223, the Flettner Fl 282 in 1941 in Germany and the Sikorsky R-4 1942 in the USA, the first time larger helicopter formations were produced and deployed.

1945–1991: The Cold War

D.H. Comet, the world's first jet airliner. As in this picture, it also saw RAF service

A 1945 newsreel covering various firsts in human flight

After World War II, commercial aviation grew rapidly, used mostly ex-military aircraft to transport people and cargo. This growth was accelerated by the glut of heavy and super-heavy bomber airframes like the B-29 and Lancaster that could be converted into commercial aircraft. The DC-3 also made for easier and longer commercial flights. The first commercial jet airliner to fly was the British De Havilland Comet. By 1952, the British state airline BOAC had introduced the De Havilland Comet into scheduled service. While a technical achievement, the plane suffered a series of highly public failures, as the shape of the windows led to cracks due to metal fatigue. The fatigue was caused by cycles of pressurization and depressurization of the cabin, and eventually led to catastrophic failure of the plane's fuselage. By the time the problems were overcome, other jet airliner designs had already taken to the skies.

USSR's Aeroflot became the first airline in the world to operate sustained regular jet services on September 15, 1956 with the Tupolev Tu-104. Boeing 707, which established new levels of comfort, safety and passenger expectations, ushered in the age of mass commercial air travel, dubbed the Jet Age.

In October 1947 Chuck Yeager took the rocket powered Bell X-1 past the speed of sound. Although anecdotal evidence exists that some fighter pilots may have done so while divebombing ground targets during the war, this was the first controlled, level flight to cross the sound barrier. Further barriers of distance fell in 1948 and 1952 with the first jet crossing of the Atlantic and the first nonstop flight to Australia.

When the Soviet Union developed long-range bombers that could deliver nuclear weapons to North America and Europe, Western countries responded with interceptor aircraft that could engage and destroy the bombers before they reached their destination. The "minister-of-everything" C.D. Howe in the Canadian government, was the key proponent of the Avro Arrow, designed as a high-speed interceptor, reputedly the fastest aircraft in its time. However, by 1955, most Western countries agreed that the interceptor age was replaced by guided missile age. Consequently, the Avro Arrow project was eventually cancelled in 1959 under Prime Minister John Diefenbaker.

In 1961, the sky was no longer the limit for manned flight, as Yuri Gagarin orbited once around the planet within 108 minutes, and then used the descent module of Vostok I to safely reenter the atmosphere and reduce speed from Mach 25 using friction and converting velocity into heat. This action further heated up the space race that had started in 1957 with the launch of Sputnik 1 by the Soviet Union. The United States responded by launching Alan Shepard into space on a suborbital flight in a Mercury space capsule. With the launch of the Alouette I in 1963, Canada became the third country to send a satellite in space. The Space race between the United States and the Soviet Union would ultimately lead to the landing of men on the moon in 1969.

In 1967, the X-15 set the air speed record for an aircraft at 4,534 mph (7,297 km/h) or Mach 6.1 (7,297 km/h). Aside from vehicles designed to fly in outer space, this record was renewed by X-43 in the 21st century.

Apollo 11 lifts off on its mission to land a man on the moon

The Harrier Jump Jet, often referred to as just "Harrier" or "the Jump Jet", is a British designed military jet aircraft capable of Vertical/Short Takeoff and Landing (V/STOL) via thrust vectoring. It first flew in 1969. The same year that Neil Armstrong and Buzz Aldrin set foot on the moon, and Boeing unveiled the Boeing 747 and the Aérospatiale-BAC Concorde supersonic passenger airliner had its maiden flight. The 747 plane was the largest aircraft ever to fly, and still carries millions of passengers each year, though it has been superseded by the Airbus A380, which is capable of carrying up to 853 passengers. In 1975 Aeroflot started regular service on the Tu-144—the first supersonic passenger plane. In 1976 British Airways began supersonic service across the Atlantic, with Concorde. A few years earlier the SR-71 Blackbird had set the record for crossing the Atlantic in under 2 hours, and Concorde followed in its footsteps.

The last quarter of the 20th century saw a slowing of the pace of advancement. No longer was revolutionary progress made in flight speeds, distances and technology. This part of the century saw the steady improvement of flight avionics, and a few minor milestones in flight progress.

For example, in 1979 the Gossamer Albatross became the first human powered aircraft to cross the English channel. This achievement finally saw the realization of centuries of dreams of human flight. In 1981, the Space Shuttle made its first orbital flight, proving that a large rocket ship can take off into space, provide a pressurised life support system for several days, reenter the atmosphere at orbital speed, precision glide to a runway and land like a plane.

In 1986 Dick Rutan and Jeana Yeager flew an aircraft, the Rutan Voyager, around the world unrefuelled, and without landing. In 1999 Bertrand Piccard became the first person to circle the earth in a balloon. Focus was turning to the ultimate conquest of space and flight at faster than the speed of sound. The ANSARI X PRIZE inspired entrepreneurs and space enthusiasts to build their own rocket ships to fly faster than sound and climb into the lower reaches of space.

2001–present

Concorde, *G-BOAB*, in storage at London Heathrow Airport following the end of all Concorde flying. This aircraft flew for 22,296 hours between its first flight in 1976 and final flight in 2000.

In commercial aviation, the early 21st century saw the end of an era with the retirement of Concorde. Supersonic flight was not commercially viable, as the planes were required to fly over the oceans if they wanted to break the sound barrier. Concorde also was fuel hungry and could carry a limited amount of passengers due to its highly streamlined design. Nevertherless, it seems to have made a significant operating profit for British Airways.

In the beginning of the 21st century, subsonic military aviation focused on eliminating the pilot in favor of remotely operated or completely autonomous vehicles. Several unmanned aerial vehicles or UAVs have been developed. In April 2001 the unmanned aircraft Global Hawk flew from Edwards AFB in the US to Australia non-stop and unrefuelled. This is the longest point-to-point flight ever undertaken by an unmanned aircraft, and took 23 hours and 23 minutes. In October 2003 the first totally autonomous flight across the Atlantic by a computer-controlled model aircraft occurred.

The *U.S. Centennial of Flight Commission* was established in 1999 to encourage the broadest national and international participation in the celebration of 100 years of powered flight. It publicized and encouraged a number of programs, projects and events intended to educate people about the history of aviation.

Major disruptions to air travel in the 21st Century included the closing of U.S. airspace due to the September 11 attacks, and the closing of northern European airspace after the 2010 eruption of Eyjafjallajökull.

Chapter-2

Airline and Civil Aviation

Airline

A FedEx Express McDonnell Douglas MD-11. FedEx Express is the world's largest cargo airline in terms of number of aircraft and in terms of freight tons flown.

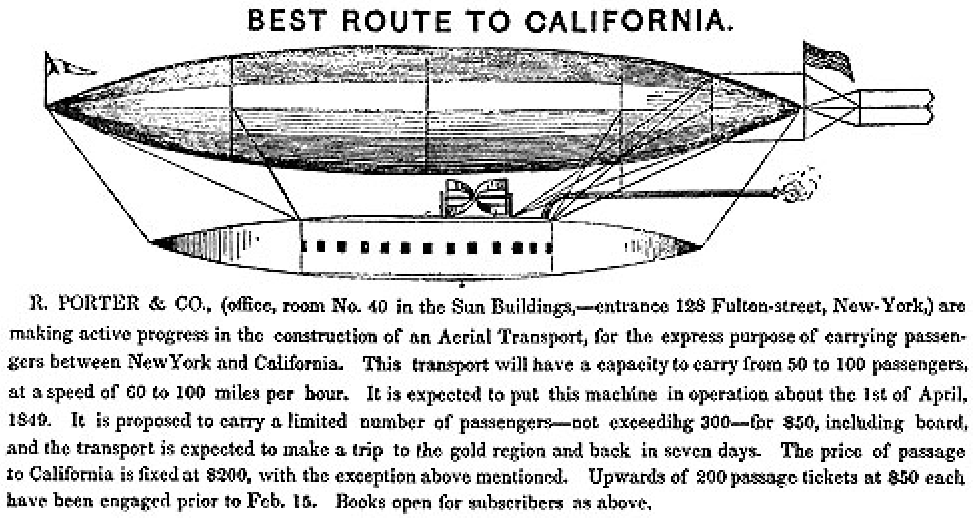
Ryanair Boeing 737-800 shortly after take-off. Ryanair is the world's largest airline in terms of number of international passengers carried.

An **airline** provides air transport services for passengers or freight, generally these companies with a recognized operating certificate or license. Airlines lease or own their aircraft with which to supply these services and may form partnerships or alliances with other airlines for mutual benefit.

Airlines vary from those with a single aircraft carrying mail or cargo, through full-service international airlines operating hundreds of aircraft. Airline services can be categorized as being intercontinental, intra continental, domestic, or international and may be operated as scheduled services or charters.

History

The first airlines



Failed attempt at an airline before DELAG

DELAG, *Deutsche Luftschiffahrts-Aktiengesellschaft* was the world's first airline. It was founded on November 16, 1909 with government assistance, and operated airships manufactured by The Zeppelin Corporation. Its headquarters were in Frankfurt. (Note: Americans, such as Rufus Porter and Frederick Marriott, attempted to start airlines using airships in the mid-19th century, focusing on the New York–California route. Those attempts floundered due to such mishaps as the aircraft catching fire and the aircraft being ripped apart by spectators.) The five oldest non-dirigible airlines that still exist are Netherlands' KLM, Colombia's Avianca, Australia's Qantas, Czech Republic's Czech Airlines, and Mexico's Mexicana. KLM first flew in May 1920, while Qantas (which stands for *Queensland and Northern Territory Aerial Services Limited*) was founded in Queensland, Australia, in late 1920.

U.S. airline industry

Early development

TWA Douglas DC-3 in 1940. The DC-3, often regarded as one of the most influential aircraft in the history of commercial aviation, revolutionized the aviation industry.

Tony Jannus conducted the United State's first scheduled commercial airline flight on 1 January 1914 for the St. Petersburg-Tampa Airboat Line. The 23-minute flight traveled between St. Petersburg, Florida and Tampa, Florida, passing some 50 feet (15 m) above Tampa Bay in Jannus' Benoist XIV biplane flying boat. Chalk's Airlines (now Chalk's International Airlines) began service between Miami and Bimini in the Bahamas in February 1919. Now based in Ft. Lauderdale, Chalk's claims to be the oldest continuously operating airline in the United States.

Following World War I, the United States found itself swamped with aviators. Many decided to take their war-surplus aircraft on barnstorming campaigns, performing acrobatic maneuvers to woo crowds. In 1918, the United States Postal Service won the financial backing of Congress to begin experimenting with air mail service, initially using Curtiss Jenny aircraft that had been procured by the United States Army for reconnaissance missions on the Western Front. Private operators were the first to fly the mail but due to numerous accidents the US Army was tasked with mail delivery. During the course of the Army's involvement they proved to be too unreliable and lost their air mail duties. By the mid-1920s, the Postal Service had developed its own air mail network, based on a transcontinental backbone between New York and San Francisco. To supplant this service, they offered twelve contracts for spur routes to independent bidders. Some of the carriers that won these routes would, through time and mergers, evolve into Pan Am, Delta Air Lines, Braniff Airways, American Airlines, United Airlines (originally a division of Boeing), Trans World Airlines, Northwest Airlines, and Eastern Air Lines.

Service during the early 1920s was sporadic: most airlines at the time were focused on carrying bags of mail. In 1925, however, the Ford Motor Company bought out the Stout Aircraft Company and began construction of the all-metal Ford Trimotor, which became the first successful American airliner. With a 12-passenger capacity, the Trimotor made passenger service potentially profitable. Air service was seen as a supplement to rail service in the American transportation network.

At the same time, Juan Trippe began a crusade to create an air network that would link America to the world, and he achieved this goal through his airline, Pan American World Airways, with a fleet of flying boats that linked Los Angeles to Shanghai and Boston to London. Pan Am and Northwest Airways (which began flights to Canada in the 1920s) were the only U.S. airlines to go international before the 1940s.

With the introduction of the Boeing 247 and Douglas DC-3 in the 1930s, the U.S. airline industry was generally profitable, even during the Great Depression. This trend continued until the beginning of World War II.

Development since 1945

In October 1945, the American Export Airlines became the first airline to offer regular commercial flights between North America and Europe. Shown here is Am Ex Boeing 377 *Stratocruiser* in 1949.

As governments met to set the standards and scope for an emergent civil air industry toward the end of the war, the U.S. took a position of maximum operating freedom; U.S. airline companies were not as hard-hit as European and the few Asian ones had been. This preference for "open skies" operating regimes continues, within limitations, to this day.

World War II, like World War I, brought new life to the airline industry. Many airlines in the Allied countries were flush from lease contracts to the military, and foresaw a future explosive demand for civil air transport, for both passengers and cargo. They were eager to invest in the newly emerging flagships of air travel such as the Boeing Stratocruiser, Lockheed Constellation, and Douglas DC-6. Most of these new aircraft were based on American bombers such as the B-29, which had spearheaded research into new technologies such as pressurization. Most offered increased efficiency from both added speed and greater payload.

In the 1950s, the De Havilland Comet, Boeing 707, Douglas DC-8, and Sud Aviation Caravelle became the first flagships of the Jet Age in the West, while the Soviet Union bloc had Tupolev Tu-104 and Tupolev Tu-124 in the fleets of state-owned carriers such as Czechoslovak ČSA, Soviet Aeroflot and East-German Interflug. The Vickers Viscount and Lockheed L-188 Electra inaugurated turboprop transport.

The next big boost for the airlines would come in the 1970s, when the Boeing 747, McDonnell Douglas DC-10, and Lockheed L-1011 inaugurated widebody ("jumbo jet") service, which is still the standard in international travel. The Tupolev Tu-144 and its Western counterpart, Concorde, made supersonic travel a reality. Concorde first flew in 1969 and operated through 2003. In 1972, Airbus began producing Europe's most commercially successful line of airliners to date. The added efficiencies for these aircraft were often not in speed, but in passenger capacity, payload, and range. Airbus also features modern electronic cockpits that were common across their aircraft to enable pilots to fly multiple models with minimal cross-training.

Pan Am Boeing 747 *Clipper Neptune's Car* in 1985. The deregulation of the American airline industry increased the financial troubles of the iconic airline which ultimately filed for bankruptcy in December 1991.

1978's U.S. airline industry deregulation lowered barriers for new airlines just as a downturn occurred. New start-ups entered during the downturn, during which time they found aircraft and funding, contracted hangar and maintenance services, trained new employees, and recruited laid off staff from other airlines.

As the business cycle returned to normalcy, major airlines dominated their routes through aggressive pricing and additional capacity offerings, often swamping new startups. Only America West Airlines (which has since merged with US Airways) remained a significant survivor from this new entrant era, as dozens, even hundreds, have gone under.

In many ways, the biggest winner in the deregulated environment was the air passenger. Indeed, the U.S. witnessed an explosive growth in demand for air travel, as many millions who had never or rarely flown before became regular fliers, even joining frequent flyer loyalty programs and receiving free flights and other benefits from their flying. New services and higher frequencies meant that business fliers could fly to another city, do business, and return the same day, for almost any point in the country. Air travel's advantages put intercity bus lines under pressure, and most have withered away.

By the 1980s, almost half of the total flying in the world took place in the U.S., and today the domestic industry operates over 10,000 daily departures nationwide.

Toward the end of the century, a new style of low cost airline emerged, offering a no-frills product at a lower price. Southwest Airlines, JetBlue, AirTran Airways, Skybus Airlines and other low-cost carriers began to represent a serious challenge to the so-called "legacy airlines", as did their low-cost counterparts in many other countries. Their commercial viability represented a serious competitive threat to the legacy carriers. However, of these, ATA and Skybus have since ceased operations.

Increasingly since 1978, US airlines have been reincorporated and spun off by newly created and interally led manangement companies, and thus becoming nothing more than operating units and subsidiaries with limited finanically decisive control. Among some of these holding companies and parent companies that are the relatively well known, are the UAL Corporation, along with the AMR Corporation, among a long list of airline holding companies sometime recognized world wide. Less recognized are the private equity firms which often seize managerial, financial, and board of directors control of distressed airline companies by temporarily investing large sums of capital in air carriers, so as to rescheme an airlines assets into a profitable organization or liquidating an air carrier of their profitable and worthwhile routes and business operations.

Thus the last 50 years of the airline industry have varied from reasonably profitable, to devastatingly depressed. As the first major market to deregulate the industry in 1978, U.S. airlines have experienced more turbulence than almost any other country or region. Today, American Airlines is the only U.S. legacy carrier to survive bankruptcy-free.

The Airline "Bailout"

Congress passed the Air Transportation Safety and System Stabilization Act (P.L. 107-42) in response to a severe liquidity crisis facing the industry in the aftermath of the September 11th terrorist attacks. Congress sought to compensate carriers for both the cost of the four-day federal shutdown of the airlines and the incremental losses incurred through December 31, 2001 as a result of the terrorist attacks. Congress expressly sought to preserve a viable, safe, and efficient air transportation system.

In recognition of the essential national economic role of a healthy aviation system, Congress authorized partial compensation of up to $5 billion in cash subject to review by the Department of Transportation and up to $10 billion in loan guarantees subject to review by a newly created Air Transportation Stabilization Board (ATSB). The applications to DOT for reimbursements were subjected to rigorous multi-year reviews not only by DOT program personnel but also by the Government Accountability Office and the DOT Inspector General.

Ultimately, the federal government provided $4.6 billion in one-time, subject-to-income-tax cash reimbursements to 427 U.S. air carriers, including numerous charter and cargo carriers. (Passenger carriers operating scheduled service received approximately $4 billion, subject to tax.) In addition, the ATSB approved loan guarantees to six airlines totaling approximately $1.6 billion. Data from the Treasury Department show that taxpayers eventually recouped the $1.6 billion and a profit of $339 million from the fees, interest and stock associated with loan guarantees.

European airline industry

The Imperial Airways Empire Terminal, Victoria, London. Trains ran from here to flying boats in Southampton, and to Croydon Airport.

The first countries in Europe to embrace air transport were Belgium, Finland, France, Germany, the Netherlands and the United Kingdom. KLM, the oldest carrier still operating under its original name, was founded in 1919. The first flight (operated on behalf of KLM by Aircraft Transport and Travel) transported two English passengers to

Schiphol, Amsterdam from London in 1920. Like other major European airlines of the time, KLM's early growth depended heavily on the needs to service links with far-flung colonial possessions (Dutch Indies). It is only after the loss of the Dutch Empire that KLM found itself based at a small country with few potential passengers, depending heavily on transfer traffic, and was one of the first to introduce the hub-system to facilitate easy connections.

France began an air mail service to Morocco in 1919 that was bought out in 1927, renamed Aéropostale, and injected with capital to become a major international carrier. In 1933, Aéropostale went bankrupt, was nationalized and merged with several other airlines into what became Air France.

In Finland, the charter establishing Aero O/Y (now Finnair) was signed in the city of Helsinki on September 12, 1923. Junkers F 13 D-335 became the first aircraft of the company, when Aero took delivery of it on March 14, 1924. The first flight was between Helsinki and Tallinn, capital of Estonia, and it took place on March 20, 1924, one week later.

Germany's Lufthansa began in 1926. Lufthansa, unlike most other airlines at the time, became a major investor in airlines outside of Europe, providing capital to Varig and Avianca. German airliners built by Junkers, Dornier, and Fokker were the most advanced in the world at the time. In 1931, the airship Graf Zeppelin began offering regular scheduled passenger service between Germany and South America, usually every two weeks, which continued until 1937. In 1936, the airship Hindenburg entered passenger service and successfully crossed the Atlantic 36 times before crashing at Lakehurst, New Jersey on May 6, 1937.

The British company Aircraft Transport and Travel commenced a London to Paris service on August 25, 1919, this was the world's first regular international flight. The United Kingdom's flag carrier during this period was Imperial Airways, which became BOAC (British Overseas Airways Co.) in 1939. Imperial Airways used huge Handley-Page biplanes for routes between London, the Middle East, and India: images of Imperial aircraft in the middle of the Rub'al Khali, being maintained by Bedouins, are among the most famous pictures from the heyday of the British Empire.

In Soviet Union the Chief Administration of the Civil Air Fleet was established in 1921. One of its first acts was to help found Deutsch-Russische Luftverkehrs A.G. (Deruluft), a German-Russian joint venture to provide air transport from Russia to the West. Domestic air service began around the same time, when Dobrolyot started operations on 15 July 1923 between Moscow and Nizhni Novgorod. Since 1932 all operations had been carried under the name Aeroflot. By the end of the 1930s Aeroflot had become the world's largest airline, employing more than 4,000 pilots and 60,000 other service personnel and operating around 3,000 aircraft (of which 75% were considered obsolete by its own standards). During the Soviet era Aeroflot was synonymous with Russian civil aviation, as it was the only air carrier. It became the first airline in the world to operate sustained regular jet services on 15 September 1956 with the Tupolev Tu-104.

Deregulation

Deregulation of the European Union airspace in the early 1990s has had substantial effect on structure of the industry there. The shift towards 'budget' airlines on shorter routes has been significant. Airlines such as EasyJet and Ryanair have grown at the expense of the traditional national airlines.

There has also been a trend for these national airlines themselves to be privatised such as has occurred for Aer Lingus and British Airways. Other national airlines, including Italy's Alitalia, have suffered - particularly with the rapid increase of oil prices in early 2008.

Asian airline industry

Although Philippine Airlines (PAL) was officially founded on February 26, 1941, its license to operate as an airliner was derived from merged Philippine Aerial Taxi Company (PATCO) established by mining magnate Emmanuel N. Bachrach in December 3, 1930, making it as Asia's oldest scheduled carrier still in operation. Commercial air service commenced three weeks later from Manila to Baguio, making it Asia's first airline route. Bachrach's death in 1937 paved the way for its eventual merger with Philippine Airlines in March 1941 and made it Asia's oldest airline. It is also the oldest airline in Asia still operating under its current name. Bachrach's majority share in PATCO was bought by beer magnate Andres R. Soriano in 1939 upon the advice of General Douglas McArthur and later merged with newly formed Philippine Airlines with PAL as the surviving entity. Soriano has controlling interest in both airlines before the merger. PAL restarted service on March 15, 1941 with a single Beech Model 18 NPC-54 aircraft, which started its daily services between Manila (from Nielson Field) and Baguio, later to expand with larger aircraft such as the DC-3 and Vickers Viscount.

India was also one of the first countries to embrace civil aviation. One of the first West Asian airline companies was Air India, which had its beginning as Tata Airlines in 1932, a division of Tata Sons Ltd. (now Tata Group). The airline was founded by India's leading industrialist, JRD Tata. On October 15, 1932, J. R. D. Tata himself flew a single engined De Havilland Puss Moth carrying air mail (postal mail of Imperial Airways) from Karachi to Mumbai via Ahmedabad. The aircraft continued to Madras via Bellary piloted by Royal Air Force pilot Nevill Vintcent. Tata Airlines was also one of the world's first major airlines which began its operations without any support from the Government.

With the outbreak of World War II, the airline presence in Asia came to a relative halt, with many new flag carriers donating their aircraft for military aid and other uses. Following the end of the war in 1945, regular commercial service was restored in India and Tata Airlines became a public limited company on July 29, 1946 under the name Air India. After the independence of India, 49% of the airline was acquired by the Government of India. In return, the airline was granted status to operate international services from India as the designated flag carrier under the name Air India International.

On July 31, 1946, a chartered Philippine Airlines (PAL) DC-4 ferried 40 American servicemen to Oakland, California from Nielson Airport in Makati City with stops in Guam, Wake Island, Johnston Atoll and Honolulu, Hawaii, making PAL the first Asian airline to cross the Pacific Ocean. A regular service between Manila and San Francisco was started in December. It was during this year that the airline was designated as the flag carrier of Philippines.

During the era of decolonization, newly-born Asian countries started to embrace air transport. Among the first Asian carriers during the era were Cathay Pacific of Hong Kong (founded in September 1946), Orient Airways (later Pakistan International Airlines; founded in October 1946), Malayan Airlines (later Singapore and Malaysia Airlines; founded in 1947), El Al in Israel in 1948, Garuda Indonesia in 1949, Japan Airlines in 1951, and Korean Air in 1962.

Latin American airline industry

TAM Airlines is the largest airline in Latin America in terms of number of annual passengers flown.

Among the first countries to have regular airlines in Latin America were Colombia with Avianca, Brazil with Varig, Chile with LAN Chile (today LAN Airlines), Dominican Republic with Dominicana de Aviación, Mexico with Mexicana de Aviación, and TACA as a brand of several airlines of Central American countries (Honduras, El Salvador, Costa Rica, Guatemala and Nicaragua). All the previous airlines started regular operations before World War II.

The air travel market has evolved rapidly over recent years in Latin America. Some industry estimations over 2000 new aircraft will begin service over the next five years in this region.

These airlines serve domestic flights within their countries, as well as connections within Latin America and also overseas flights to North America, Europe, Australia, Africa and Asia.

Just three airlines: LAN (Latin American Networks), Oceanair and TAM Airlines have international subsidiaries with Chile as the central operation along with Peru, Ecuador, Argentina and some operations in the Dominican Republic and TAM with TAM Mercosur have a base in Asuncion, Paraguay. Avianca have the control of Oceanair, VIP Airlines and also have an estrategic alliance with TACA.

The three main hubs in Latin America are Mexico City in Mexico, São Paulo in Brazil and Santiago in Chile.

Regulatory considerations

National

Pakistan International Airlines Boeing 747-300. The Government of Pakistan is the majority stake-holder in the country's flag carrier.

Garuda Indonesia Boeing 747-400 parked at Narita International Airport. Garuda will replaced its 747s with 777-300ER in late 2010. This Indonesian Flag carrier is wholly owned by the Indonesian Government

Many countries have national airlines that the government owns and operates. Fully private airlines are subject to a great deal of government regulation for economic, political, and safety concerns. For instance, governments often intervene to halt airline labor actions in order to protect the free flow of people, communications, and goods between different regions without compromising safety.

The United States, Australia, and to a lesser extent Brazil, Mexico, the United Kingdom and Japan have "deregulated" their airlines. In the past, these governments dictated airfares, route networks, and other operational requirements for each airline. Since deregulation, airlines have been largely free to negotiate their own operating arrangements with different airports, enter and exit routes easily, and to levy airfares and supply flights according to market demand.

Cyprus Airways national airline of Cyprus

The entry barriers for new airlines are lower in a deregulated market, and so the U.S. has seen hundreds of airlines start up (sometimes for only a brief operating period). This has produced far greater competition than before deregulation in most markets, and average fares tend to drop 20% or more. The added competition, together with pricing freedom, means that new entrants often take market share with highly reduced rates that, to a limited degree, full service airlines must match. This is a major constraint on profitability for established carriers, which tend to have a higher cost base.

As a result, profitability in a deregulated market is uneven for most airlines. These forces have caused some major airlines to go out of business, in addition to most of the poorly established new entrants.

International

Singapore Airlines Airbus A380 lands at Changi Airport. Singapore Airlines was the first international airline to operate the A380, the world's largest passenger airliner.

Groups such as the International Civil Aviation Organization establish worldwide standards for safety and other vital concerns. Most international air traffic is regulated by bilateral agreements between countries, which designate specific carriers to operate on specific routes. The model of such an agreement was the Bermuda Agreement between the US and UK following World War II, which designated airports to be used for transatlantic flights and gave each government the authority to nominate carriers to operate routes.

Bilateral agreements are based on the "freedoms of the air", a group of generalized traffic rights ranging from the freedom to overfly a country to the freedom to provide domestic flights within a country (a very rarely granted right known as cabotage). Most agreements permit airlines to fly from their home country to designated airports in the other country: some also extend the freedom to provide continuing service to a third country, or to another destination in the other country while carrying passengers from overseas.

In the 1990s, "open skies" agreements became more common. These agreements take many of these regulatory powers from state governments and open up international routes to further competition. Open skies agreements have met some criticism, particularly within the European Union, whose airlines would be at a comparative disadvantage with the United States' because of cabotage restrictions.

Economic considerations

Juan Trippe, the founder of Pan American World Airways, surveying his globe. The collapse of Pan Am, an airline often credited for shaping the international airline industry, in December 1991 highlighted the financial complexities faced by major airline companies.

Historically, air travel has survived largely through state support, whether in the form of equity or subsidies. The airline industry as a whole has made a cumulative loss during its 100-year history, once the costs include subsidies for aircraft development and airport construction.

One argument is that positive externalities, such as higher growth due to global mobility, outweigh the microeconomic losses and justify continuing government intervention. A historically high level of government intervention in the airline industry can be seen as part of a wider political consensus on strategic forms of transport, such as highways and railways, both of which receive public funding in most parts of the world. Profitability is likely to improve in the future as privatization continues and more competitive low-cost carriers proliferate.

Although many countries continue to operate state-owned or parastatal airlines, many large airlines today are privately owned and are therefore governed by microeconomic principles in order to maximize shareholder profit.

Ticket revenue

Airlines assign prices to their services in an attempt to maximize profitability. The pricing of airline tickets has become increasingly complicated over the years and is now largely determined by computerized yield management systems.

Because of the complications in scheduling flights and maintaining profitability, airlines have many loopholes that can be used by the knowledgeable traveler. Many of these airfare secrets are becoming more and more known to the general public, so airlines are forced to make constant adjustments.

Most airlines use differentiated pricing, a form of price discrimination, in order to sell air services at varying prices simultaneously to different segments. Factors influencing the price include the days remaining until departure, the booked load factor, the forecast of total demand by price point, competitive pricing in force, and variations by day of week of departure and by time of day. Carriers often accomplish this by dividing each cabin of the aircraft (first, business and economy) into a number of travel classes for pricing purposes.

A complicating factor is that of origin-destination control ("O&D control"). Someone purchasing a ticket from Melbourne to Sydney (as an example) for AU$200 is competing with someone else who wants to fly Melbourne to Los Angeles through Sydney on the same flight, and who is willing to pay AU$1400. Should the airline prefer the $1400 passenger, or the $200 passenger plus a possible Sydney-Los Angeles passenger willing to pay $1300? Airlines have to make hundreds of thousands of similar pricing decisions daily.

Lufthansa Boeing 747-400.

The advent of advanced computerized reservations systems in the late 1970s, most notably Sabre, allowed airlines to easily perform cost-benefit analyses on different pricing structures, leading to almost perfect price discrimination in some cases (that is, filling each seat on an aircraft at the highest price that can be charged without driving the consumer elsewhere).

The intense nature of airfare pricing has led to the term "fare war" to describe efforts by airlines to undercut other airlines on competitive routes. Through computers, new airfares can be published quickly and efficiently to the airlines' sales channels. For this purpose the airlines use the Airline Tariff Publishing Company (ATPCO), who distribute latest fares for more than 500 airlines to Computer Reservation Systems across the world.

The extent of these pricing phenomena is strongest in "legacy" carriers. In contrast, low fare carriers usually offer preannounced and simplified price structure, and sometimes quote prices for each leg of a trip separately.

Computers also allow airlines to predict, with some accuracy, how many passengers will actually fly after making a reservation to fly. This allows airlines to overbook their flights enough to fill the aircraft while accounting for "no-shows," but not enough (in most cases) to force paying passengers off the aircraft for lack of seats. Since an average of ⅓ of all seats are flown empty, stimulative pricing for low demand flights coupled with overbooking on high demand flights can help reduce this figure. This is especially crucial during tough economic times as airlines undertake massive cuts to ticket prices in order to retain demand.

Operating costs

An Airbus A340-600 of Virgin Atlantic Airways. In October 2008, Virgin Atlantic offered to combine its operations with BMI in an effort to reduce operating costs.

Full-service airlines have a high level of fixed and operating costs in order to establish and maintain air services: labor, fuel, airplanes, engines, spares and parts, IT services and networks, airport equipment, airport handling services, sales distribution, catering, training, aviation insurance and other costs. Thus all but a small percentage of the income from ticket sales is paid out to a wide variety of external providers or internal cost centers.

Moreover, the industry is structured so that airlines often act as tax collectors. Airline fuel is untaxed because of a series of treaties existing between countries. Ticket prices include a number of fees, taxes and surcharges beyond the control of airlines. Airlines are also responsible for enforcing government regulations. If airlines carry passengers without proper documentation on an international flight, they are responsible for returning them back to the original country.

Analysis of the 1992–1996 period shows that every player in the air transport chain is far more profitable than the airlines, who collect and pass through fees and revenues to them from ticket sales. While airlines as a whole earned 6% return on capital employed (2-

3.5% less than the cost of capital), airports earned 10%, catering companies 10-13%, handling companies 11-14%, aircraft lessors 15%, aircraft manufacturers 16%, and global distribution companies more than 30%. (Source: Spinetta, 2000, quoted in Doganis, 2002)

In contrast, Southwest Airlines has been the most profitable of airline companies since 1973.

The widespread entrance of a new breed of low cost airlines beginning at the turn of the century has accelerated the demand that full service carriers control costs. Many of these low cost companies emulate Southwest Airlines in various respects, and like Southwest, they are able to eke out a consistent profit throughout all phases of the business cycle.

As a result, a shakeout of airlines is occurring in the U.S. and elsewhere. United Airlines, Continental Airlines (twice), US Airways (twice), Delta Air Lines, and Northwest Airlines have all declared Chapter 11 bankruptcy. Some argue that it would be far better for the industry as a whole if a wave of actual closures were to reduce the number of "undead" airlines competing with healthy airlines while being artificially protected from creditors via bankruptcy law. On the other hand, some have pointed out that the reduction in capacity would be short lived given that there would be large quantities of relatively new aircraft that bankruptcies would want to get rid of and would re-enter the market either as increased fleets for the survivors or the basis of cheap planes for new startups.

Where an airline has established an engineering base at an airport then there may be considerable economic advantages in using that same airport as a preferred focus (or "hub") for its scheduled flights.

Assets and financing

The 'Golden Lounge' of Malaysia Airlines at Kuala Lumpur International Airport (KLIA). The airline has ownership of special slots at KLIA giving it a competitive edge over other airlines operating at the airport.

Airline financing is quite complex, since airlines are highly leveraged operations. Not only must they purchase (or lease) new airliner bodies and engines regularly, they must make major long-term fleet decisions with the goal of meeting the demands of their markets while producing a fleet that is relatively economical to operate and maintain. Compare Southwest Airlines and their reliance on a single airplane type (the Boeing 737 and derivatives), with the now defunct Eastern Air Lines which operated 17 different aircraft types, each with varying pilot, engine, maintenance, and support needs.

A second financial issue is that of hedging oil and fuel purchases, which are usually second only to labor in its relative cost to the company. However, with the current high fuel prices it has become the largest cost to an airline. While hedging instruments can be expensive, they can easily pay for themselves many times over in periods of increasing fuel costs, such as in the 2000–2005 period.

In view of the congestion apparent at many international airports, the ownership of slots at certain airports (the right to take-off or land an aircraft at a particular time of day or night) has become a significant tradable asset for many airlines. Clearly take-off slots at popular times of the day can be critical in attracting the more profitable business traveler to a given airline's flight and in establishing a competitive advantage against a competing airline. If a particular city has two or more airports, market forces will tend to attract the less profitable routes, or those on which competition is weakest, to the less congested airport, where slots are likely to be more available and therefore cheaper. Other factors, such as surface transport facilities and onward connections, will also affect the relative appeal of different airports and some long distance flights may need to operate from the one with the longest runway.

Airline partnerships

A Japan Airlines Boeing 777-300 with special Oneworld livery. Oneworld is the third largest airline alliance after Star Alliance and SkyTeam.

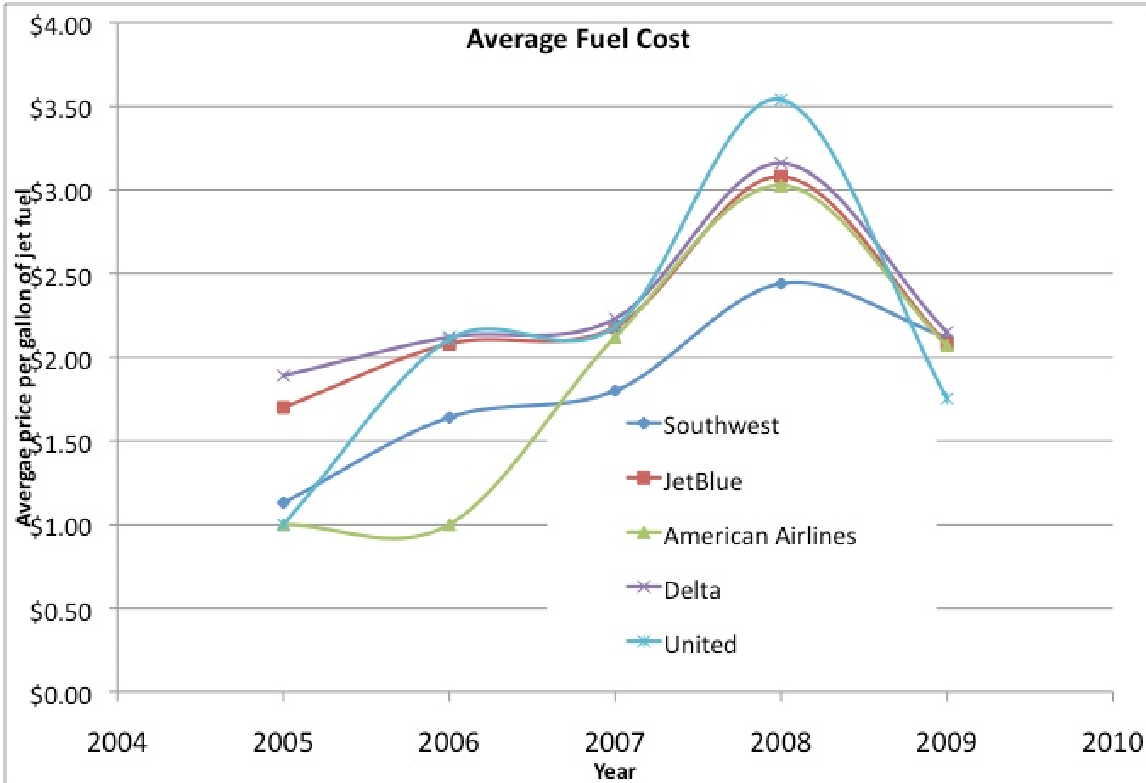
Code sharing is the most common type of airline partnership; it involves one airline selling tickets for another airline's flights under its own airline code. An early example of this was Japan Airlines' code sharing partnership with Aeroflot in the 1960s on flights from Tokyo to Moscow: Aeroflot operated the flights using Aeroflot aircraft, but JAL sold tickets for the flights as if they were JAL flights. This practice allows airlines to expand their operations, at least on paper, into parts of the world where they cannot afford to establish bases or purchase aircraft. Another example was the Austrian- Sabena partnership on the Vienna-Brussels-New York JFK route during the late '60s, using a Sabena Boeing 707 with Austrian colors.

Since airline reservation requests are often made by city-pair (such as "show me flights from Chicago to Düsseldorf"), an airline who is able to code share with another airline for a variety of routes might be able to be listed as indeed offering a Chicago-Düsseldorf flight. The passenger is advised however, that Airline 1 operates the flight from say Chicago to Amsterdam, and Airline 2 operates the continuing flight (on a different airplane, sometimes from another terminal) to Düsseldorf. Thus the primary rationale for code sharing is to expand one's service offerings in city-pair terms so as to increase sales.

A more recent development is the airline alliance, which became prevalent in the 1990s. These alliances can act as virtual mergers to get around government restrictions. Groups of airlines such as the Star Alliance, Oneworld, and SkyTeam coordinate their passenger service programs (such as lounges and frequent flyer programs), offer special interline tickets, and often engage in extensive codesharing (sometimes systemwide). These are increasingly integrated business combinations—sometimes including cross-equity arrangements—in which products, service standards, schedules, and airport facilities are standardized and combined for higher efficiency. One of the first airlines to start an alliance with another airline was KLM, who partnered with Northwest Airlines. Both airlines later entered the SkyTeam alliance after the fusion of KLM and Air France in 2004.

Often the companies combine IT operations, buy fuel, or purchase airplanes as a bloc in order to achieve higher bargaining power. However, the alliances have been most successful at purchasing invisible supplies and services, such as fuel. Airlines usually prefer to purchase items visible to their passengers to differentiate themselves from local competitors. If an airline's main domestic competitor flies Boeing airliners, then the airline may prefer to use Airbus aircraft regardless of what the rest of the alliance chooses.

Fuel hedging

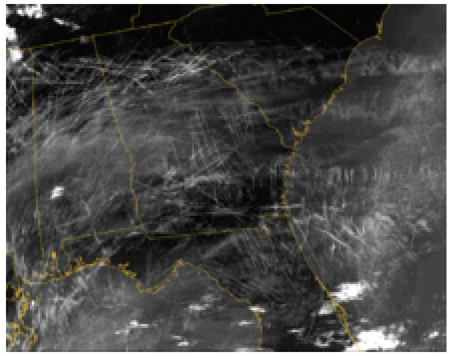


Average jet fuel prices per gallon for major United States airlines.

Southwest was one credited with maintaining strong business profits between 1999 and the early 2000's due to its fuel hedging policy. Looking at the annual reports many other airlines are replicating Southwest's hedging policy to control their fuel costs.

Average fuel cost per gallon	2005	2006	2007	2008	2009
Southwest Airlines	$1.13	$1.64	$1.80	$2.44	$2.12
JetBlue Airlines	$1.70	$2.08	$2.18	$3.08	$2.08
American Airlines			$2.12	$3.03	$2.07
Delta Air Lines	$1.89	$2.12	$2.23	$3.16	$2.15
United Airlines		$2.11	$2.18	$3.54	$1.75

Environmental impacts



MODIS tracking of contrails generated by air traffic over the southeastern United States on January 29, 2004.

Aircraft engines emit noise pollution, gases and particulate emissions, and contribute to global warming and global dimming.

Modern turbofan and turboprop engines are considerably more fuel-efficient and less polluting than earlier models. However, despite this, the rapid growth of air travel in recent years contributes to an increase in total pollution attributable to aviation, offsetting some of the reductions achieved by automobiles. In the EU greenhouse gas emissions from aviation increased by 87% between 1990 and 2006.

CO2 emissions from the jet fuel burned per passenger on an average 3200 kilometers (1992 miles) airline flight is about 353 kilograms (776 pounds). Loss of natural habitat potential associated with the jet fuel burned per passenger on a 3200 kilometers (1992 miles) airline flight is estimated to be 250 square meters (2700 square feet).

In the context of purported climate change and peak oil, there is a debate about possible taxation of air travel and the inclusion of aviation in an emissions trading scheme, with a view to ensuring that the total external costs of aviation are taken into account.

The airline industry is responsible for about 11 percent of greenhouse gases emitted by the U.S. transportation sector. Boeing estimates that biofuels could reduce flight-related greenhouse-gas emissions by 60 to 80 percent. The solution would be blending algae fuels with existing jet fuel:

- Boeing and Air New Zealand are collaborating with leading Brazilian biofuels maker Tecbio and Aquaflow Bionomic of New Zealand and other jet biofuel developers around the world.
- Virgin Atlantic and Virgin Green Fund are looking into the technology as part of a biofuels initiative.
- KLM has made the first commercial flight with bio-fuel in 2009.

Call signs

Each operator of a scheduled or charter flight uses an airline call sign when communicating with airports or air traffic control centres. Most of these call-signs are derived from the airline's trade name, but for reasons of history, marketing, or the need to reduce ambiguity in spoken English (so that pilots do not mistakenly make navigational decisions based on instructions issued to a different aircraft), some airlines and air forces use call-signs less obviously connected with their trading name. For example, British Airways uses a *Speedbird* call-sign, named after the logo of its predecessor, BOAC, while SkyEurope used *Relax*.

Airline personnel

The various types of airline personnel include: Flight operations personnel including flight safety personnel.

- Flight crews, responsible for the operation of the aircraft. Flight crew members include:
    - Pilots (Captain and First Officer: some older aircraft also required a Flight Engineer and or a Navigator)
    - Flight attendants, (led by a purser on larger aircraft)
    - in-flight security personnel on some airlines (most notably El Al)
- Groundcrew, responsible for operations at airports. Ground crew members include:
    - Aerospace and avionics engineers responsible for certifying the aircraft for flight and management of aircraft maintenance
        - Aerospace engineers, responsible for airframe, powerplant and electrical systems maintenance
        - Avionics engineers responsible for avionics and instruments maintenance
    - Airframe and powerplant technicians
    - Electric System technicians, responsible for maintenance of electrical systems
    - Avionics technicians, responsible for maintenance of avionics
    - Flight dispatchers
    - Baggage handlers
    - Ramp Agents
    - Gate agents
    - Ticket agents
    - Passenger service agents (such as airline lounge employees)
    - Reservation agents, usually (but not always) at facilities outside the airport.

Airlines follow a corporate structure where each broad area of operations (such as maintenance, flight operations(including flight safety), and passenger service) is supervised by a vice president. Larger airlines often appoint vice presidents to oversee each of the airline's hubs as well. Airlines employ lawyers to deal with regulatory procedures and other administrative tasks.

Industry trends

Map of scheduled airline traffic in 2009

The pattern of ownership has gone from government owned or supported to independent, for-profit public companies. This occurs as regulators permit greater freedom and non-government ownership, in steps that are usually decades apart. This pattern is not seen for all airlines in all regions.

The overall trend of demand has been consistently increasing. In the 1950s and 1960s, annual growth rates of 15% or more were common. Annual growth of 5-6% persisted through the 1980s and 1990s. Growth rates are not consistent in all regions, but countries with a de-regulated airline industry have more competition and greater pricing freedom. This results in lower fares and sometimes dramatic spurts in traffic growth. The U.S., Australia, Canada, Japan, Brazil, Mexico,India and other markets exhibit this trend. The industry has been observed to be cyclical in its financial performance. Four or five years of poor earnings precede five or six years of improvement. But profitability even in the good years is generally low, in the range of 2-3% net profit after interest and tax. In times of profit, airlines lease new generations of airplanes and upgrade services in response to higher demand. Since 1980, the industry has not earned back the cost of capital during the best of times. Conversely, in bad times losses can be dramatically worse. Warren Buffett once said that despite all the money that has been invested in all airlines, the net profit is less than zero. He believes it is one of the hardest businesses to manage.

As in many mature industries, consolidation is a trend. Airline groupings may consist of limited bilateral partnerships, long-term, multi-faceted alliances between carriers, equity arrangements, mergers, or takeovers. Since governments often restrict ownership and merger between companies in different countries, most consolidation takes place within a country. In the U.S., over 200 airlines have merged, been taken over, or gone out of business since deregulation in 1978. Many international airline managers are lobbying their governments to permit greater consolidation to achieve higher economy and efficiency.

Civil Aviation

Scheduled airline traffic in 2009

Civil aviation is one of two major categories of flying, representing all non-military aviation, both private and commercial. Most of the countries in the world are members of the International Civil Aviation Organization (ICAO) and work together to establish common standards and recommended practices for civil aviation through that agency.

Civil aviation includes two major categories:

- Scheduled air transport, including all passenger and cargo flights operating on regularly-scheduled routes; and
- General aviation (GA), including all other civil flights, private or commercial

Although scheduled air transport is the larger operation in terms of passenger numbers, GA is larger in the number of flights (and flight hours, in the U.S.) In the U.S., GA carries 166 million passengers each year, more than any individual airline, though less than all the airlines combined.

Some countries also make a regulatory distinction based on whether aircraft are flown for hire:

- Commercial aviation includes most or all flying done for hire, particularly scheduled service on airlines; and

- Private aviation includes pilots flying for their own purposes (recreation, business meetings, etc.) without receiving any kind of remuneration.

All scheduled air transport is commercial, but general aviation can be either commercial or private. Normally, the pilot, aircraft, and operator must all be authorized to perform commercial operations through separate commercial licensing, registration, and operation certificates.

Civil aviation authorities

The Convention on International Civil Aviation (the *Chicago Convention*) was originally established in 1944: it states that signatories should collectively work to harmonize and standardize the use of airspace for safety, efficiency and regularity of air transport. All the States signatory to the Chicago Convention, now 188, are obliged to implement the Standards and Recommended Practices (SARPs) of the Convention.

Each signatory country has a Civil Aviation Authority (CAA) (such as the FAA in the United States) to oversee the following areas of civil aviation:

- **Personnel Licensing** — regulating the basic training and issuance of licenses and certificates.
- **Flight Operations** — carrying out safety oversight of commercial operators.
- **Airworthiness** — issuing certificates of registration and certificates of airworthiness to civil aircraft, and overseeing the safety of maintenance organizations.
- **Aerodromes** — designing and constructing aerodrome facilities.
- **Air Traffic Services** — managing the traffic inside of a country's airspace.

General aviation

A Diamond DA20, a popular trainer used by the United States Air Force and many flight schools.

A general aviation scene at Kemble Airfield, England. The aircraft in the foreground is a homebuilt Vans RV-4

Aircraft at general aviation airport Helsinki-Malmi, Finland.

The General Aviation Terminal at Raleigh Durham International Airport. Terminal A is in the background.

General aviation (**GA**) is one of the two categories of civil aviation. It refers to all flights *other than* military and scheduled airline and regular cargo flights, both private and commercial. General aviation flights range from gliders and powered parachutes to large, non-scheduled cargo jet flights. The majority of the world's air traffic falls into this category, and most of the world's airports serve general aviation exclusively.

General aviation is particularly popular in North America, with over 6,300 airports available for public use by pilots of general aviation aircraft (around 5,300 airports in the U.S., and over 1,000 in Canada). In comparison, scheduled flights operate from around 600 airports in the U.S. According to the U.S. Aircraft Owners and Pilots Association, general aviation provides more than one percent of the United States' GDP, accounting for 1.3 million jobs in professional services and manufacturing.

General aviation covers a large range of activities, both commercial and non-commercial, including private flying, flight training, air ambulance, police aircraft, aerial firefighting, air charter, bush flying, gliding, skydiving, and many others. Experimental aircraft, light-sport aircraft and very light jets have emerged in recent years as new trends in general aviation.

Regulation and safety

Most countries have authorities that oversee all civil aviation, including general aviation, adhering to the standardized codes of the International Civil Aviation Organization (ICAO). Examples include the Federal Aviation Administration (FAA) in the United States, the Civil Aviation Authority (CAA) in Great Britain, the Luftfahrt-Bundesamt (LBA) in Germany, and Transport Canada in Canada.

Since it includes both non-scheduled commercial operations and private operations, with aircraft of many different types and sizes, and pilots with a variety of different training and experience levels, it is not possible to make blanket statements about the regulation or safety record of general aviation. At one extreme, in most countries business jets and large cargo jets face most of the same regulations as scheduled air transport and fly mostly to the same airports. Commercial bush flying and air ambulance operations normally do not operate under as heavy a regulatory burden, and often only use small airports or off-airport strips, where there is less governmental oversight.

Aviation accident rate statistics are necessarily estimates. According to the U.S. National Transportation Safety Board, in 2005 general aviation in the United States (excluding charter) suffered 1.31 fatal accidents for every 100,000 hours of flying in that country, compared to 0.016 for scheduled airline flights. In Canada, recreational flying accounted for 0.7 fatal accidents for every 1000 aircraft, while air taxi accounted for 1.1 fatal accident for every 100,000 hours.

Commercial aviation

Route map of the world's scheduled commercial airline traffic, 2009

Commercial aviation is the part of civil aviation (both general aviation and scheduled airline service) that involves operating aircraft for hire to transport passengers or cargo. In most countries, a flight may be operated for money only if it meets three criteria:

- the pilot must hold a valid commercial pilot's certificate
- the aircraft must hold a valid commercial registration
- the operator must hold a certificate or some other authorization for commercial operations

There are some exceptions — for example, a flight instructor is normally allowed to fly for money in a private aircraft owned by the student — but the above requirements hold for most flights where money changes hands.

Typically, a commercial certificate or registration requires higher standards than a private one. For example, a commercial pilot may have to demonstrate more maneuvers to a higher standard, and may need to pass more frequent medical examinations. A commercially-registered plane may require more frequent or more extensive maintenance.

It is the purpose of the flight, not the type of aircraft or pilot, that determines whether the flight is commercial. For example, a two-seat Cessna 150 towing a banner for money would be a commercial flight, while a large jet flown by its owners for a private vacation would not be, even if the pilots were commercially certificated and the jet were commercially registered.

Private aviation

Pilot and family

Private aviation is the part of civil aviation that does not include flying for hire. In most countries, private flights are always general aviation flights, but the opposite is not true: many general aviation flights (such as banner towing, charter, crop dusting, and others) are commercial in that the pilot is hired and paid. Many private pilots fly for their own enjoyment, or to share the joys and convenience of general aviation with friends and family.

In private flight the pilot is not paid, and all aircraft operating expenses are generally paid by the pilot. In some countries such as the United States, aircraft operating expenses for a flight may optionally be divided with any passengers up to a pro rata amount. For example, if aircraft operating expenses total $120 for a flight with pilot and three passengers, each of the three passengers could pay not more than $30 (one fourth) of the expenses with the remainder paid by the pilot.

In many countries, private aviation operates to less strict standards than commercial aviation. For example, in Canada and the United States, aircraft owners are allowed to perform basic maintenance tasks (such as oil or tire changes) on their own privately-registered aircraft, but only licensed mechanics may perform those tasks on commercially-registered aircraft.

Aerobatic Flying

Private pilots normally are not required to demonstrate the same level of proficiency on their flight tests and take fewer and less rigorous medical examinations, than are required for Commercial pilots who are paid for operating an aircraft. The majority of active pilots hold a Private Pilot license.

It is the purpose of the flight, not the aircraft or pilot, that determines whether the flight is private. For example, if a commercially-licensed pilot flies a commercially-registered plane to visit a friend or attend a business meeting, most countries would consider this to be a private flight. Conversely, a private pilot could legally fly a multi-engine complex aircraft carrying six passengers for non-commercial purposes (no compensation paid to the pilot, and a pro rata or larger portion of the aircraft operating expenses paid by the pilot). Some particularly skillful aerobatic "stunt pilots" hold a private license, paying their own expenses and earning no income from this very challenging flying.

Chapter-3

Helicopter

An LAPD Bell 206

A **helicopter** is a type of rotorcraft in which lift and thrust are supplied by one or more engine driven rotors. In contrast with fixed-wing aircraft, this allows the helicopter to take off and land vertically, to hover, and to fly forwards, backwards and laterally. These attributes allow helicopters to be used in congested or isolated areas where fixed-wing aircraft would not be able to take off or land. The capability to efficiently hover for extended periods of time allows a helicopter to accomplish tasks that fixed-wing aircraft and other forms of vertical takeoff and landing aircraft cannot perform.

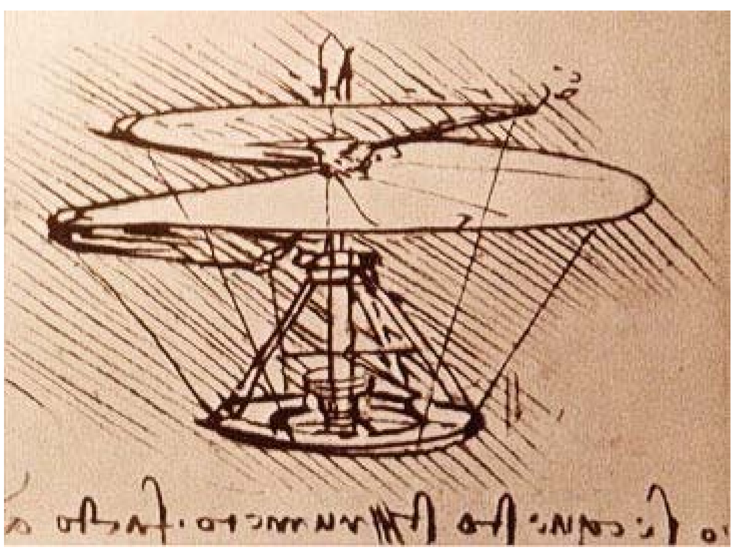
The word 'helicopter' is adapted from the French *hélicoptère*, coined by Gustave de Ponton d'Amecourt in 1861, which originates from the Greek *helix/helik-* (ἕλικ-) = 'spiral' or 'turning' and *pteron* (πτερόν) = 'wing'.

Helicopters were developed and built during the first half-century of flight, with the Focke-Wulf Fw 61 being the first operational helicopter in 1936. Some helicopters reached limited production, but it was not until 1942 that a helicopter designed by Igor Sikorsky reached full-scale production, with 131 aircraft built. Though most earlier designs used more than one main rotor, it was the single main rotor with antitorque tail rotor configuration of this design that would come to be recognized worldwide as *the helicopter*.

History

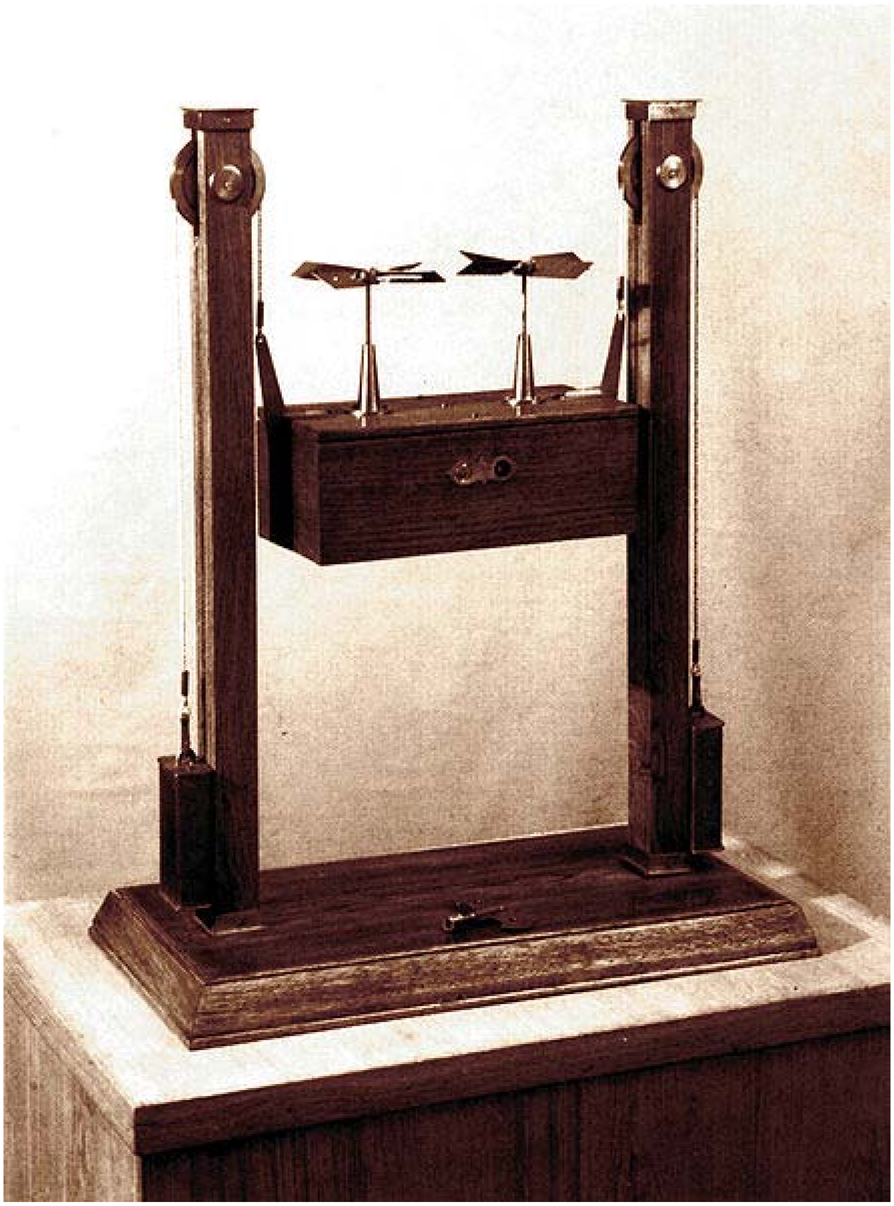
The earliest references for vertical flight have come from China. Since around 400 BC, Chinese children have played with bamboo flying toys, and the 4th-century AD Daoist book *Baopuzi* ("Master who Embraces Simplicity") reportedly describes some of the ideas inherent to rotary wing aircraft:

> "Someone asked the master about the principles of mounting to dangerous heights and traveling into the vast inane. The Master said, "Some have made flying cars with wood from the inner part of the jujube tree, using ox-leather [straps] fastened to returning blades so as to set the machine in motion.""



da Vinci's "aerial screw"

It was not until the early 1480s, when Leonardo da Vinci created a design for a machine that could be described as an "aerial screw", that any recorded advancement was made towards vertical flight. His notes suggested that he built small flying models, but there were no indications for any provision to stop the rotor from making the whole craft rotate. As scientific knowledge increased and became more accepted, men continued to pursue the idea of vertical flight. Many of these later models and machines would more closely resemble the ancient bamboo flying top with spinning wings, rather than Da Vinci's screw.



Prototype created by M. Lomonosov, 1754

In July 1754, Mikhail Lomonosov demonstrated a small coaxial rotor to the Russian Academy of Sciences. It was powered by a spring and suggested as a method to lift meteorological instruments. In 1783, Christian de Launoy, and his mechanic, Bienvenu, made a model with a pair of counter-rotating rotors, using turkey flight feathers as rotor blades, and in 1784, demonstrated it to the French Academy of Sciences. Sir George Cayley, influenced by a childhood fascination with the Chinese flying top, grew up to develop a model of feathers, similar to Launoy and Bienvenu, but powered by rubber bands. By the end of the century, he had progressed to using sheets of tin for rotor blades and springs for power. His writings on his experiments and models would become influential on future aviation pioneers. Alphonse Pénaud would later develop coaxial rotor model helicopter toys in 1870, also powered by rubber bands. One of these toys, given as a gift by their father, would inspire the Wright brothers to pursue the dream of flight.

In 1861, the word "helicopter" was coined by Gustave de Ponton d'Amécourt, a French inventor who demonstrated a small, steam-powered model. While celebrated as an innovative use of a new metal, aluminum, the model never lifted off the ground. D'Amecourt's linguistic contribution would survive to eventually describe the vertical flight he had envisioned. Steam power was popular with other inventors as well. In 1878 Enrico Forlanini's unmanned helicopter was also powered by a steam engine. It was the first of its type that rose to a height of 12 meters (40 ft), where it hovered for some 20 seconds after a vertical take-off. Emmanuel Dieuaide's steam-powered design featured counter-rotating rotors powered through a hose from a boiler on the ground.

In 1885, Thomas Edison was given US$1,000 by James Gordon Bennett, Jr., to conduct experiments towards developing flight. Edison built a helicopter and used the paper for a stock ticker to create guncotton, with which he attempted to power an internal combustion engine. The helicopter was damaged by explosions and one of his workers was badly burned. Edison reported that it would take a motor with a ratio of three to four pounds per horsepower produced to be successful, based on his experiments. Ján Bahýľ, a Slovak inventor, adapted the internal combustion engine to power his helicopter model that reached a height of 0.5 meters (1.6 ft) in 1901. On 5 May 1905, his helicopter reached four meters (13 ft) in altitude and flew for over 1,500 meters (4,900 ft). In 1908, Edison patented his own design for a helicopter powered by a gasoline engine with box kites attached to a mast by cables for a rotor, but it never flew.

First flights

Paul Cornu's helicopter in 1907

In 1906, two French brothers, Jacques and Louis Breguet, began experimenting with airfoils for helicopters and in 1907, those experiments resulted in the *Gyroplane No.1*.

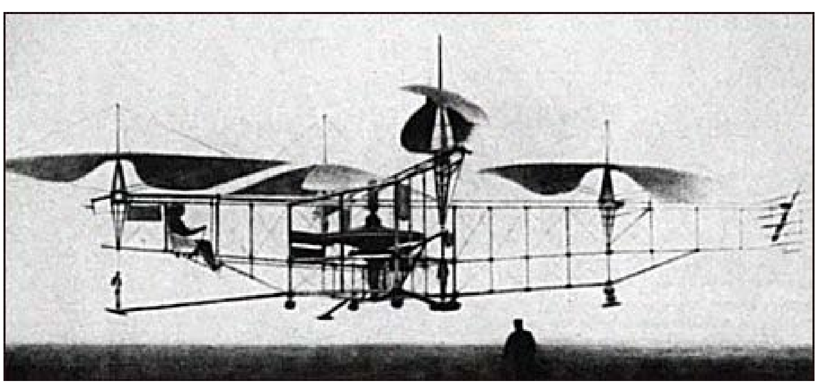
Although there is some uncertainty about the dates, sometime between 14 August and 29 September 1907, the Gyroplane No. 1 lifted its pilot up into the air about two feet (0.6 m) for a minute. However, the Gyroplane No. 1 proved to be extremely unsteady and required a man at each corner of the airframe to hold it steady. For this reason, the flights of the Gyroplane No. 1 are considered to be the first manned flight of a helicopter, but not a free or untethered flight.

That same year, fellow French inventor Paul Cornu designed and built a Cornu helicopter that used two 20-foot (6 m) counter-rotating rotors driven by a 24-hp (18-kW) Antoinette engine. On 13 November 1907, it lifted its inventor to 1 foot (0.3 m) and remained aloft for 20 seconds. Even though this flight did not surpass the flight of the Gyroplane No. 1, it was reported to be the first truly free flight with a pilot. Cornu's helicopter would complete a few more flights and achieve a height of nearly 6.5 feet (2 m), but it proved to be unstable and was abandoned.

The Danish inventor Jacob Ellehammer built the Ellehammer helicopter in 1912. It consisted of a frame equipped with two contra-rotating discs, each of which was fitted with six vanes around its circumference. After a number of indoor tests, the aircraft was demonstrated outdoors and made a number of free take-offs. Experiments with the helicopter continued until September 1916, when it tipped over during take-off, destroying its rotors.

Early development

In the early 1920s, Argentine Raúl Pateras Pescara, while working in Europe, demonstrated one of the first successful applications of cyclic pitch. Coaxial, contra-rotating, biplane rotors could be warped to cyclically increase and decrease the lift they produced. The rotor hub could also be tilted forward a few degrees, allowing the aircraft to move forward without a separate propeller to push or pull it. Pescara was also able to demonstrate the principle of autorotation, by which helicopters safely land after engine failure. By January 1924, Pescara's helicopter No. 3 could fly for up ten minutes.



Oehmichen N°2 1922

One of Pescara's contemporaries, Frenchman Etienne Oehmichen, set the first helicopter world record recognized by the *Fédération Aéronautique Internationale* (FAI) on 14 April 1924, flying his helicopter 360 meters (1,181 ft). On 18 April 1924, Pescara beat Oemichen's record, flying for a distance of 736 meters (nearly a half mile) in 4 minutes and 11 seconds (about 8 mph, 13 km/h) maintaining a height of six feet (2 m). Not to be outdone, Oehmichen reclaimed the world record on 4 May when he flew his No. 2 machine again for a 14-minute flight covering 5,550 feet (1.05 mi, 1.69 km) while climbing to a height of 50 feet (15 m). Oehmichen also set the 1 km closed-circuit record at 7 minutes 40 seconds.

In the USA, George de Bothezat built the quadrotor De Bothezat helicopter for the United States Army Air Service but the Army cancelled the program in 1924, and the aircraft was scrapped.

Meanwhile, Juan de la Cierva was developing the first practical rotorcraft in Spain. In 1923, the aircraft that would become the basis for the modern helicopter rotor began to take shape in the form of an autogyro, Cierva's C.4. Cierva had discovered aerodynamic and structural deficiencies in his early designs that could cause his autogyros to flip over after takeoff. The flapping hinges that Cierva designed for the C.4 allowed the rotor to develop lift equally on the left and right halves of the rotor disk. A crash in 1927, led to the development of a drag hinge to relieve further stress on the rotor from its flapping motion. These two developments allowed for a stable rotor system, not only in a hover, but in forward flight.

Albert Gillis von Baumhauer, a Dutch aeronautical engineer, began studying rotorcraft design in 1923. His first prototype "flew" ("hopped" and hovered in reality) on 24 September 1925, with Dutch Army-Air arm Captain Floris Albert van Heijst at the controls. The controls that Captain van Heijst used were Von Baumhauer's inventions, the cyclic and collective. Patents were granted to von Baumhauer for his cyclic and collective controls by the British ministry of aviation on 31 January 1927, under patent number 265,272.

In 1928, Hungarian aviation engineer Oszkár Asbóth constructed a helicopter prototype that took off and and landed at least 182 times, with a maximum single flight duration of 53 minutes.

In 1930, the Italian engineer Corradino D'Ascanio built his D'AT3, a coaxial helicopter. His relatively large machine had two, two-bladed, counter-rotating rotors. Control was achieved by using auxiliary wings or servo-tabs on the trailing edges of the blades, a concept that was later adopted by other helicopter designers, including Bleeker and Kaman. Three small propellers mounted to the airframe were used for additional pitch, roll, and yaw control. The D'AT3 held modest FAI speed and altitude records for the time, including altitude (18 m or 59 ft), duration (8 minutes 45 seconds) and distance flown (1,078 m or 3,540 ft).

In the Soviet Union, Boris N. Yuriev and Alexei M. Cheremukhin, two aeronautical engineers working at the *Tsentralniy Aerogidrodinamicheskiy Institut* (TsAGI, Russian: Центра́льный аэрогидродинами́ческий институ́т (ЦАГИ), English: *Central Aerohydrodynamic Institute*), constructed and flew the TsAGI 1-EA single rotor helicopter, which used an open tubing framework, a four blade main rotor, and twin sets of 1.8-meter (6-foot) diameter anti-torque rotors; one set of two at the nose and one set of two at the tail. Powered by two M-2 powerplants, up-rated copies of the Gnome Monosoupape rotary radial engine of World War I, the TsAGI 1-EA made several successful low altitude flights. By 14 August 1932, Cheremukhin managed to get the 1-EA up to an unofficial altitude of 605 meters (1,985 ft), shattering d'Ascanio's earlier achievement. As the Soviet Union was not yet a member of the FAI, however, Cheremukhin's record remained unrecognized.

Nicolas Florine, a Russian engineer, built the first twin tandem rotor machine to perform a free flight. It flew in Sint-Genesius-Rode, at the *Laboratoire Aérotechnique de Belgique* (now von Karman Institute) in April 1933, and attained an altitude of six meters (20 ft) and an endurance of eight minutes. Florine chose a co-rotating configuration because the gyroscopic stability of the rotors would not cancel. Therefore the rotors had to be tilted slightly in opposite directions to counter torque. Using hingeless rotors and co-rotation also minimised the stress on the hull. At the time, it was one of the most stable helicopter in existence.

The Bréguet-Dorand *Gyroplane Laboratoire* was built in 1933. After many ground tests and an accident, it first took flight on 26 June 1935. Within a short time, the aircraft was setting records with pilot Maurice Claisse at the controls. On 14 December 1935, he set a record for closed-circuit flight with a 500-meter (1,600 ft) diameter. The next year, on 26 September 1936, Claisse set a height record of 158 meters (520 ft). And, finally, on 24 November 1936, he set a flight duration record of one hour, two minutes and 5 seconds over a 44 kilometer (27 mi) closed circuit at 44.7 kilometers per hour (27.8 mph). The aircraft was destroyed in 1943 by an Allied airstrike at Villacoublay airport.

Birth of an industry

First airmail service by helicopter in Los Angeles, 1947

Despite the success of the *Gyroplane Laboratoire*, the German Focke-Wulf Fw 61, first flown in 1936, would eclipse its accomplishments. The Fw 61 broke all of the helicopter world records in 1937, demonstrating a flight envelope that had only previously been achieved by the autogyro. Nazi Germany would use helicopters in small numbers during World War II for observation, transport, and medical evacuation. The Flettner Fl 282 *Kolibri* synchropter was used in the Mediterranean, while the Focke Achgelis Fa 223 *Drache* was used in Europe. Extensive bombing by the Allied forces prevented Germany from producing any helicopters in large quantities during the war.

In the United States, Igor Sikorsky and W. Lawrence LePage, were competing to produce the United States military's first helicopter. Prior to the war, LePage had received the patent rights to develop helicopters patterned after the Fw 61, and built the XR-1. Meanwhile, Sikorsky had settled on a simpler, single rotor design, the VS-300. After experimenting with configurations to counteract the torque produced by the single main rotor, he settled on a single, smaller rotor mounted vertically on the tailboom.

Developed from the VS-300, Sikorsky's R-4 became the first mass produced helicopter with a production order for 100 aircraft. The R-4 was the only Allied helicopter to see service in World War II, primarily being used for rescue in Burma, Alaska, and other areas with harsh terrain. Total production would reach 131 helicopters before the R-4 was replaced by other Sikorsky helicopters such as the R-5 and the R-6. In all, Sikorsky would produce over 400 helicopters before the end of World War II.

As LePage and Sikorsky were building their helicopters for the military, Bell Aircraft hired Arthur Young to help build a helicopter using Young's semi-rigid, teetering-blade rotor design, which used a weighted stabilizing bar. The subsequent Model 30 helicopter demonstrated the simplicity and ease of the design. The Model 30 was developed into the Bell 47, which became the first helicopter certificated for civilian use in the United States. Produced in several countries, the Bell 47 would become the most popular helicopter model for nearly 30 years.

Turbine age

In 1951, at the urging of his contacts at the Department of the Navy, Charles Kaman modified his K-225 helicopter with a new kind of engine, the turboshaft engine. This adaptation of the turbine engine provided a large amount of power to the helicopter with a lower weight penalty than piston engines, with their heavy engine blocks and auxiliary components. On 11 December 1951, the Kaman K-225 became the first turbine-powered helicopter in the world. Two years later, on 26 March 1954, a modified Navy HTK-1, another Kaman helicopter, became the first twin-turbine helicopter to fly. However, it was the Sud Aviation Alouette II that would become the first helicopter to be produced with a turbine-engine.

Reliable helicopters capable of stable hover flight were developed decades after fixed-wing aircraft. This is largely due to higher engine power density requirements than fixed-wing aircraft. Improvements in fuels and engines during the first half of the 20th century were a critical factor in helicopter development. The availability of lightweight turboshaft engines in the second half of the 20th century led to the development of larger, faster, and higher-performance helicopters. While smaller and less expensive helicopters still use piston engines, turboshaft engines are the preferred powerplant for helicopters today.

Uses

Due to the operating characteristics of the helicopter—its ability to takeoff and land vertically, and to hover for extended periods of time, as well as the aircraft's handling properties under low airspeed conditions—it has been chosen to conduct tasks that were previously not possible with other aircraft, or were time- or work-intensive to accomplish on the ground. Today, helicopter uses include transportation, construction, firefighting, search and rescue, and military uses.

Sikorsky S-64 Skycrane lifting a prefab house

Kern County (California) Fire Department Bell 205 dropping water on fire

A helicopter used to carry loads connected to long cables or slings is called an aerial crane. Aerial cranes are used to place heavy equipment, like radio transmission towers and large air conditioning units, on the tops of tall buildings, or when an item must be raised up in a remote area, such as a radio tower raised on the top of a hill or mountain. Helicopters are used as aerial cranes in the logging industry to lift trees out of terrain where vehicles cannot travel and where environmental concerns prohibit the building of roads. These operations are referred to as longline because of the long, single sling line used to carry the load.

Helitack is the use of helicopters to combat wildland fires. The helicopters are used for aerial firefighting (or water bombing) and may be fitted with tanks or carry helibuckets. Helibuckets, such as the Bambi bucket, are usually filled by submerging the bucket into lakes, rivers, reservoirs, or portable tanks. Tanks fitted onto helicopters are filled from a hose while the helicopter is on the ground or water is siphoned from lakes or reservoirs through a hanging snorkel as the helicopter hovers over the water source. Helitack helicopters are also used to deliver firefighters, who rappel down to inaccessible areas, and to resupply firefighters. Common firefighting helicopters include variants of the Bell 205 and the Erickson S-64 Aircrane helitanker.

Helicopters are used as air ambulances for emergency medical assistance in situations when an ambulance cannot easily or quickly reach the scene. Helicopters are also used when a patient needs to be transported between medical facilities and air transportation is the most practical method for the safety of the patient. Air ambulance helicopters are equipped to provide medical treatment to a patient while in flight. The use of helicopters as an air ambulance is often referred to as MEDEVAC, and patients are referred to as being "airlifted", or "medevaced".

Police departments and other law enforcement agencies use helicopters to pursue suspects. Since helicopters can achieve a unique aerial view, they are often used in conjunction with police on the ground to report on suspects' locations and movements. They are often mounted with lighting and heat-sensing equipment for night pursuits.

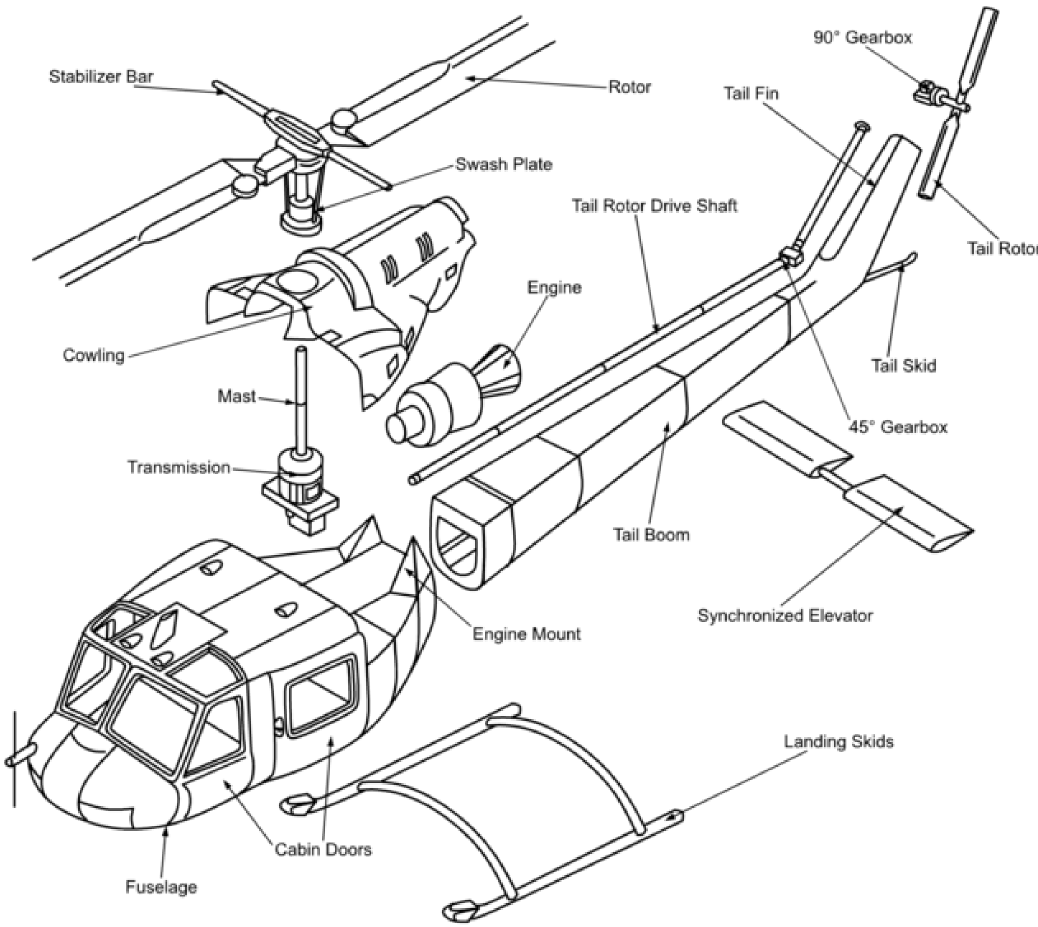
Military forces use attack helicopters to conduct aerial attacks on ground targets. Such helicopters are mounted with missile launchers and miniguns. Transport helicopters are used to ferry troops and supplies where the lack of an airstrip would make transport via fixed-wing aircraft impossible. The use of transport helicopters to deliver troops as an attack force on an objective is referred to as Air Assault. Unmanned Aerial Systems (UAS) helicopter systems of varying sizes are being developed by companies for military reconnaissance and surveillance duties. Naval forces also use helicopters equipped with dipping sonar for anti-submarine warfare, since they can operate from small ships.

Oil companies charter helicopters to move workers and parts quickly to remote drilling sites located out to sea or in remote locations. The speed over boats makes the high operating cost of helicopters cost effective to ensure that oil platforms continue to flow. Various companies specialize in this type of operation.

Other uses of helicopters include, but are not limited to:

- Aerial photography
- Motion picture photography
- Electronic news gathering
- Reflection seismology
- Search and Rescue
- Tourism or recreation
- Transport

Design features



Basic anatomy of a Helicopter

Antitorque configurations

MD Helicopters 520N NOTAR

Most helicopters have a single main rotor, but torque created as the engine turns the rotor against its air drag causes the body of the helicopter to turn in the opposite direction to the rotor. To eliminate this effect, some sort of antitorque control must be used. The design that Igor Sikorsky settled on for his VS-300 was a smaller rotor mounted vertically on the tail. The tail rotor pushes or pulls against the tail to counter the torque effect, and has become the recognized convention for helicopter design. Some helicopters utilize alternate antitorque controls in place of the tail rotor, such as the ducted fan (called *Fenestron* or *FANTAIL*), and NOTAR. NOTAR provides antitorque similar to the way a wing develops lift, through the use of a Coandă effect on the tailboom.

The use of two or more horizontal rotors turning in opposite directions is another configuration used to counteract the effects of torque on the aircraft without relying on an antitorque tail rotor. This allows the power normally required to drive the tail rotor to be applied to the main rotors, increasing the aircraft's lifting capacity. Primarily, there are three common configurations that use the counterrotating effect to benefit the rotorcraft. Tandem rotors are two rotors with one mounted behind the other. Coaxial rotors are two rotors that are mounted one above the other with the same axis. Intermeshing rotors are two rotors that are mounted close to each other at a sufficient angle to allow the rotors to intermesh over the top of the aircraft. Transverse rotors is another configuration found on tiltrotors and some earlier helicopters, where the pair of rotors are mounted at each end of the wings or outrigger structures. Tip jet designs permit the rotor to push itself through the air, and avoid generating torque.

Engines

The number, size and type of engine used on a helicopter determines the size, function and capability of that helicopter design. The earliest helicopter engines were simple mechanical devices, such as rubber bands or spindles, which relegated the size of helicopters to toys and small models. For a half century before the first airplane flight, steam engines were used to forward the development of the understanding of helicopter aerodynamics, but the limited power did not allow for manned flight. The introduction of the internal combustion engine at the end of the 19th century became the watershed for helicopter development as engines began to be developed and produced that were powerful enough to allow for helicopters able to lift humans.

Early helicopter designs utilized custom-built engines or rotary engines designed for airplanes, but these were soon replaced by more powerful automobile engines and radial engines. The single, most-limiting factor of helicopter development during the first half of the 20th century was that the amount of power produced by an engine was not able to overcome the engine's weight in vertical flight. This was overcome in early successful helicopters by using the smallest engines available. When the compact, flat engine was developed, the helicopter industry found a lighter-weight powerplant easily adapted to small helicopters, although radial engines continued to be used for larger helicopters.

Turbine engines revolutionized the aviation industry, and the turboshaft engine finally gave helicopters an engine with a large amount of power and a low weight penalty. The turboshaft engine was able to be scaled to the size of the helicopter being designed, so that all but the lightest of helicopter models are powered by turbine engines today.

Special jet engines developed to drive the rotor from the rotor tips are referred to as tip jets. Tip jets powered by a remote compressor are referred to as cold tip jets, while those powered by combustion exhaust are referred to as hot tip jets. An example of a cold jet helicopter is the Sud-Ouest Djinn, and an example of the hot tip jet helicopter is the YH-32 Hornet.

Some radio-controlled helicopters and smaller, helicopter-type unmanned aerial vehicles, such as Rotomotion's SR20 use electric motors. Radio-controlled helicopters may also have piston engines that use fuels other than gasoline, such as Nitromethane. Some turbine engines commonly used in helicopters can also use biodiesel instead of jet fuel.

Flight controls

Cockpit of an Alouette III

A helicopter has four flight control inputs. These are the cyclic, the collective, the anti-torque pedals, and the throttle. The cyclic control is usually located between the pilot's legs and is commonly called the *cyclic stick* or just *cyclic*. On most helicopters, the cyclic is similar to a joystick. Although, the Robinson R22 and Robinson R44 have a unique teetering bar cyclic control system and a few helicopters have a cyclic control that descends into the cockpit from overhead.

The control is called the cyclic because it changes the pitch of the rotor blades cyclically. The result is to tilt the rotor disk in a particular direction, resulting in the helicopter moving in that direction. If the pilot pushes the cyclic forward, the rotor disk tilts forward, and the rotor produces a thrust in the forward direction. If the pilot pushes the cyclic to the side, the rotor disk tilts to that side and produces thrust in that direction, causing the helicopter to hover sideways.

The collective pitch control or *collective* is located on the left side of the pilot's seat with a settable friction control to prevent inadvertent movement. The collective changes the pitch angle of all the main rotor blades collectively (i.e. all at the same time) and independently of their position. Therefore, if a collective input is made, all the blades change equally, and the result is the helicopter increasing or decreasing in altitude.

The anti-torque pedals are located in the same position as the rudder pedals in a fixed-wing aircraft, and serve a similar purpose, namely to control the direction in which the nose of the aircraft is pointed. Application of the pedal in a given direction changes the pitch of the tail rotor blades, increasing or reducing the thrust produced by the tail rotor and causing the nose to yaw in the direction of the applied pedal. The pedals mechanically change the pitch of the tail rotor altering the amount of thrust produced.

Helicopter rotors are designed to operate at a specific RPM. The throttle controls the power produced by the engine, which is connected to the rotor by a transmission. The purpose of the throttle is to maintain enough engine power to keep the rotor RPM within allowable limits in order to keep the rotor producing enough lift for flight. In single-engine helicopters, the throttle control is a motorcycle-style twist grip mounted on the collective control, while dual-engine helicopters have a power lever for each engine.

A Swashplate transmits the pilot commands to the main rotor blades for articulated rotors.

Flight conditions

There are two basic flight conditions for a helicopter; hover and forward flight.

- Hover
  Hovering is the most challenging part of flying a helicopter. This is because a helicopter generates its own gusty air while in a hover, which acts against the fuselage and flight control surfaces. The end result is constant control inputs and corrections by the pilot to keep the helicopter where it is required to be. Despite the complexity of the task, the control inputs in a hover are simple. The cyclic is used to eliminate drift in the horizontal plane, that is to control forward and back, right and left. The collective is used to maintain altitude. The pedals are used to control nose direction or heading. It is the interaction of these controls that makes hovering so difficult, since an adjustment in any one control requires an adjustment of the other two, creating a cycle of constant correction.
- Forward flight
  In forward flight a helicopter's flight controls behave more like that in a fixed-wing aircraft. Displacing the cyclic forward will cause the nose to pitch down, with a resultant increase in airspeed and loss of altitude. Aft cyclic will cause the nose to pitch up, slowing the helicopter and causing it to climb. Increasing collective (power) while maintaining a constant airspeed will induce a climb while decreasing collective will cause a descent. Coordinating these two inputs, down collective plus aft cyclic or up collective plus forward cyclic, will result in airspeed changes while maintaining a constant altitude. The pedals serve the same function in both a helicopter and a fixed-wing aircraft, to maintain balanced flight. This is done by applying a pedal input in whichever direction is necessary to center the ball in the turn and bank indicator.

Safety

Limitations

HAL Dhruv performing aerobatics during the Royal International Air Tattoo in 2008.

Royal Australian Navy Squirrel helicopters during a display at the 2008 Melbourne Grand Prix

The main limitation of the helicopter is its low speed. There are several reasons a helicopter cannot fly as fast as a fixed wing aircraft. When the helicopter is hovering, the outer tips of the rotor travel at a speed determined by the length of the blade and the RPM. In a moving helicopter, however, the speed of the blades relative to the air depends on the speed of the helicopter as well as on their rotational velocity. The airspeed of the advancing rotor blade is much higher than that of the helicopter itself. It is possible for this blade to exceed the speed of sound, and thus produce vastly increased drag and vibration.

Because the advancing blade has higher airspeed than the retreating blade and generates a dissymmetry of lift, rotor blades are designed to "flap" – lift and twist in such a way that the advancing blade flaps up and develops a smaller angle of attack. Conversely, the retreating blade flaps down, develops a higher angle of attack, and generates more lift. At high speeds, the force on the rotors is such that they "flap" excessively and the retreating blade can reach too high an angle and stall. For this reason, the maximum safe forward airspeed of a helicopter is given a design rating called V_{NE}, *Velocity, Never Exceed*. In addition, at extremely high speeds, it is possible for the helicopter to travel faster than the retreating blade which would inevitably stall the blade, regardless of the angle of attack.

During the closing years of the 20th century designers began working on helicopter noise reduction. Urban communities have often expressed great dislike of noisy aircraft, and police and passenger helicopters can be unpopular. The redesigns followed the closure of some city heliports and government action to constrain flight paths in national parks and other places of natural beauty.

Helicopters also vibrate; an unadjusted helicopter can easily vibrate so much that it will shake itself apart. To reduce vibration, all helicopters have rotor adjustments for height and weight. Blade height is adjusted by changing the pitch of the blade. Weight is adjusted by adding or removing weights on the rotor head and/or at the blade end caps. Most also have vibration dampers for height and pitch. Some also use mechanical feedback systems to sense and counter vibration. Usually the feedback system uses a mass as a "stable reference" and a linkage from the mass operates a flap to adjust the rotor's angle of attack to counter the vibration. Adjustment is difficult in part because measurement of the vibration is hard, usually requiring sophisticated accelerometers mounted throughout the airframe and gearboxes. The most common blade vibration adjustment measurement system is to use a stroboscopic flash lamp, and observe painted markings or coloured reflectors on the underside of the rotor blades. The traditional low-tech system is to mount coloured chalk on the rotor tips, and see how they mark a linen sheet. Gearbox vibration most often requires a gearbox overhaul or replacement. Gearbox or drive train vibrations can be extremely harmful to a pilot. The most severe being pain, numbness, loss of tactile discrimination and dexterity.

Hazards

As with any moving vehicle, unsafe operation could result in loss of control, structural damage, or fatality. The following is a list of some of the potential hazards for helicopters:

- Settling with power, also known as a vortex ring state, is when the aircraft is unable to arrest its descent due to the rotor's downwash interfering with the aerodynamics of the rotor.
- Retreating blade stall is experienced during high speed flight and is the most common limiting factor of a helicopter's forward speed.
- Ground resonance affects helicopters with fully articulated rotor systems having a natural lead-lag frequency less than the blade rotation frequency.
- Low-G condition affects helicopters with two-bladed main rotors, particularly lightweight helicopters.
- Dynamic rollover in which the helicopter pivots around one of the skids and 'pulls' itself onto its side.
- Powertrain failures, especially those that occur within the shaded area of the height-velocity diagram.
- Tail rotor failures which occur from either a mechanical malfunction of the tail rotor control system or a loss of tail rotor thrust authority, called Loss of Tail-rotor Effectiveness (LTE).
- Brownout in dusty conditions or whiteout in snowy conditions.
- Low Rotor RPM, or *rotor droop*, in which the engine cannot drive the blades at sufficient RPM to maintain flight.

- Rotor Overspeed, which can over-stress the rotor hub pitch bearings (Brinelling) and, if severe enough, cause blade separation from the aircraft.
- Wire and tree strikes due to low altitude operations and take-offs and landings in remote locations.
- Controlled flight into terrain in which the aircraft is flown into the ground unintentionally due to lack of situational awareness.

Deadliest crashes

1. 2002: A Mil Mi-26 was shot down over Chechnya; 127 killed.
2. 1997: An Israeli CH-53 crashed in Israel; 73 killed.
3. December 14, 1992: Georgian forces in Abkhazia shot down a Russian Army Mi-8 by SA-14 MANPADs with the loss of three crew members and 58 passengers, mainly Russian refugees.
4. October 4, 1993: A Georgian Mi-8 was shot down while transporting 60 refugees from eastern Abkhazia.
5. May 10, 1977: An Israeli CH-53 crashed near Yitav in the Jordan Valley; 54 killed.
6. September 11, 1982: A U.S. Army CH-47 Chinook crashed at an air show in Mannheim, Germany; 46 killed.
7. 1966: A British International Helicopters Boeing 234LR Chinook crashed in the Shetland Islands; 45 killed.
8. 1992 Azerbaijani Mil Mi-8 shootdown: 44 killed.
9. 2009 Pakistan Army Mil Mi-17 crash: 41 killed.
10. January 26, 2005: An USMC CH-53E crashed near Ar Rutbah, Iraq killing all 31 service members onboard.

Helicopter rotor

A **helicopter main rotor** or **rotor system** is a type of fan that is used to generate both the aerodynamic lift force that supports the weight of the helicopter, and thrust which counteracts aerodynamic drag in forward flight. Each main rotor is mounted on a vertical mast over the top of the helicopter, as opposed to a helicopter tail rotor, which is connected through a combination a drive shaft(s) and gearboxes along the tail boom. A helicopter's rotor is generally made up of two or more rotor blades. The blade pitch is typically controlled by a swashplate connected to the helicopter flight controls.

Helicopter rotor diameters are relatively large, as this gives much better energy and propellant efficiency for the speeds at which helicopters fly.

History and development

Helicopter rotor of Engelbert Zaschka, German master engineer, 1931, image from the German Federal Archives

Before the development of powered helicopters in the mid 20th century, autogyro pioneer Juan de la Cierva researched and developed many of the fundamentals of the rotor. Cierva is credited with successful development of multi-bladed, fully articulated rotor systems. This type of system is widely used today in many multi-bladed helicopters.

In the 1930s, Arthur Young improved the stability of two-bladed rotor systems with the introduction of a stabilizer bar. This system was used in several Bell and Hiller helicopter models. It is also used in many remote control model helicopters.

Design

A helicopter rotor is powered by the engine, through the transmission, to the rotating mast. The mast is a cylindrical metal shaft which extends upward from—and is driven by—the transmission. At the top of the mast is the attachment point for the rotor blades called the hub. The rotor blades are then attached to the hub. Main rotor systems are classified according to how the main rotor blades are attached and move relative to the main rotor hub. There are three basic classifications: rigid, semirigid, or fully articulated, although some modern rotor systems use an engineered combination of these classifications.

Unlike the small diameter fans used in turbofan jet engines, the main rotor on a helicopter has a quite large diameter, permitting a large quantity of air to be accelerated. This permits a lower downwash velocity for a given amount of thrust. As it is more efficient at low speeds to accelerate a large amount of air by a small degree than a small amount of air by a large degree it greatly increases the aircraft's energy efficiency and this reduces the fuel use and permits reasonable range.

Parts and functions

The simple rotor of a Robinson R22

Robinson R44 rotor head

The simple rotor of a Robinson R22 showing (from the top):

- The following are driven by the link rods from the rotating part of the swashplate.
    - Pitch hinges, allowing the blades to twist about the axis extending from blade root to blade tip.
- Teeter hinge, allowing one blade to rise vertically while the other falls vertically. This motion occurs whenever translational relative wind is present, or in response to a cyclic control input.
- Scissor link and counterweight, carries the main shaft rotation down to the upper swashplate
- Rubber covers protect moving and stationary shafts
- Swashplates, transmitting cyclic and collective pitch to the blades (the top one rotates)
- Three non-rotating control rods transmit pitch information to the lower swashplate
- Main mast leading down to main gearbox

Swash plate

An advanced rotor head for a Sikorsky S-92

The pitch of main rotor blades can be varied cyclically throughout its rotation in order to control the direction of rotor thrust vector (the part of the rotor disc where the maximum thrust will be developed, front, rear, right side, etc.). Collective pitch is used to vary the magnitude of rotor thrust (increasing or decreasing thrust over the whole rotor disc at the same time). These blade pitch variations are controlled by tilting and/or raising or lowering the swash plate with the flight controls. The vast majority of helicopters maintain a constant rotor speed (RPM) during flight, leaving only the angle of attack of the blades as the sole means of adjusting thrust from the rotor.

The swash plate is two concentric disks or plates, one plate rotates with the mast, connected by idle links, while the other does not rotate. The rotating plate is also connected to the individual blades through pitch links and pitch horns. The non-rotating plate is connected to links which are manipulated by pilot controls, specifically, the collective and cyclic controls.

The swash plate can shift vertically and tilt. Through shifting and tilting, the non-rotating plate controls the rotating plate, which in turn controls the individual blade pitch.

Fully articulated

Juan de la Cierva developed the fully articulating rotor for the autogyro, and it is the basis of his design that permitted successful helicopter development. In a fully articulated rotor system, each rotor blade is attached to the rotor hub through a series of hinges which allow the blade to move independently of the others. These rotor systems usually have three or more blades. The blades are allowed to flap, feather, and lead or lag independently of each other. The horizontal hinge, called the flapping hinge, allows the blade to move up and down. This movement is called flapping and is designed to compensate for dissymmetry of lift. The flapping hinge may be located at varying distances from the rotor hub, and there may be more than one hinge. The vertical hinge, called the lead-lag or drag hinge, allows the blade to move back and forth. This movement is called lead-lag, dragging, or hunting. Dampers are usually used to prevent excess back and forth movement around the drag hinge. The purpose of the drag hinge and dampers is to compensate for the acceleration and deceleration caused by momentum conservation, and not by Coriolis Effect. Each blade can also be feathered, that is, rotated around its spanwise axis. Feathering the blade means changing the pitch angle of the blade. By changing the pitch angle of the blades the thrust and direction of the main rotor disc can be controlled.

Rigid

The term "rigid rotor" usually refers to a hingeless rotor system with blades flexibly attached to the hub. The two basic types of rigid rotor include the Reiseler-Kreiser feathering system and the Lockheed flapping system. The Reiseler-Kreiser feathering rigid rotor was developed and tested on a series of gyroplanes sponsored by E.B. Wilford in Pennsylvania. Irven Culver of Lockheed developed one of the first flapping rigid rotors and was tested and developed on a series of helicopters in the 1960s and 1970s. In a flapping rigid rotor system, each blade flaps, drags, and feathers (depending on the design) about flexible sections of the root. The flapping rigid rotor system is mechanically simpler than the fully articulated rotor system. Loads from flapping and lead/lag forces are accommodated by bending rather than through hinges. By flexing, the blades themselves compensate for the forces which previously required rugged hinges. The result is a rotor system that has less lag in the control response, because the rotor has much less oscillation. The rigid rotor system also negates the danger of mast bumping inherent in semi-rigid rotors. The rigid rotor can also be called a hingeless rotor. Developed most notably for the XH-51 high speed and AH-56 Cheyenne attack compound helicopter, the rotors simplified aerobatic maneuvers at high speeds, but proved troublesome to perfect on the AH-56, and would never be produced in large numbers or adopted by other helicopter makers.

However, to completely contradict the previous statement, flapping rigid rotors have long been standard equipment on the Bolkow series of helicopters, as well as models produced by Aerospatiale, AgustaWestland, and MD helicopters.

Semirigid

Semirigid rotor system

The confusingly termed "semirigid" rotor is more accurately known as a "teetering" or "seesaw" rotor. This rotor system allows for flapping and feathering motions with two per rev inplane motions accommodated by the blade roots and rotor shaft. This system is normally composed of two blades which meet at a common flapping hinge at the rotor shaft. This allows the blades to see-saw or flap together. This teetering hinge combined with an adequate coning angle and undersling minimizes variations in the radius of each blade's center of mass from the axis of rotation as the rotor turns. Secondary flapping hinges may also be provided to provide sufficient flexibility to minimize bouncing. Feathering is accomplished by the feathering hinge, which changes the pitch angle of the blade.

Stabilizer bar

Arthur M. Young found that stability could be increased significantly with the addition of a stabilizer bar (also called a *flybar*) perpendicular to the two blades. The stabilizer bar has weighted ends which cause the bar to stay relatively stable in the plane of rotation. The stabilizer bar is linked with the swash plate in such a manner as to reduce the effect of external forces on the rotor. The result is a much more stable rotor system which eases the workload of the pilot to maintain control of the aircraft. Stanley Hiller also arrived at a method to improve stability by adding a bar perpendicular to the rotor, but he added short, stubby airfoils, or paddles, at each end. Hiller's "Rotormatic" system was used to deliver cyclic control inputs to the main rotor as a sort of control rotor, the paddles providing added stability by also dampening the effects of external forces on the rotor.

In fly by wire helicopters or RC models, a computer with gyroscopes and a venturi sensor can replace the stabilizer. This flybar-less design has the advantage of easy reconfiguration.

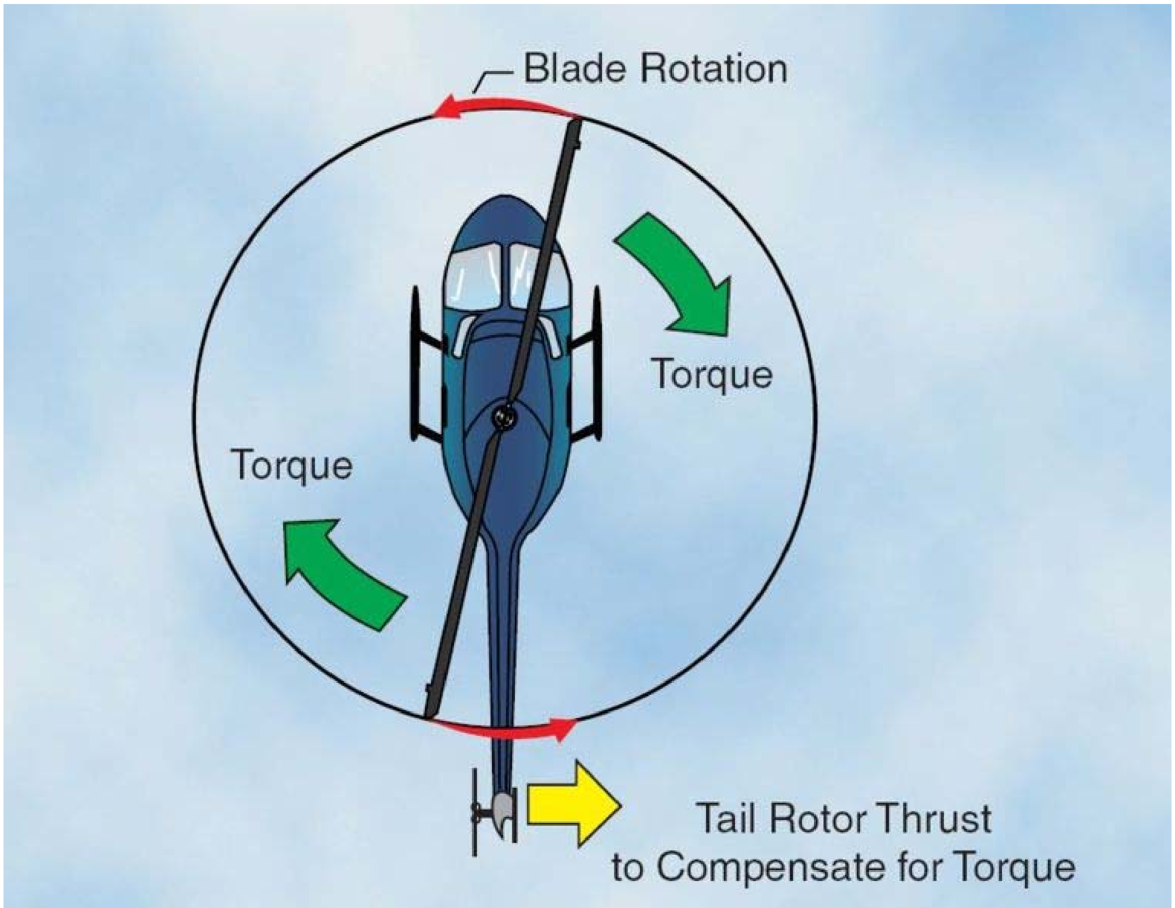
Combination

Modern rotor systems may use the combined principles of the rotor systems mentioned above. Some rotor hubs incorporate a flexible hub, which allows for blade bending (flexing) without the need for bearings or hinges. These systems, called "flextures", are usually constructed from composite material. Elastomeric bearings may also be used in place of conventional roller bearings. Elastomeric bearings are bearings constructed from a rubber type material and have limited movement that is perfectly suited for helicopter applications. Flextures and elastomeric bearings require no lubrication and, therefore, require less maintenance. They also absorb vibration, which means less fatigue and longer service life for the helicopter components.

Rotor configurations

Most helicopters have a single, main rotor but require a separate rotor to overcome torque. This is accomplished through a variable pitch, antitorque rotor or tail rotor. This is the design that Igor Sikorsky settled on for his VS-300 helicopter and it has become the recognized convention for helicopter design, although designs do vary. When viewed from above, the main rotors of helicopter designs from Germany, United Kingdom and the United States rotate counter-clockwise, all others rotate clockwise. This can make it difficult when discussing aerodynamic effects on the main rotor between different designs, since the effects may manifest on opposite sides of each aircraft.

Single main rotor



Antitorque: Torque effect on a helicopter

With a single main rotor helicopter, the creation of torque as the engine turns the rotor creates a torque effect that causes the body of the helicopter to turn in the opposite direction of the rotor. To eliminate this effect, some sort of antitorque control must be used, with a sufficient margin of power available to allow the helicopter to maintain its heading and provide yaw control. The three most common controls used today are the traditional *tail rotor*, Eurocopter's *Fenestron* (also called a *fantail*), and MD Helicopters' *NOTAR*.

Tail rotor of an SA 330 Puma

Tail rotor

The tail rotor is a smaller rotor mounted so that it rotates vertically or near-vertically at the end of the tail of a traditional single-rotor helicopter. The tail rotor's position and distance from the center of gravity allow it to develop thrust in a direction opposite of the main rotor's rotation, to counter the torque effect created by the main rotor. Tail rotors are simpler than main rotors since they require only collective changes in pitch to vary thrust. The pitch of the tail rotor blades is adjustable by the pilot via the anti-torque pedals, which also provide directional control by allowing the pilot to rotate the helicopter around its vertical axis (thereby changing the direction the craft is pointed).

Ducted fan

Fenestron on a EC 120B

Fenestron and FANTAIL are trademarks for a ducted fan mounted at the end of the tail boom of the helicopter and used in place of a tail rotor. Ducted fans have between eight and 18 blades arranged with irregular spacing, so that the noise is distributed over different frequencies. The housing is integral with the aircraft skin and allows a high rotational speed, therefore a ducted fan can have a smaller size than a conventional tail rotor.

The Fenestron was used for the first time at the end of the 1960s on the second experimental model of Sud Aviation's SA 340, and produced on the later model Aérospatiale SA 341 Gazelle. Besides Eurocopter and its predecessors, a ducted fan tail rotor was also used on the canceled military helicopter project, the United States Army's RAH-66 Comanche, as the FANTAIL.

NOTAR

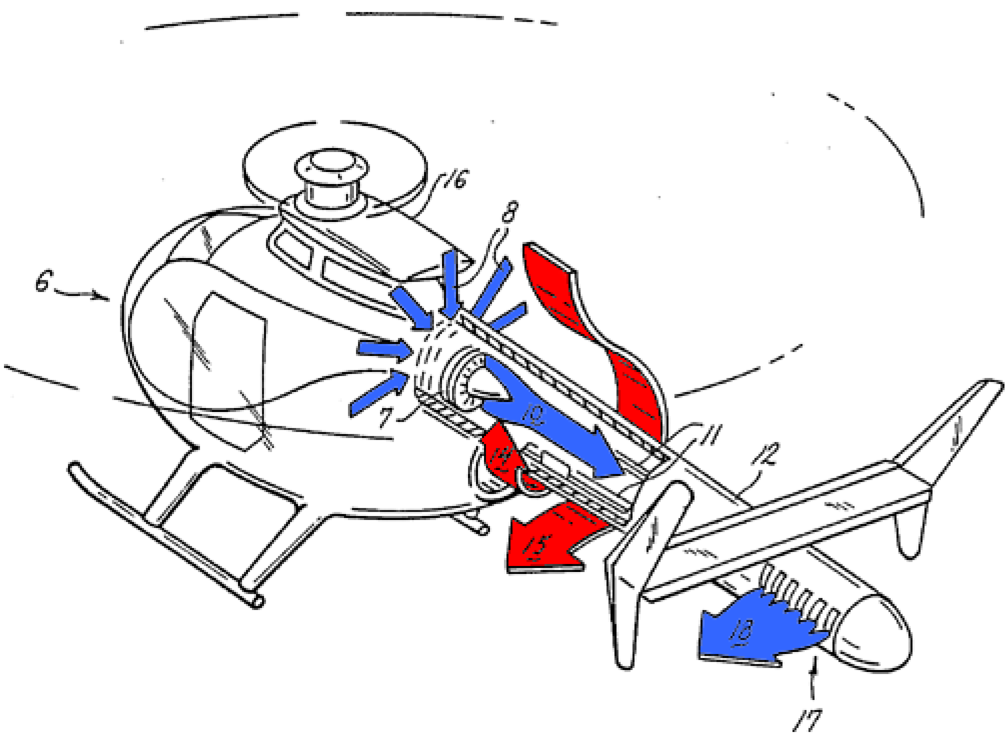


Diagram showing the movement of air through the NOTAR system

NOTAR, an acronym for ***NO TA****il* ***R****otor*, is a helicopter anti-torque system that eliminates the use of the tail rotor on a helicopter. Although the concept took some time to refine, the NOTAR system is simple in theory and works to provide antitorque the same way a wing develops lift using the Coandă effect. A variable pitch fan is enclosed in the aft fuselage section immediately forward of the tail boom and driven by the main rotor transmission. This fan forces low pressure air through two slots on the right side of the tailboom, causing the downwash from the main rotor to hug the tailboom, producing lift, and thus a measure of antitorque proportional to the amount of airflow from the rotorwash. This is augmented by a direct jet thruster (which also provides directional yaw control) and vertical stabilizers.

Development of the NOTAR system dates back to 1975 when engineers at Hughes Helicopters began concept development work. In December 1981 Hughes flew a OH-6A fitted with NOTAR for the first time. A more heavily modified prototype demonstrator first flew in March 1986 and successfully completed an advanced flight-test program, validating the system for future application in helicopter design. There are currently three production helicopters that incorporate the NOTAR design, all produced by MD Helicopters. This antitorque design also improves safety by eliminating the possibility of personnel walking into the tail rotor.

Tip jets

Another single main rotor configuration without a tail rotor is the tip jet rotor, where the main rotor is not driven by the mast, but from nozzles on the rotor blade tips; which are either pressurized from a fuselage-mounted gas turbine or have their own turbojet, ramjet or rocket thrusters. Although this method is simple and eliminates torque, the prototypes that have been built are less fuel efficient than conventional helicopters and produced more noise. The Percival P.74 was underpowered and was not able to achieve flight, while the Hiller YH-32 Hornet had good lifting capability but performed poorly otherwise. Other aircraft relied on supplemental thrust so that the tipjets could be shut down and the rotor could autorotate after the fashion of an autogyro. The experimental Fairey Jet Gyrodyne and 40-seat Fairey Rotodyne passenger prototype were evaluated to have flown very well using this method. Perhaps the most unusual design of this type was the Rotary Rocket Roton ATV, which was originally envisioned to take off utilizing a rocket-tipped rotor. No tip jet rotorcraft have ever entered into production.

Dual rotors (counterrotating)

Kamov Ka-50 of the Russian Air Force, with coaxial rotors

Counterrotating rotors are rotorcraft configurations with a pair or more of large horizontal rotors turning in opposite directions to counteract the effects of torque on the aircraft without relying on an antitorque tail rotor. This allows the power normally required to drive the tail rotor to be applied to the main rotors, increasing the aircraft's lifting capacity. Primarily, there are three common configurations that use the counterrotating effect to benefit the rotorcraft. Tandem rotors are two rotors with one mounted behind the other. Coaxial rotors are two rotors that are mounted one above the other with the same axis. Intermeshing rotors are two rotors that are mounted close to each other at a sufficient angle to allow the rotors to intermesh over the top of the aircraft. Another configuration found on tiltrotors and some earlier helicopters is called transverse rotors where the pair of rotors are mounted at each end of wing-type structures or outriggers.

Tandem

CH-47 Chinook

Tandem rotors are two horizontal main rotor assemblies mounted one behind the other. Tandem rotors achieve pitch attitude changes to accelerate and decelerate the helicopter through a process called differential collective pitch. To pitch forward and accelerate, the rear rotor increases collective pitch, raising the tail and the front rotor decreases collective pitch, simultaneously dipping the nose. To pitch upward while decelerating (or moving rearward), the front rotor increases collective pitch to raise the nose and the rear rotor decreases collective pitch to lower the tail. Yaw control is developed through opposing cyclic pitch in each rotor; to pivot right, the front rotor tilts right and the rear rotor tilts left, and to pivot left, the front rotor tilts left and the rear rotor tilts right. All of the rotor power contributes to lift, and it is simpler to handle changes in the center of gravity fore-aft. However, it requires the expense of two large rotors rather than the more common one large main rotor and a much smaller tail rotor. The CH-47 Chinook is the most common tandem rotor helicopter today.

Coaxial

Kamov Ka-50

Coaxial rotors are a pair of rotors mounted one above the other on the same shaft and turning in opposite directions. The advantage of the coaxial rotor is that, in forward flight, the lift provided by the advancing halves of each rotor compensates for the retreating half of the other, eliminating one of the key effects of dissymmetry of lift: retreating blade stall. However, other design considerations plague coaxial rotors. There is an increased mechanical complexity of the rotor system because it requires linkages and swashplates for two rotor systems. Add that each rotor system needs to be turned in opposite directions means that the mast itself is more complex, and provisions for making pitch changes to the upper rotor system must pass through the lower rotor system.

Intermeshing

HH-43 Huskie

Intermeshing rotors on a helicopter are a set of two rotors turning in opposite directions, with each rotor mast mounted on the helicopter with a slight angle to the other so that the blades intermesh without colliding. This configuration is sometimes referred to as a synchropter. Intermeshing rotors have high stability and powerful lifting capability. The arrangement was successfully used in Nazi Germany for a small anti-submarine warfare helicopter, the Flettner Fl 282 Kolibri. During the Cold War, the American company, Kaman Aircraft produced the HH-43 Huskie for the USAF firefighting and rescue missions. The latest Kaman model, the Kaman K-MAX, is a dedicated sky crane design.

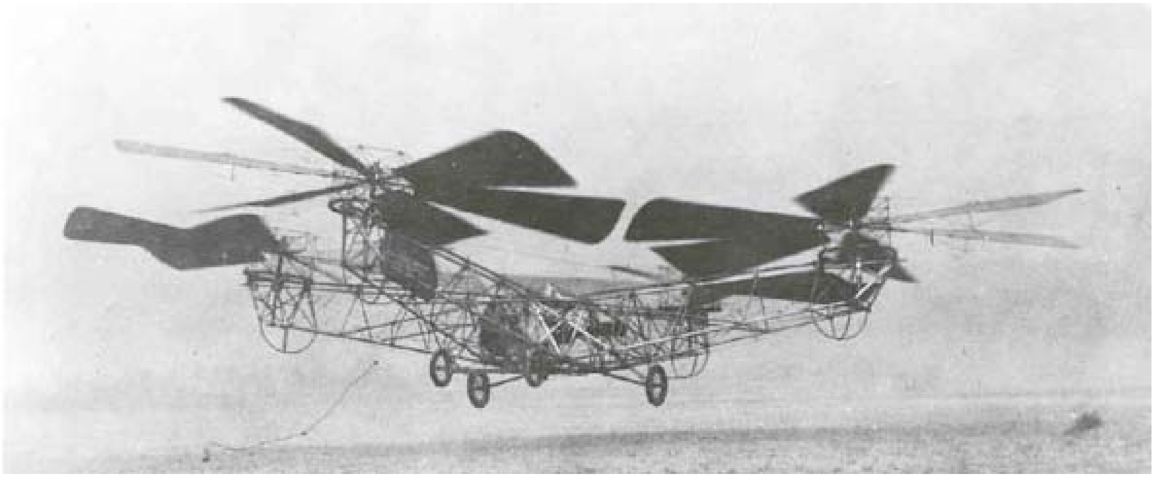
Transverse

Mi-12

Transverse rotors are mounted on the end of wings or outriggers, perpendicular to the body of the aircraft. Similar to tandem rotors and intermeshing rotors, the transverse rotor also uses differential collective pitch. But like the intermeshing rotors, the transverse rotors use the concept for changes in the roll attitude of the rotorcraft. This configuration is found on two of the first viable helicopters, the Focke-Wulf Fw 61 and the Focke-Achgelis Fa 223, as well as the world's largest helicopter ever built, the Mil Mi-12. It is also the configuration found on tiltrotors, such as Bell's XV-15 and the newer V-22 Osprey.

Quadrotor

Quadrotor



De Bothezat Quadrotor, 1923.

A quadrotor helicopter has four rotors in an "X" configuration designated as front-left, front-right, rear-left, and rear-right. Rotors to the left and right are in a transverse configuration while those in the front and to the rear are in a tandem configuration.

The main attraction of quadrotors is their mechanical simplicity—a quadrotor helicopter using electric motors and fixed-pitch rotors uses only four moving parts.

Blade design

The blades of a helicopter are long, narrow airfoils with a high aspect ratio, a shape which minimises drag from tip vortices. They generally contain a degree of washout to reduce the lift generated at the tips, where the airflow is fastest and vortex generation would be a significant problem. Rotor blades are made out of various materials, including aluminium, composite structure and steel or titanium with abrasion shields along the leading edge. Rotorcraft blades are traditionally passive, but research into active blade control trailing edge flaps is performed.

Limitations and hazards

Helicopters with teetering rotors, for example the two-blade system on the Bell, Robinson and others, must not be subjected to a low-g condition because such rotor systems do not control the fuselage attitude. This can result in the fuselage assuming an attitude controlled by momentum and tail rotor thrust that causes the tail boom to intersect the main rotor tip-path plane, or result in the blade roots contacting the main rotor drive shaft causing the blades to separate from the hub (mast bumping).

Abrasion in sandy environments

When operating in sandy environments, sand hitting the moving rotor blades erodes their surface. This can damage the rotors; the erosion also presents serious and costly maintenance problems.

The abrasion strips on helicopter rotor blades are made of metal, often titanium or nickel, which are very hard, but less hard than sand. When a helicopter is flown near to the ground in desert environments abrasion occurs from the sand striking the rotor blade. At night, the sand hitting the metal abrasion strip causes a visible corona or halo around the rotor blades. The corona effect is caused by the oxidation of eroded particles resulting in visible corona. In 2009, war correspondent Michael Yon referred to this corona effect as "Kopp-Etchells effect", to honor Cpl. Benjamin Kopp, and Cpl. Joseph Etchells, recently fallen American and British soldiers respectively.

Chapter-4

Air Traffic Control

Airport Traffic Control Towers (ATCTs) at Amsterdam's Schiphol Airport, the Netherlands

Air traffic control (**ATC**) is a service provided by ground-based controllers who direct aircraft on the ground and in the air. The primary purpose of ATC systems worldwide is to *separate* aircraft to prevent collisions, to organize and expedite the flow of traffic, and to provide information and other support for pilots when able. In some countries, ATC may also play a security or defense role (as in the United States), or be run entirely by the military (as in Brazil).

Preventing collisions is referred to as separation, which is a term used to prevent aircraft from coming too close to each other by use of lateral, vertical and longitudinal separation minima; many aircraft now have collision avoidance systems installed to act as a backup to ATC observation and instructions. In addition to its primary function, the ATC can provide additional services such as providing information to pilots, weather and navigation information and NOTAMs (*NOtices To AirMen*).

In many countries, ATC services are provided throughout the majority of airspace, and its services are available to all users (private, military, and commercial). When controllers are responsible for separating some or all aircraft, such airspace is called "controlled airspace" in contrast to "uncontrolled airspace" where aircraft may fly without the use of the air traffic control system. Depending on the type of flight and the class of airspace, ATC may issue *instructions* that pilots are required to follow, or merely *flight information* (in some countries known as *advisories*) to assist pilots operating in the airspace. In all cases, however, the pilot in command has final responsibility for the safety of the flight, and may deviate from ATC instructions in an emergency.

History

Contrails of aircraft entering and leaving Heathrow Airport. Intersecting flight paths are carefully controlled to prevent collisions.

In 1919, the International Commission for Air Navigation (ICAN) was created to develop General Rules for Air Traffic. Its rules and procedures were applied in most countries where aircraft operated. The United States did not sign the ICAN Convention, but later developed its own set of air traffic rules after passage of the Air Commerce Act of 1926. This legislation authorized the Department of Commerce to establish air traffic rules for the navigation, protection, and identification of aircraft, including rules as to safe altitudes of flight and rules for the prevention of collisions between vessels and aircraft. The first rules were brief and basic. For example, pilots were told not to begin their takeoff until there is no risk of collision with landing aircraft and until preceding aircraft are clear of the field. As traffic increased, some airport operators realized that such general rules were not enough to prevent collisions. They began to provide a form of air traffic control (ATC) based on visual signals. Early controllers, like Archie League (one of the first system's flagmen), stood on the field, waving flags to communicate with pilots.

As more aircraft were fitted for radio communication, radio-equipped airport traffic control towers began to replace the flagmen. In 1930, the first radio-equipped control tower in the United States began operating at the Cleveland Municipal Airport. By 1935, about 20 radio control towers were operating.

Increases in the number of flights created a need for ATC that was not just confined to airport areas but also extended out along the airways. In 1935, the principal airlines using the Chicago, Cleveland, and Newark airports agreed to coordinate the handling of airline traffic between those cities. In December, the first Airway Traffic Control Center opened at Newark, New Jersey. Additional centers at Chicago and Cleveland followed in 1936.

The early controllers tracked the position of planes using maps and blackboards and little boat-shaped weights that came to be called shrimp boats. They had no direct radio link with aircraft but used telephones to stay in touch with airline dispatchers, airway radio operators, and airport traffic controllers.

In July 1936, en route ATC became a federal responsibility and the first appropriation of $175,000 was made ($2,665,960 today). The Federal Government provided airway traffic control service, but local government authorities where the towers were located continued to operate those facilities.

In 1941, Congress appropriated funds for the Civil Aeronautics Administration (CAA) to construct and operate ATC towers, and soon the CAA began taking over operations at the first of these towers, with their number growing to 115 by 1944. In the postwar era, ATC at most airports was eventually to become a permanent federal responsibility. In response to wartime needs, the CAA also greatly expanded its en route air traffic control system.

The postwar years saw the beginning of a revolutionary development in ATC, the introduction of radar, a system that uses radio waves to detect distant objects. Originally developed by the British for military defense, this new technology allowed controllers to see the position of aircraft tracked on visual displays. In 1946, the CAA unveiled an experimental radar-equipped tower for control of civil flights. By 1952, the agency had begun its first routine use of radar for approach and departure control. Four years later, it placed a large order for long-range radars for use in en route ATC.

In 1960, the Federal Aviation Administration (FAA) began successful testing of a system under which flights in certain positive control areas were required to carry a radar beacon, called a transponder that identified the aircraft and helped to improve radar performance. Pilots in this airspace were also required to fly on instruments regardless of the weather and to remain in contact with controllers. Under these conditions, controllers were able to reduce the separation between aircraft by as much as half the standard distance.

For many years, pilots had negotiated a complicated maze of airways. In September 1964, the FAA instituted two layers of airways, one from 1,000 to 18,000 feet (305 to 5,486 meters) above ground level and the second from 18,000 to 45,000 feet (13,716 m) above mean sea level. It also standardized aircraft instrument settings and navigation checkpoints to reduce the controllers' workload.

From 1965 to 1975, the FAA developed complex computer systems that would replace the plastic markers for tracking aircraft thereby modernizing the National Airspace System. Controllers could now view information sent by aircraft transponders to form alphanumeric symbols on a simulated three dimensional radar screen. The system allowed controllers to focus on providing separation by automating complex tasks.

The FAA established a Central Flow Control Facility in April 1970, to prevent clusters of congestion from disrupting the nationwide air traffic flow. This type of ATC became increasingly sophisticated and important, and in 1994, the FAA opened a new Air Traffic Control System Command Center with advanced equipment.

In January 1982, the FAA unveiled the National Airspace System (NAS) Plan. The plan called for modernized flight service stations, more advanced systems for ATC, and improvements in ground-to-air surveillance and communication. Better computers and software were developed, air route traffic control centers were consolidated, and the number of flight service stations reduced. New Doppler Radars and better transponders complemented automatic, radio broadcasts of surface and flight conditions.

In July 1988, the FAA selected IBM to develop the new multi-billion-dollar Advanced Automation System (AAS) for the Nation's en route ATC centers. AAS would include controller workstations, called "sector suites," that would incorporate new display, communications and processing capabilities. The system had upgraded hardware enabling increased automation of complex tasks.

In December 1993, the FAA reviewed its order for the planned AAS. IBM was far behind schedule and had major cost overruns. In 1994 the FAA simplified its needs and picked new contractors. The revised modernization program continued under various project names. In 1999, controllers began their first use of an early version of the Standard

Terminal Automation Replacement System, which included new displays and capabilities for approach control facilities. During the following year, FAA completed deployment of the Display System Replacement, providing more efficient workstations for en route controllers.

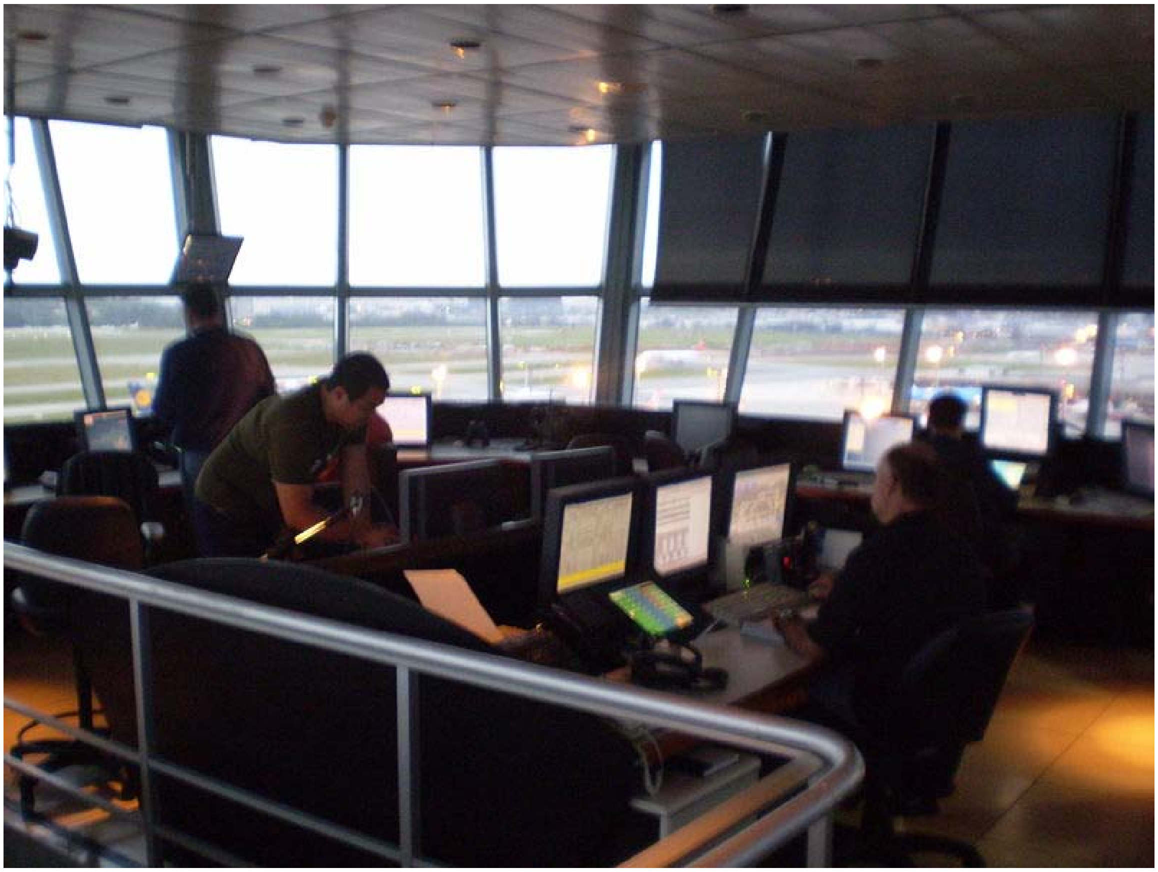
In 1994, the concept of Free Flight was introduced. It might eventually allow pilots to use on board instruments and electronics to maintain a safe distance between planes and to reduce their reliance on ground controllers. Full implementation of this concept would involve technology that made use of the Global Positioning System to help track the position of aircraft. In 1998, the FAA and industry began applying some of the early capabilities developed by the Free Flight program.

Current studies to upgrade ATC include the Communication, Navigation and Surveillance for Air Traffic Management System that relies on the most advanced aircraft transponder, a global navigation satellite system, and ultra-precise radar. Tests are underway to design new cockpit displays that will allow pilots to better control their aircraft by combining as many as 32 types of information about traffic, weather, and hazards.

Language

Pursuant to requirements of the International Civil Aviation Organization (ICAO), ATC operations are conducted either in the English language or the language used by the station on the ground. In practice, the native language for a region is normally used, however the English language must be used upon request.

Airport control



Inside the São Paulo-Guarulhos International Airport's tower, Latin America's second busiest airport.

The primary method of controlling the immediate airport environment is visual observation from the airport traffic control tower (ATCT). The ATCT is a tall, windowed structure located on the airport grounds. **Aerodrome** or **Tower** controllers are responsible for the separation and efficient movement of aircraft and vehicles operating on the taxiways and runways of the airport itself, and aircraft in the air near the airport, generally 5 to 10 nautical miles (3.7 to 9.2 km) depending on the airport procedures.

Radar displays are also available to controllers at some airports. Controllers may use a radar system called Secondary Surveillance Radar for airborne traffic approaching and departing. These displays include a map of the area, the position of various aircraft, and data tags that include aircraft identification, speed, heading, and other information described in local procedures.

The areas of responsibility for ATCT controllers fall into three general operational disciplines; Local Control or Air Control, Ground Control, and Flight Data/Clearance

Delivery—other categories, such as Apron Control or Ground Movement Planner, may exist at extremely busy airports. While each ATCT may have unique airport-specific procedures, such as multiple teams of controllers ('crews') at major or complex airports with multiple runways, the following provides a general concept of the delegation of responsibilities within the ATCT environment.

Ground control

Ground Control (sometimes known as Ground Movement Control abbreviated to GMC or Surface Movement Control abbreviated to SMC) is responsible for the airport "movement" areas, as well as areas not released to the airlines or other users. This generally includes all taxiways, inactive runways, holding areas, and some transitional aprons or intersections where aircraft arrive, having vacated the runway or departure gate. Exact areas and control responsibilities are clearly defined in local documents and agreements at each airport. Any aircraft, vehicle, or person walking or working in these areas is required to have clearance from Ground Control. This is normally done via VHF/UHF radio, but there may be special cases where other processes are used. Most aircraft and airside vehicles have radios. Aircraft or vehicles without radios must respond to ATC instructions via aviation light signals or else be led by vehicles with radios. People working on the airport surface normally have a communications link through which they can communicate with Ground Control, commonly either by handheld radio or even cell phone. Ground Control is vital to the smooth operation of the airport, because this position impacts the sequencing of departure aircraft, affecting the safety and efficiency of the airport's operation.

Some busier airports have Surface Movement Radar (SMR), such as, ASDE-3, AMASS or ASDE-X, designed to display aircraft and vehicles on the ground. These are used by Ground Control as an additional tool to control ground traffic, particularly at night or in poor visibility. There are a wide range of capabilities on these systems as they are being modernized. Older systems will display a map of the airport and the target. Newer systems include the capability to display higher quality mapping, radar target, data blocks, and safety alerts, and to interface with other systems such as digital flight strips.

Local control or air control

Local Control (known to pilots as "Tower" or "Tower Control") is responsible for the active runway surfaces. Local Control clears aircraft for takeoff or landing, ensuring that prescribed runway separation will exist at all times. If Local Control detects any unsafe condition, a landing aircraft may be told to "go-around" and be re-sequenced into the landing pattern by the approach or terminal area controller.

Within the ATCT, a highly disciplined communications process between Local Control and Ground Control is an absolute necessity. Ground Control must request and gain approval from Local Control to cross any active runway with any aircraft or vehicle. Likewise, Local Control must ensure that Ground Control is aware of any operations that will impact the taxiways, and work with the approach radar controllers to create "holes" or "gaps" in the arrival traffic to allow taxiing traffic to cross runways and to allow departing aircraft to take off. Crew Resource Management (CRM) procedures are often used to ensure this communication process is efficient and clear, although this is not as prevalent as CRM for pilots.

Flight data / clearance delivery

Clearance Delivery is the position that issues route clearances to aircraft, typically before they commence taxiing. These contain details of the route that the aircraft is expected to fly after departure. Clearance Delivery or, at busy airports, the Traffic Management Coordinator (TMC) will, if necessary, coordinate with the en route center and national command center or flow control to obtain releases for aircraft. Often, however, such releases are given automatically or are controlled by local agreements allowing "free-flow" departures. When weather or extremely high demand for a certain airport or airspace becomes a factor, there may be ground "stops" (or "slot delays") or re-routes may be necessary to ensure the system does not get overloaded. The primary responsibility of Clearance Delivery is to ensure that the aircraft have the proper route and slot time. This information is also coordinated with the en route center and Ground Control in order to ensure that the aircraft reaches the runway in time to meet the slot time provided by the command center. At some airports, Clearance Delivery also plans aircraft pushbacks and engine starts, in which case it is known as the Ground Movement Planner (GMP): this position is particularly important at heavily congested airports to prevent taxiway and apron gridlock.

Flight Data (which is routinely combined with Clearance Delivery) is the position that is responsible for ensuring that both controllers and pilots have the most current information: pertinent weather changes, outages, airport ground delays/ground stops, runway closures, etc. Flight Data may inform the pilots using a recorded continuous loop on a specific frequency known as the Automatic Terminal Information Service (ATIS).

Approach and terminal control

Potomac TRACON, Washington, D.C., United States.

Many airports have a radar control facility that is associated with the airport. In most countries, this is referred to as *Terminal Control*; in the U.S., it is referred to as a TRACON (Terminal Radar Approach Control.) While every airport varies, terminal controllers usually handle traffic in a 30 to 50 nautical mile (56 to 93 km) radius from the airport. Where there are many busy airports close together, one consolidated TRACON may service all the airports. The airspace boundaries and altitudes assigned to a TRACON, which vary widely from airport to airport, are based on factors such as traffic flows, neighboring airports and terrain. A large and complex example is the London Terminal Control Centre which controls traffic for five main London airports up to 20,000 feet (6,100 m) and out to 100 nautical miles (190 km).

Terminal controllers are responsible for providing all ATC services within their airspace. Traffic flow is broadly divided into departures, arrivals, and overflights. As aircraft move in and out of the terminal airspace, they are handed off to the next appropriate control facility (a control tower, an en-route control facility, or a bordering terminal or approach control). Terminal control is responsible for ensuring that aircraft are at an appropriate altitude when they are handed off, and that aircraft arrive at a suitable rate for landing.

Not all airports have a radar approach or terminal control available. In this case, the en-route center or a neighboring terminal or approach control may co-ordinate directly with the tower on the airport and vector inbound aircraft to a position from where they can land visually. At some of these airports, the tower may provide a non-radar procedural approach service to arriving aircraft handed over from a radar unit before they are visual to land. Some units also have a dedicated approach unit which can provide the procedural approach service either all the time or for any periods of radar outage for any reason.

En-route, center, or area control

The training department at the Washington Air Route Traffic Control Center, Washington, D.C., United States.

ATC provides services to aircraft in flight between airports as well. Pilots fly under one of two sets of rules for separation: Visual Flight Rules (VFR) or Instrument Flight Rules (IFR). Air traffic controllers have different responsibilities to aircraft operating under the different sets of rules. While IFR flights are under positive control, in the US VFR pilots can request flight following, which provides traffic advisory services on a time permitting basis and may also provide assistance in avoiding areas of weather and flight restrictions. In the UK, a pilot can request for "Deconfliction Service", which is similar to flight following.

En-route air traffic controllers issue clearances and instructions for airborne aircraft, and pilots are required to comply with these instructions. En-route controllers also provide air traffic control services to many smaller airports around the country, including clearance off of the ground and clearance for approach to an airport. Controllers adhere to a set of separation standards that define the minimum distance allowed between aircraft. These distances vary depending on the equipment and procedures used in providing ATC services.

General characteristics

En-route air traffic controllers work in facilities called Area Control Centers, each of which is commonly referred to as a "Center". The United States uses the equivalent term Air Route Traffic Control Center (ARTCC). Each center is responsible for many thousands of square miles of airspace (known as a Flight Information Region) and for the airports within that airspace. Centers control IFR aircraft from the time they depart from an airport or terminal area's airspace to the time they arrive at another airport or terminal area's airspace. Centers may also "pick up" VFR aircraft that are already airborne and integrate them into the IFR system. These aircraft must, however, remain VFR until the Center provides a clearance.

Center controllers are responsible for climbing the aircraft to their requested altitude while, at the same time, ensuring that the aircraft is properly separated from all other aircraft in the immediate area. Additionally, the aircraft must be placed in a flow consistent with the aircraft's route of flight. This effort is complicated by crossing traffic, severe weather, special missions that require large airspace allocations, and traffic density. When the aircraft approaches its destination, the center is responsible for meeting altitude restrictions by specific points, as well as providing many destination airports with a traffic flow, which prohibits all of the arrivals being "bunched together". These "flow restrictions" often begin in the middle of the route, as controllers will position aircraft landing in the same destination so that when the aircraft are close to their destination they are sequenced.

As an aircraft reaches the boundary of a Center's control area it is "handed off" or "handed over" to the next Area Control Center. In some cases this "hand-off" process involves a transfer of identification and details between controllers so that air traffic control services can be provided in a seamless manner; in other cases local agreements may allow "silent handovers" such that the receiving center does not require any co-ordination if traffic is presented in an agreed manner. After the hand-off, the aircraft is given a frequency change and begins talking to the next controller. This process continues until the aircraft is handed off to a terminal controller ("approach").

Radar coverage

Since centers control a large airspace area, they will typically use long range radar that has the capability, at higher altitudes, to see aircraft within 200 nautical miles (370 km) of the radar antenna. They may also use TRACON radar data to control when it provides a better "picture" of the traffic or when it can fill in a portion of the area not covered by the long range radar.

In the U.S. system, at higher altitudes, over 90% of the U.S. airspace is covered by radar and often by multiple radar systems; however, coverage may be inconsistent at lower altitudes used by unpressurized aircraft due to high terrain or distance from radar facilities. A center may require numerous radar systems to cover the airspace assigned to them, and may also rely on pilot position reports from aircraft flying below the floor of radar coverage. This results in a large amount of data being available to the controller. To address this, automation systems have been designed that consolidate the radar data for the controller. This consolidation includes eliminating duplicate radar returns, ensuring the best radar for each geographical area is providing the data, and displaying the data in an effective format.

Centers also exercise control over traffic travelling over the world's ocean areas. These areas are also FIRs. Because there are no radar systems available for oceanic control, oceanic controllers provide ATC services using procedural control. These procedures use aircraft position reports, time, altitude, distance, and speed to ensure separation. Controllers record information on flight progress strips and in specially developed oceanic computer systems as aircraft report positions. This process requires that aircraft be separated by greater distances, which reduces the overall capacity for any given route.

Some Air Navigation Service Providers (e.g. Airservices Australia, The Federal Aviation Administration, NAV CANADA, etc.) have implemented Automatic Dependent Surveillance - Broadcast (ADS-B) as part of their surveillance capability. This new technology reverses the radar concept. Instead of radar "finding" a target by interrogating the transponder, the ADS-equipped aircraft sends a position report as determined by the navigation equipment on board the aircraft. Normally, ADS operates in the "contract" mode where the aircraft reports a position, automatically or initiated by the pilot, based on a predetermined time interval. It is also possible for controllers to request more frequent reports to more quickly establish aircraft position for specific reasons. However, since the cost for each report is charged by the ADS service providers to the company operating the aircraft, more frequent reports are not commonly requested except in emergency situations. ADS is significant because it can be used where it is not possible to locate the infrastructure for a radar system (e.g. over water). Computerized radar displays are now being designed to accept ADS inputs as part of the display. This technology is currently used in portions of the North Atlantic and the Pacific by a variety of states who share responsibility for the control of this airspace.

Precision approach radars are commonly used by military controllers of airforces of several countries, to assist the Pilot in final phases of landing in places where Instrument Landing System and other sophisticated air borne equipements are unavailable to assist the pilots in marginal or *near zero visibility* conditions. This procedure is also called **Talkdowns**.

A Radar Archive System (RAS) keeps an electronic record of all radar information, preserving it for a few weeks. This information can be useful for search and rescue. When an aircraft has 'disappeared' from radar screens, a controller can review the last radar returns from the aircraft to determine its likely position. RAS is also useful to technicians who are maintaining radar systems.

Flight traffic mapping

The mapping of flights in real-time is based on the air traffic control system. In 1991, data on the location of aircraft was made available by the Federal Aviation Administration to the airline industry. The National Business Aviation Association (NBAA), the General Aviation Manufacturers Association, the Aircraft Owners & Pilots Association, the Helicopter Association International, and the National Air Transportation Association petitioned the FAA to make ASDI information available on a "need-to-know" basis. Subsequently, NBAA advocated the broad-scale dissemination of air traffic data. The Aircraft Situational Display to Industry (ASDI) system now conveys up-to-date flight information to the airline industry and the public. Some companies that distribute ASDI information are FlightExplorer, FlightView, and FlyteComm. Each company maintains a website that provides free updated information to the public on flight status. Stand-alone programs are also available for displaying the geographic location of airborne IFR (Instrument Flight Rules) air traffic anywhere in the FAA air traffic system. Positions are reported for both commercial and general aviation traffic. The programs can overlay air traffic with a wide selection of maps such as, geo-political boundaries, air traffic control center boundaries, high altitude jet routes, satellite cloud and radar imagery.

Problems

Traffic

The day-to-day problems faced by the air traffic control system are primarily related to the volume of air traffic demand placed on the system and weather. Several factors dictate the amount of traffic that can land at an airport in a given amount of time. Each landing aircraft must touch down, slow, and exit the runway before the next crosses the approach end of the runway. This process requires at least one and up to four minutes for each aircraft. Allowing for departures between arrivals, each runway can thus handle about 30 arrivals per hour. A large airport with two arrival runways can handle about 60 arrivals per hour in good weather. Problems begin when airlines schedule more arrivals into an airport than can be physically handled, or when delays elsewhere cause groups of aircraft that would otherwise be separated in time to arrive simultaneously. Aircraft must then be delayed in the air by holding over specified locations until they may be safely sequenced to the runway. Up until the 1990s, holding, which has significant environmental and cost implications, was a routine occurrence at many airports. Advances in computers now allow the sequencing of planes hours in advance. Thus, planes may be delayed before they even take off (by being given a "slot"), or may reduce speed in flight and proceed more slowly thus significantly reducing the amount of holding.

Weather

Beyond runway capacity issues, weather is a major factor in traffic capacity. Rain, ice or snow on the runway cause landing aircraft to take longer to slow and exit, thus reducing the safe arrival rate and requiring more space between landing aircraft. Fog also requires a decrease in the landing rate. These, in turn, increase airborne delay for holding aircraft. If more aircraft are scheduled than can be safely and efficiently held in the air, a ground delay program may be established, delaying aircraft on the ground before departure due to conditions at the arrival airport.

In Area Control Centers, a major weather problem is thunderstorms, which present a variety of hazards to aircraft. Aircraft will deviate around storms, reducing the capacity of the en-route system by requiring more space per aircraft, or causing congestion as many aircraft try to move through a single hole in a line of thunderstorms. Occasionally weather considerations cause delays to aircraft prior to their departure as routes are closed by thunderstorms.

Much money has been spent on creating software to streamline this process. However, at some ACCs, air traffic controllers still record data for each flight on strips of paper and personally coordinate their paths. In newer sites, these flight progress strips have been replaced by electronic data presented on computer screens. As new equipment is brought in, more and more sites are upgrading away from paper flight strips.

Call signs

A prerequisite to safe air traffic separation is the assignment and use of distinctive call signs. These are permanently allocated by ICAO (pronounced "ai-kay-oh") on request usually to scheduled flights and some air forces for military flights. They are written callsigns with 3-letter combination like KLM, AAL, SWA, BAW, VLG followed by the flight number, like AAL872, VLG1011. As such they appear on flight plans and ATC radar labels. There are also the *audio* or *Radio-telephony* callsigns used on the radio contact between pilots and Air Traffic Control not always identical with the written ones. For example BAW symbolises British Airways but on the radio you will only hear the word *Speedbird* followed by an alpha-numeric code instead. By default, the callsign for any other flight is the registration number (tail number) of the aircraft, such as "N12345", "C-GABC" or "EC-IZD". The term *tail number* is because a registration number is usually painted somewhere on the tail of a plane, yet this is not a rule. Registration numbers may appear on the engines, anywhere on the fuselage, and often on the wings. The short *Radio-telephony* callsigns for these tail numbers is the last 3 letters only like ABC spoken Alpha-Bravo-Charlie for C-GABC or the last 3 numbers like 345 spoken as TREE-FORE-FIFE for N12345. In the United States the abbreviation of callsigns is required to be a prefix (such as aircraft type, aircraft manufacturer, or first letter of registration) followed by the last three characters of the callsign. This abbreviation is only allowed after communications has been established in each sector.

The flight number part is decided by the aircraft operator. In this arrangement, an identical call sign might well be used for the same scheduled journey each day it is operated, even if the departure time varies a little across different days of the week. The call sign of the return flight often differs only by the final digit from the outbound flight. Generally, airline flight numbers are even if eastbound, and odd if westbound. In order to reduce the possibility of two callsigns on one frequency at any time sounding too similar, a number of airlines, particularly in Europe, have started using alphanumeric callsigns that are not based on flight numbers. For example DLH23LG, spoken as lufthansa-two-tree-lima-golf. Additionally it is the right of the air traffic controller to change the 'audio' callsign for the period the flight is in his sector if there is a risk of confusion, usually choosing the tail number instead.

Before around 1980 International Air Transport Association (IATA) and ICAO were using the same 2-letter callsigns. Due to the larger number of new airlines after deregulation ICAO established the 3-letter callsigns as mentioned above. The IATA callsigns are currently used in aerodromes on the announcement tables but never used any longer in Air Traffic Control. For example, AA is the IATA callsign for American Airlines — ATC equivalent AAL. Other examples include LY/ELY for El Al, DL/DAL for Delta Air Lines, VY/VLG for Vueling Airlines, etc.

Technology

Many technologies are used in air traffic control systems. Primary and secondary radar are used to enhance a controller's situation awareness within his assigned airspace — all types of aircraft send back primary echoes of varying sizes to controllers' screens as radar energy is bounced off their skins, and transponder-equipped aircraft reply to secondary radar interrogations by giving an ID (Mode A), an altitude (Mode C) and/or a unique callsign (Mode S). Certain types of weather may also register on the radar screen.

These inputs, added to data from other radars, are correlated to build the air situation. Some basic processing occurs on the radar tracks, such as calculating ground speed and magnetic headings.

Usually, a Flight Data Processing System manages all the flight plan related data, incorporating - in a low or high degree - the information of the track once the correlation between them (flight plan and track) is established. All this information is distributed to modern operational display systems, making it available to controllers.

The FAA has spent over USD$3 billion on software, but a fully-automated system is still over the horizon. In 2002 the UK brought a new area control centre into service at Swanwick, in Hampshire, relieving a busy suburban centre at West Drayton in Middlesex, north of London Heathrow Airport. Software from Lockheed-Martin predominates at Swanwick. However, Swanwick was initially troubled by software and communications problems causing delays and occasional shutdowns.

Some tools are available in different domains to help the controller further:

- Flight Data Processing Systems: this is the system (usually one per Center) that processes all the information related to the Flight (the Flight Plan), typically in the time horizon from Gate to gate (airport departure/arrival gates). It uses such processed information to invoke other Flight Plan related tools (such as e.g. MTCD), and distributes such processed information to all the stakeholders (Air Traffic Controllers, collateral Centers, Airports, etc.).
- Short Term Conflict Alert (STCA) that checks possible conflicting trajectories in a time horizon of about 2 or 3 minutes (or even less in approach context - 35 seconds in the French Roissy & Orly approach centres) and alerts the controller prior to the loss of separation. The algorithms used may also provide in some systems a possible vectoring solution, that is, the manner in which to turn, descend, or climb the aircraft in order to avoid infringing the minimum safety distance or altitude clearance.
- Minimum Safe Altitude Warning (MSAW): a tool that alerts the controller if an aircraft appears to be flying too low to the ground or will impact terrain based on its current altitude and heading.
- System Coordination (SYSCO) to enable controller to negotiate the release of flights from one sector to another.
- Area Penetration Warning (APW) to inform a controller that a flight will penetrate a restricted area.
- Arrival and Departure Manager to help sequence the takeoff and landing of aircraft.
    - The Departure Manager (DMAN): A system aid for the ATC at airports, that calculates a planned departure flow with the goal to maintain an optimal throughput at the runway, reduce queuing at holding point and distribute the information to various stakeholders at the airport (i.e. the airline, ground handling and Air Traffic Control (ATC)).
    - The Arrival Manager (AMAN): A system aid for the ATC at airports, that calculates a planned Arrival flow with the goal to maintain an optimal throughput at the runway, reduce arrival queuing and distribute the information to various stakeholders.
    - passive Final Approach Spacing Tool (pFAST), a CTAS tool, provides runway assignment and sequence number advisories to terminal controllers to improve the arrival rate at congested airports. pFAST was deployed and operational at five US TRACONs before being cancelled. NASA research included an Active FAST capability that also provided vector and speed advisories to implement the runway and sequence advisories.
- Converging Runway Display Aid (CRDA) enables Approach controllers to run two final approaches that intersect and make sure that go arounds are minimized
- Center TRACON Automation System (CTAS) is a suite of human centered decision support tools developed by NASA Ames Research Center. Several of the CTAS tools have been field tested and transitioned to the FAA for operational evaluation and use. Some of the CTAS tools are: Traffic Management Advisor

(TMA), passive Final Approach Spacing Tool (pFAST), Collaborative Arrival Planning (CAP), Direct-To (D2), En Route Descent Advisor (EDA) and Multi Center TMA. The software is running on linux.

- Traffic Management Advisor (TMA), a CTAS tool, is an en route decision support tool that automates time based metering solutions to provide an upper limit of aircraft to a TRACON from the Center over a set period of time. Schedules are determined that will not exceed the specified arrival rate and controllers use the scheduled times to provide the appropriate delay to arrivals while in the en route domain. This results in an overall reduction in en route delays and also moves the delays to more efficient airspace (higher altitudes) than occur if holding near the TRACON boundary is required to not overload the TRACON controllers. TMA is operational at most en route air route traffic control centers (ARTCCs) and continues to be enhanced to address more complex traffic situations (e.g. Adjacent Center Metering (ACM) and En Route Departure Capability (EDC))
- MTCD & URET
    - In the US, User Request Evaluation Tool (URET) takes paper strips out of the equation for En Route controllers at ARTCCs by providing a display that shows all aircraft that are either in or currently routed into the sector.
    - In Europe, several MTCD tools are available: iFACTS (NATS), ERATO (DSNA fr:DSNA), VAFORIT (DFS), New FDPS (MASUAC). The SESAR Programme should soon launch new MTCD concepts.

URET and MTCD provide conflict advisories up to 30 minutes in advance and have a suite of assistance tools that assist in evaluating resolution options and pilot requests.

- Mode S: provides a data downlink of flight parameters via Secondary Surveillance Radars allowing radar processing systems and therefore controllers to see various data on a flight, including airframe unique id (24-bits encoded), indicated airspeed and flight director selected level, amongst others.
- CPDLC: Controller Pilot Data Link Communications — allows digital messages to be sent between controllers and pilots, avoiding the need to use radiotelephony. It is especially useful in areas where difficult-to-use HF radiotelephony was previously used for communication with aircraft, e.g. oceans. This is currently in use in various parts of the world including the Atlantic and Pacific oceans.
- ADS-B: Automatic Dependent Surveillance Broadcast — provides a data downlink of various flight parameters to air traffic control systems via the Transponder (1090 MHz) and reception of those data by other aircraft in the vicinity. The most important is the aircraft's latitude, longitude and level: such data can be utilized to create a radar-like display of aircraft for controllers and thus allows a form of pseudo-radar control to be done in areas where the installation of radar is either prohibitive on the grounds of low traffic levels, or technically not feasible (e.g. oceans). This is currently in use in Australia, Canada and parts of the Pacific Ocean and Alaska.

- The Electronic Flight Strip system (e-strip): A system of electronic flight strips replacing the old paper strips is being used by several Service Providers, such as NAV CANADA, MASUAC, DFS, being produced by several industries, such as Indra Sistemas, Thales Group, Frequentis, Avibit, SAAB etc. E-strips allows controllers to manage electronic flight data online without Paper Strips, reducing the need for manual functions.
- Screen Content Recording: Hardware or software based recording function which is part of most modern Automation System and that captures the screen content shown to of the ATCO. Such recordings are used for a later replay together with audio recording for investigations and post event analysis.

Major accidents

A list of recent accidents can be found in this list.

On July 1, 2002 a Tupolev Tu-154 and Boeing 757 collided above Überlingen near the boundary between German and Swiss-controlled airspace when a Skyguide-employed controller (Peter Nielsen who was murdered by a relative of people who died in the crash), unaware that the flight was receiving instruction from the on-board automatic Traffic Collision Avoidance System software to climb, instructed the southbound Tupolev to descend.

The deadliest mid-air crash, the 1996 Charkhi Dadri mid-air collision over India, partly resulted from the fact that the New Delhi-area airspace was shared by departures and arrivals, when in most cases departures and arrivals would use separate airspaces. However investigations later found that the causative factor for this mid air accident was non adherence to air traffic control instructions by not maintaining **the assigned flight level** during descent phase by the pilot.

The deadliest collision between airliners took place on the ground, on March 27, 1977, in what is known as the Tenerife disaster, although ATC is only partly to blame for this incident.

Air navigation service providers (ANSPs) and traffic service providers (ATSPs)

The regulatory function remains the responsibility of the State and can be exercised by Government and/or independent Safety, Airspace and Economic Regulators depending on the national institutional arrangements. Often you will see a division between the Civil Aviation Authority (CAA) (the Regulator) and the ANSP (the Air Navigation Service Provider).

An Air Navigation Service Provider — The air navigation service provider is the authority directly responsible for providing both visual and non-visual aids to navigation within a specific airspace in compliance with, but not limited to, International Civil

Aviation Organization (ICAO) Annexes 2, 6, 10 and 11; ICAO Documents 4444 and 9426; and, other international, multi-national, and national policy, agreements or regulations.

An Air Traffic Service Provider is the relevant authority designated by the State responsible for providing air traffic services in the airspace concerned. *Air traffic services* is generic and can mean: flight information service, alerting service, air traffic advisory service, air traffic control service (area control service, approach control service or aerodrome control service), etc.

Both ANSPs and ATSPs can be public, private or corporatized organisations and examples of the different legal models exist throughout the world today. The world's ANSPs are united in and represented by the Civil Air Navigation Services Organisation (CANSO) based at Amsterdam Airport Schiphol in the Netherlands.

In the United States, the Federal Aviation Administration (FAA) provides this service to all aircraft in the National Airspace System (NAS). With the exception of facilities operated by the Department of Defense (DoD), the FAA is responsible for all aspects of U.S. Air Traffic Control including hiring and training controllers, although there are contract towers located in many parts of the country. A contract tower is an Airport Traffic Control Tower (ATCT) that performs the same function as an FAA-run ATCT but is staffed by employees of a private company (Martin State Airport in Maryland is an example). DoD facilities are generally staffed by military personnel and operate separately but concurrently with FAA facilities, under similar rules and procedures. In Canada, Air Traffic Control is provided by NAV CANADA, a private, non-share capital corporation that operates Canada's civil air navigation service.

- Albania - Agjencia Nacionale e Trafikut Ajror
- Armenia - Armenian Air Traffic Services (ARMATS)
- Austria - Austro Control
- Australia - Airservices Australia (State Owned Corporation) and Royal Australian Air Force.
- Belarus - Republican Unitary Enterprise "Белаэронавигация (Belarusian Air Navigation)"
- Belgium - Belgocontrol
- Brazil - Departmento de Controle de Tráfego Aéreo (Military Authority) and ANAC - Agência Nacional de Aviação Civil
- Bulgaria - Air Traffic Services Authority
- Canada - NAV CANADA - formerly provided by Transport Canada and Canadian Forces
- Central America - Corporación Centroamericana de Servicios de Navegación Aérea
    - Guatemala - DGAC (Dirección General de Aeronáutica Civil)
    - El Salvador
    - Honduras
    - Nicaragua

    - Costa Rica - Dirección General de Aviación Civil
    - Belize
- Colombia - (UAEAC) Aeronáutica Civil Colombiana
- Croatia - Hrvatska kontrola zračne plovidbe (Croatia Control Ltd.)
- Cuba - IACC (Instituto de Aeronáutica Civil de Cuba)
- Czech Republic - Řízení letového provozu ČR
- Denmark - Naviair (Danish ATC)
- Dominican Republic - IDAC (Instituto Dominicano de Aviación Civil) "Dominican Institute of Civil Aviation"
- Estonia - Estonian Air Navigation Services
- Europe - Eurocontrol - (European Organisation for the Safety of Air Navigation)
- Finland - Finavia
- France - Direction Générale de l'Aviation Civile (DGAC): Direction des Services de la Navigation Aérienne (DSNA) (Government body)
- Georgia - SAKAERONAVIGATSIA, Ltd. (Georgian Air Navigation)
- Germany - Deutsche Flugsicherung (German ATC - State-owned company)
- Greece - Hellenic Civil Aviation Authority (HCAA)
- Hong Kong - CAD (Civil Aviation Department)
- Hungary - HungaroControl Magyar Légiforgalmi Szolgálat Zrt. (HungaroControl Hungarian Air Navigation Services Pte. Ltd. Co.)
- Iceland - ISAVIA
- Indonesia - Angkasa Pura II
- Ireland - IAA (Irish Aviation Authority)
- India - Airports Authority of India (AAI) (under Ministry of Civil Aviation, Government Of India)
- Italy - ENAV (Italian ATC)(Ente Nazionale Assistenza al Volo - Italian ATC)
- Jamaica - JCAA (Jamaica Civil Aviation Authority)
- Latvia - LGS (Latvian ATC)
- Lithuania - ANS (Lithuanian ATC)
- Macedonia - DGCA (Macedonian ATC)
- Malaysia - DCA-Department of Civil Aviation
- Malta - Malta Air Traffic Services Ltd
- Mexico - Servicios a la Navegación en el Espacio Aéreo Mexicano
- Nepal - Civil Aviation Authority of Nepal
- Netherlands - Luchtverkeersleiding Nederland (LVNL) (Dutch ATC) Eurocontrol (European area control ATC)
- New Zealand - Airways New Zealand (State Owned Enterprise)
- Norway - Avinor (State-owned private company)
- Pakistan - Civil Aviation Authority (under Government of Pakistan)
- Peru - Centro de Instrucción de Aviación Civil CIAC Civil Aviation Training Center
- Philippines - Civil Aviation Authority of the Philippines (CAAP) (under the Philippine Government)
- Poland - PANSA - Polish Air Navigation Services Agency
- Portugal - NAV - NAV (Portuguese ATC)

- Romania - Romanian Air Traffic Services Administration - (ROMATSA)
- Russia - Federal State Unitary Enterprise "State ATM Corporation" - (State ATM Corporation)
- Saudi Arabia - General Authority of Civil Aviation (GACA)
- Singapore - CAAS (Civil Aviation Authority of Singapore)
- Serbia - Serbia and Montenegro Air Traffic Services Agency Ltd. (SMATSA)
- Slovakia - Letové prevádzkové služby Slovenskej republiky
- Slovenia - Slovenia Control
- South Africa - Air Traffic and Navigation Services,
- Spain - AENA (Spanish ATC and Airports)
- Sweden - The LFV Group (Swedish ATC)
- Switzerland - Skyguide
- Taiwan - ANWS Civil Aeronautical Administration
- Thailand - AEROTHAI (Aeronautical Radio of Thailand)
- Trinidad and Tobago - TTCAA (Trinidad and Tobago Civil Aviation Authority)
- Turkey - DGCA (Turkish Directorate General of Civil Aviation)
- United Arab Emirates - General Civil Aviation Authority (GCAA)
- United Kingdom - National Air Traffic Services (49% State Owned Public-Private Partnership)
- United States - Federal Aviation Administration (Government Body)
- Ukraine - Ukrainian State Air Traffic Service Enterprise (UkSATSE)
- Venezuela - INAC (Instituto Nacional de Aviación Civil)

Proposed changes

In the United States, some alterations to traffic control procedures are being examined.

- The Next Generation Air Transportation System examines how to overhaul the United States national airspace system.
- Free flight is a developing air traffic control method that uses no centralized control (e.g. air traffic controllers). Instead, parts of airspace are reserved dynamically and automatically in a distributed way using computer communication to ensure the required separation between aircraft.

In Europe, the SESAR (Single European Sky ATM Research) Programme plans to develop new methods, new technologies, new procedures, new systems to accommodate future (2020 and beyond) Air Traffic Needs.

Many countries have also privatized or corporatized their air navigation service providers.

Chapter-5

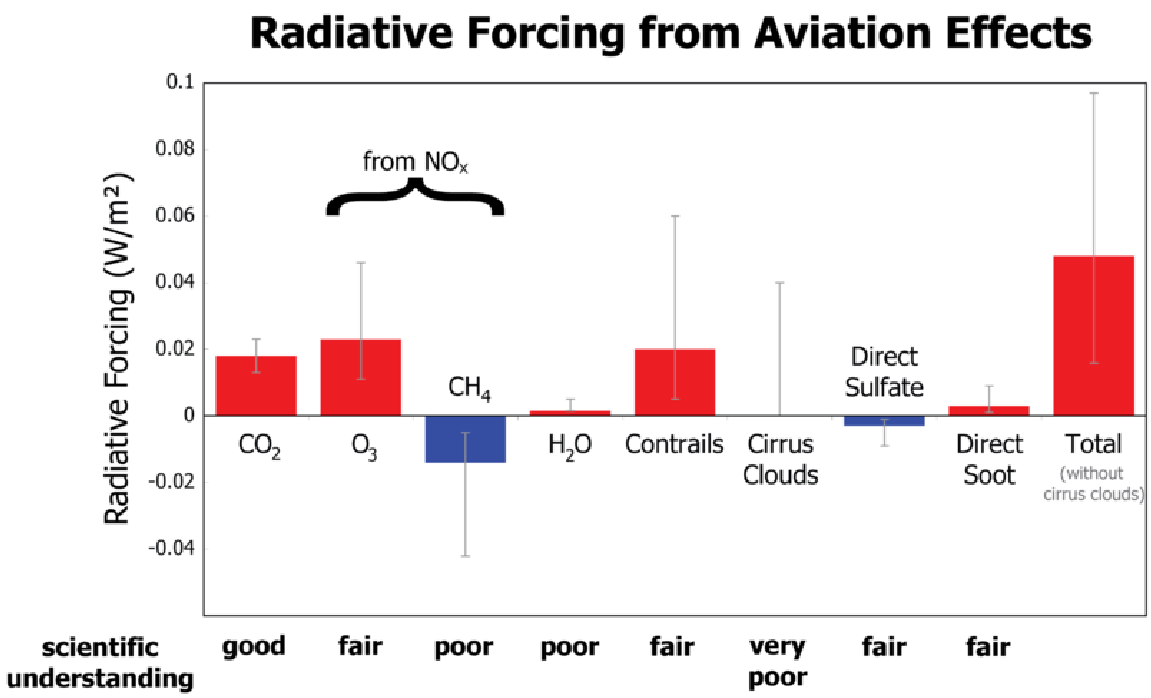
Aviation and the Environment

A C-141 Starlifter leaves exhaust contrails over Antarctica.

Aviation impacts the environment because aircraft engines emit noise, particulates, and gases which contribute to climate change and global dimming. Despite emission reductions from automobiles and more fuel-efficient and less polluting turbofan and turboprop engines, the rapid growth of air travel in recent years contributes to an increase in total pollution attributable to aviation. In the EU, greenhouse gas emissions from aviation increased by 87% between 1990 and 2006.

There is an ongoing debate about possible taxation of air travel and the inclusion of aviation in an emissions trading scheme, with a view to ensuring that the total external costs of aviation are taken into account.

Climate change



Radiative forcings from aviation emissions (gases and aerosols) in 1992 as estimated by the IPCC

Like all human activities involving combustion, most forms of aviation release carbon dioxide (CO_2) into the Earth's atmosphere, contributing to the acceleration of global warming.

In addition to the CO_2 released by most aircraft in flight through the burning of fuels such as Jet-A (turbine aircraft) or Avgas (piston aircraft), the aviation industry also contributes greenhouse gas emissions from ground airport vehicles and those used by passengers and staff to access airports, as well as through emissions generated by the production of energy used in airport buildings, the manufacture of aircraft and the construction of airport infrastructure.

While the principal greenhouse gas emission from powered aircraft in flight is CO_2, other emissions may include nitric oxide and nitrogen dioxide, (together termed oxides of nitrogen or NO_x), water vapour and particulates (soot and sulfate particles), sulfur oxides, carbon monoxide (which bonds with oxygen to become CO_2 immediately upon release), incompletely burned hydrocarbons, tetra-ethyl lead (piston aircraft only), and radicals such as hydroxyl, depending on the type of aircraft in use.

The contribution of civil aircraft-in-flight to global CO_2 emissions has been estimated at around 2%. However, in the case of high-altitude airliners which frequently fly near or in the stratosphere, non-CO_2 altitude-sensitive effects may increase the total impact on anthropogenic (man-made) climate change significantly.

Mechanisms

Subsonic aircraft-in-flight contribute to climate change in four ways:

Carbon dioxide (CO_2)

CO_2 emissions from aircraft-in-flight are the most significant and best understood element of aviation's total contribution to climate change. The level and effects of CO_2 emissions are currently believed to be broadly the same regardless of altitude (i.e. they have the same atmospheric effects as ground based emissions). In 1992, emissions of CO_2 from aircraft were estimated at around 2% of all such anthropogenic emissions, though CO_2 concentration attributable to aviation in 1992 was around 1% of the total anthropogenic increase, because emissions occurred only in the last 50 years.

Oxides of nitrogen (NO_x)

At the high altitudes flown by large jet airliners around the tropopause, emissions of NO_x are particularly effective in forming ozone (O_3) in the upper troposphere. High altitude (8-13km) NO_x emissions result in greater concentrations of O_3 than surface NO_x emissions, and these in turn have a greater global warming effect. The effect of O_3 concentrations are regional and local (as opposed to CO_2 emissions, which are global).

NO_x emissions also reduce ambient levels of methane, another greenhouse gas, resulting in a climate cooling effect. But this effect does not offset the O_3 forming effect of NO_x emissions. It is now believed that aircraft sulfur and water emissions in the stratosphere tend to deplete O_3, partially offsetting the NO_x-induced O_3 increases. These effects have not been quantified. This problem does not apply to aircraft that fly lower in the troposphere, such as light aircraft or many commuter aircraft.

Water vapor (H_2O)

Contrails

Cirrus cloud formation

One of the products of burning hydrocarbons in oxygen is water vapour, a greenhouse gas. Water vapour produced by aircraft engines at high altitude, under certain atmospheric conditions, condenses into droplets to form Condensation trails, or contrails. Contrails are visible line clouds that form in cold, humid atmospheres and are thought to have a global warming effect (though one less significant than either CO_2 emissions or NO_x induced effects) SPM-2. Contrails are extremely rare from lower-altitude aircraft, or from propeller aircraft or rotorcraft.

Cirrus clouds have been observed to develop after the persistent formation of contrails and have been found to have a global warming effect over-and-above that of contrail formation alone. There is a degree of scientific uncertainty about the contribution of contrail and cirrus cloud formation to global warming and attempts to estimate aviation's overall climate change contribution do not tend to include its effects on cirrus cloud enhancement.

Particulates

Least significant is the release of soot and sulfate particles. Soot absorbs heat and has a warming effect; sulfate particles reflect radiation and have a small cooling effect. In addition, they can influence the formation and properties of clouds. All aircraft powered by combustion will release some amount of soot.

Emissions per passenger kilometre

Emissions of passenger aircraft per passenger kilometre vary extensively, according to variables such as the size of the aircraft, the number of passengers on board, and the altitude and distance of the journey (the practical effect of emissions at high altitides may be greater than those of emissions at low altitudes). However, some representative figures for emissions are provided by LIPASTO's survey of average passenger aircraft emissions per passenger kilometre in Finland 2008: expressed as CO_2 equivalent,

- Domestic, short distance, less than 463 km (288 mi): 259 g (9 oz)
- Domestic, long distance, greater than 463 km (288 mi): 178 g (6 oz)
- Long distance flights: 114 g (4 oz)

This is similar to the emissions from a four-seat car with one person on board.

Per passenger kilometre, figures from British Airways suggest carbon dioxide emissions of 0.1 kg for large jet airliners (a figure which does not account for the production of other pollutants or condensation trails).

Total effect

In attempting to aggregate and quantify the climate impact of aircraft emissions the Intergovernmental Panel on Climate Change (IPCC) has estimated that aviation's total climate impact is some 2-4 times that of its CO_2 emissions alone (excluding the potential impact of cirrus cloud enhancement). This is measured as radiative forcing. While there is uncertainty about the exact level of impact of NO_x and water vapour, governments have accepted the broad scientific view that they do have an effect. Accordingly, more recent UK government policy statements have stressed the need for aviation to address its total climate change impacts and not simply the impact of CO_2.

The IPCC has estimated that aviation is responsible for around 3.5% of anthropogenic climate change, a figure which includes both CO_2 and non-CO_2 induced effects. The IPCC has produced scenarios estimating what this figure could be in 2050. The central case estimate is that aviation's contribution could grow to 5% of the total contribution by 2050 if action is not taken to tackle these emissions, though the highest scenario is 15%. Moreover, if other industries achieve significant cuts in their own greenhouse gas emissions, aviation's share as a proportion of the remaining emissions could also rise.

Potential reductions

Modern jet aircraft are significantly more fuel efficient (and thus emit less CO_2 in particular) than 30 years ago.. Moreover, manufacturers have forecast and are committed to achieving reductions in both CO_2 and NO_x emissions with each new generation of design of aircraft and engine. Thus, the accelerated introduction of more modern aircraft represents a major opportunity to reduce emissions per passenger kilometre flown.

Other opportunities arise from the optimisation of airline timetables, route networks and flight frequencies to increase load factors (minimise the number of empty seats flown), together with the optimisation of airspace.

Another possible reduction of the climate-change impact is the limitation of cruise altitude of aircraft. This would lead to a significant reduction in high-altitude contrails for a marginal trade-off of increased flight time and an estimated 4% increase in CO_2 emissions. Drawbacks of this solution include very limited airspace capacity to do this, especially in Europe and North America and increased fuel burn because jet aircraft are less efficient at lower cruise altitudes.

However, the total number of passenger kilometres is growing at a faster rate than manufacturers can reduce emissions, and at present there is no readily available alternative to burning kerosene. Thus, the growth in the aviation sector is likely to continue to generate an increasing volume of greenhouse gas emissions. However some scientists and companies such as GE Aviation and Virgin Fuels are researching biofuel technology for use in jet aircraft. As part of this test Virgin Atlantic Airways flew a Boeing 747 from London Heathrow Airport to Amsterdam Schiphol Airport on 24 February 2008, with one engine burning a combination of coconut oil and babassu oil. Greenpeace's chief scientist Doug Parr said that the flight was "high-altitude greenwash" and that producing organic oils to make biofuel could lead to deforestation and a large increase in greenhouse gas emissions.

The majority of the world's aircraft are not large jetliners but smaller piston aircraft, and many are capable of using ethanol as a fuel, with major modifications. While ethanol also releases CO_2 during combustion, the plants cultivated to make it draw that same CO_2 out of the atmosphere while they are growing, making the fuel closer to climate-change-neutral. The only problem is the US government's choice of using ethanol from corn, since it takes more energy to produce than is returned, it displaces food crops and thus raises the price of food, and causes soil degradation.

While they are not suitable for long-haul or transoceanic flights, turboprop aircraft used for commuter flights bring two significant benefits: they often burn considerably less fuel per passenger mile, and they typically fly at lower altitudes, well inside the tropopause, where there are no concerns about ozone or contrail production.

Reducing travel

An alternative method for reducing the environmental impact of aviation is to constrain demand for air travel. The UK study *Predict and Decide - Aviation, climate change and UK policy*, notes that a 10% increase in fares generates a 5% to 15% reduction in demand, and recommends that the British government should manage demand rather than provide for it. This would be accomplished via a strategy that presumes "… against the expansion of UK airport capacity" and constrains demand by the use of economic instruments to price air travel less attractively. A study published by the campaign group Aviation Environment Federation (AEF) concludes that by levying £9 billion of additional taxes, the annual rate of growth in demand in the UK for air travel would be reduced to 2%. The ninth report of the House of Commons Environmental Audit Select Committee, published in July 2006, recommends that the British government rethinks its airport expansion policy and considers ways, particularly via increased taxation, in which future demand can be managed in line with industry performance in achieving fuel efficiencies, so that emissions are not allowed to increase in absolute terms.

Kyoto Protocol

Greenhouse gas emissions from fuel consumption in international aviation, in contrast to those from domestic aviation and from energy use by airports, are not assigned under the first round of the Kyoto Protocol, neither are the non-CO_2 climate effects. In place of agreement, Governments agreed to work through the International Civil Aviation Organization (ICAO) to limit or reduce emissions and to find a solution to the allocation of emissions from international aviation in time for the second round of Kyoto in 2009 in Copenhagen.

Emissions trading

As part of that process the ICAO has endorsed the adoption of an open emissions trading system to meet CO_2 emissions reduction objectives. Guidelines for the adoption and implementation of a global scheme are currently being developed, and will be presented to the ICAO Assembly in 2007, although the prospects of a comprehensive inter-governmental agreement on the adoption of such a scheme are uncertain.

Within the European Union, however, the European Commission has resolved to incorporate aviation in the European Union Emissions Trading Scheme (ETS). A new directive has been adopted by the European Parliament in July 2008 and approved by the Council in October 2008. It will enter into force on 1 January 2012.

Mitigation

Emissions from aviation are continuing to grow despite advances in aircraft efficiency. Currently 2% of global emissions are created by the aviation industry.

Aviation has an impact on the environment due to aircraft engines emitting noise, particulates, and gases which contribute to climate change and global dimming. Despite emission reductions from automobiles and more fuel-efficient (and therefore less polluting) turbofan and turboprop engines, the rapid growth of air travel in recent years contributes to an increase in total pollution attributable to aviation. In the EU, greenhouse gas emissions from aviation increased by 87% between 1990 and 2006.

At present aviation accounts for 2% of global CO_2 emissions and this is projected by the IPCC to rise to 3% by 2050. This presents the operators of aircraft with a responsibility to reduce emissions.

Methods of mitigating aviation’s CO_2 emissions

Mitigation of aviation's environmental impact can be achieved through a variety of measures, the most obvious and arguably the most economical of which is to reduce the fuel burn of the aircraft as this accounts for 28% of an airlines costs. However there is a wide variety of other options available to minimise aviation's growing impact upon the environment as are listed below:

Aircraft efficiency

The Boeing 787 "Dreamliner" promises to provide 20% lower fuel burn than current-generation aircraft.

As stated previously, reducing the direct fuel burn of an aircraft is the most obvious and arguably the most economical way of reducing emissions attributable to aviation. Over the last 40 years, commercial jet airliners have become 70% more fuel efficient and are predicted to be another 25% more fuel efficient by 2025.

The next-generation of aircraft, including the Boeing 787, Airbus A350 and Bombardier CSeries, are 20% more fuel efficient per passenger kilometre than current generation aircraft. This is primarily achieved through more fuel-efficient engines and lighter airframes & supporting structures made of composite materials but is also achieved through more aerodynamic shapes, winglets, a "one-piece" fuselage and more advanced computer systems for optimising routes and loading of the aircraft.

Route optimization

Currently, air traffic corridors that aircraft are forced to follow place unnecessary detours on an aircraft's route forcing higher fuel burn and an increase in emissions. An improved Air Traffic Management System with more direct routes and optimized cruising altitudes would allow airlines to reduce their emissions by up to 18%.

In the European Union, a Single European Sky has been proposed for the last 15 years so that there are no overlapping airspace restrictions between countries in the EU and so reduce emissions. As of yet, the Single European Sky is still only a plan but progress has been made. If the Single European Sky had been created 15 years ago, 12 million tons of CO_2 could have been saved.

Biofuels

British Airways will be using half a million tonnes of waste annually to create biofuels for commercial use from 2014 onwards.

Biofuels are fuels derived from biomass material such as plants and waste. Plant derived biofuels offer large savings in CO_2 emissions as they absorb Carbon Dioxide and release it as Oxygen when they grow and so in a life-cycle, emissions can be drastically reduced. A number of airlines have operated biofuel test flights including Virgin Atlantic Airways, which flew with one engine operating on a blend of 20% coconut oil and 80% traditional jet fuel, and Continental Airlines which flew with one engine operating on a blend of 44% Jatropha oil, 6% Algae oil and 50% traditional jet fuel. Other airlines to demonstrate biofuels include Air New Zealand and Japan Airlines.

In the Continental Airlines test, the engine running partly on biofuel burned 46 kg less fuel than the conventionally fuelled engine in 1 and a half hours while producing more thrust from the same volume of fuel. Continental Airlines' CEO, Larry Kellner, commented "This is a good step forward, an opportunity to really make a difference to the environment" citing jatropha's 50-80% lower CO_2 emissions as opposed to Jet-A1 in its lifecycle.

From 2014 onwards, British Airways, in co-operation with Solena, is going to turn half a million tonnes of waste annually that would normally go to landfill from the City of London into biofuel to be used in the British Airways fleet. Waste derived biofuel produces up to 95% less pollution in its life-cycle and so therefore this measure will reduce emissions by the equivalent of taking 42,000 cars off the road every year.

Improved operating procedures

Scandinavian Airlines is operating their 737 aircraft at slower cruising speeds to reduce emissions by 7-8%.

Airlines and airports are looking at ways of reducing emissions and fuel burn through the use of improved operating procedures. Two of the more common ones in operation are a single-engine taxi to and from the runway and the use of a Continuous Descent Approach, or CDA, which can reduce emissions significantly during the operations in and around an airport. Scandinavian Airlines (SAS) is now operating its Boeing 737 fleet at a slower cruising speed to help reduce emissions by 7-8%.

Emission Trading Scheme

In the EU, aviation will be including the European Emission Trading Scheme from 2012 onwards. The scheme places a cap on the emissions an aircraft operator can emit and forces the operator to either lower emissions through more efficient technology or to buy "Carbon Credits" from other companies who have produced fewer emissions than their cap. It is thought that this will reduce aviation's net environmental impact.

Methods of mitigating aviation’s non-CO_2 emissions

Aviation produces a number of other pollutants besides carbon dioxide including nitrogen oxides (NO_X), particulates, unburned hydrocarbons (UHC) and contrails. A number of methods to reduce the level of these pollutants follows:

Nitrogen oxides (NO_X)

Nitrogen Oxides have a far stronger impact upon climate change than Carbon Oxides and are produced in small quantities from aircraft engines. Engine designers have worked since the start of the jet age to reduce NO_X emissions and the result is ever reducing levels of Nitrogen Oxide emissions. For example, between 1997 and 2003, NO_X emissions from jet engines fell by over 40%.

Particulates

Particulates and smoke were a problem with early jet engines at high power settings but modern engines are disigned so that no smoke is produced at any point in the flight.

Unburned hydrocarbons (UHC)

Contrails formed by high altitude aircraft.

Unburned hydrocarbons (UHC) are products of incomplete combustion of fuel and are produced in greater quantities in engines with low pressure gains in the compressors and/or relatively low temperatures in the combustor. As with particulates, UHC has all but been eliminated in modern jet engines through improved design and technology.

Contrails

Aircraft flying at high altitude form condensation trails or contrails in the exhaust plume of their engines. While in the Troposphere these have very little climatic impact.

However, jet aircraft cruising in the Stratosphere do create an impact from their contrails, although the extent of the damage to the environment is as yet unknown. Contrails can also trigger the formation of high-altitude Cirrus cloud thus creating a greater climatic effect.

In the three days following the September 11 Atacks on the World Trade Centre in New York City, when no commercial aircraft flew in the USA, climate scientists measured the daily temperature range over 5000 weather stations across the USA. The results showed a 1^{o} Celsius change in the average daily temperature range for those days of the year, thus showing contrails do have a significant impact on climate. Potential ways of reducing the impact of contrails on our climate include reducing the maximum cruising altitude of aircraft so high-altitude contrails can not form. Cruising at lower altitudes would marginally increase flight time and increase fuel consumption by 4%.

Methods of mitigating aviation's noise emissions

Serrated edges of the nacelle on the Rolls-Royce Trent 1000 fitted to the new Boeing 787 "Dreamliner".

One of the by-products of an aircraft's engine is noise and this has become an increasingly important issue which is being dealt with through many different methods:

Engines

Next-Generation engines are not only more fuel-efficient but also tend to be quieter with Pratt & Whitney's PurePower PW1000G fitted to the Bombardier CSeries aircraft being 4 times quieter than aircraft currently in service. Engines can also incorporate serrated edges on the back of the nacelle to reduce noise impact as shown in this picture.

Improved operating procedures

A Continuous Descent Approach, or CDA, not only reduces fuel burn but also allows airlines to provide quieter approaches for part of the descent to a runway. As the engines are at close to idle power, less noise emissions are produced and combined with new engine technology, the reductions in noise emissions can be large.

Carbon offset

Money generated by carbon offsets from airlines often go to fund green-energy projects such as wind farms.

A carbon offset is a means of reducing emissions to zero by saving enough carbon to balance the carbon emitted by a particular action. Several airlines have begun offering carbon offsets to passengers to offset the emissions created by their proportion of the flight. Money generated is put to projects around the world to invest in green technology such as renewable energy and research into future technology. Airlines offering carbon offsets include British Airways, easyJet, Continental Airlines, Delta Airlines, Lufthansa and Qantas although there are many more carriers participating in such schemes.

British Airways' scheme

British Airways' carbon offsetting scheme involves paying a fee dependant on aircraft type, class of travel and distance flown and therefore prices vary. Funds generated are currently awarded to three renewable energy projects around the world: Bayin'aobao wind farm in Inner Mongolia, Faxinal dos Guedes hydroelectric power plant in Brazil and Xiaohe hydroelctric power plant in Gansu Province, China.

Continental Airlines' scheme

Continental Airlines' carbon offsetting scheme involves paying a fixed fee of $2 to cancel out emissions through reforestation. Passengers can also choose to pay $50 for offsetting emissions through renewable energy projects.

Noise

A Qantas Boeing 747-400 passes close to houses on the boundary of London Heathrow Airport, England.

Aircraft noise is noise pollution produced by any aircraft or its components, during various phases of a flight: on the ground while parked such as auxiliary power units, while taxiing, on run-up from propeller and jet exhaust, during take off, underneath and lateral to departure and arrival paths, over-flying while en route, or during landing.

Mechanisms of sound production

Small general aviation aircraft produce localized aircraft noise.

Helicopter main and tail rotors produce aerodynamic noise.

A moving aircraft including the jet engine or propeller causes compression and rarefaction of the air, producing motion of air molecules. This movement propagates through the air as pressure waves. If these pressure waves are strong enough and within the audible frequency spectrum, a sensation of hearing is produced. Different aircraft types have different noise levels and frequencies. The noise originates from three main sources:

- Aerodynamic noise
- Engine and other mechanical noise
- Noise from aircraft systems

Aerodynamic noise

Aerodynamic noise arises from the airflow around the aircraft fuselage and control surfaces. This type of noise increases with aircraft speed and also at low altitudes due to the density of the air. Jet-powered aircraft create intense noise from aerodynamics. Low-flying, high-speed military aircraft produce especially loud aerodynamic noise.

The shape of the nose, windshield or canopy of an aircraft affects the sound produced. Much of the noise of a propeller aircraft is of aerodynamic origin due to the flow of air around the blades. The helicopter main and tail rotors also give rise to aerodynamic noise. This type of aerodynamic noise is mostly low frequency determined by the rotor speed.

Typically noise is generated when flow passes an object on the aircraft, for example the wings or landing gear. There are broadly two main types of airframe noise:

- Bluff Body Noise - the alternating vortex shedding from either side of a bluff body, creates low pressure regions (at the core of the shed vortices) which manifest themselves as pressure waves (or sound). The separated flow around the bluff body is quite unstable, and the flow "rolls up" into ring vortices - which later break down into turbulence.

- Edge Noise - when turbulent flow passes the end of an object, or gaps in a structure (high lift device clearance gaps) the associated fluctuations in pressure are heard as the sound propagates from the edge of the object (radially downwards).

Engine and other mechanical noise

Much of the noise in propeller aircraft comes equally from the propellers and aerodynamics. Helicopter noise is aerodynamically induced noise from the main and tail rotors and mechanically induced noise from the main gearbox and various transmission chains. The mechanical sources produce narrow band high intensity peaks relating to the rotational speed and movement of the moving parts. In computer modelling terms noise from a moving aircraft can be treated as a line source.

Aircraft Gas Turbine engines (Jet Engines) are responsible for much of the aircraft noise during takeoff and climb. However, with advances in noise reduction technologies - the airframe is typically more noisy during landing.

The majority of engine noise is due to Jet Noise - although high bypass-ratio turbofans do have considerable Fan Noise. The high velocity jet leaving the back of the engine has an inherent shear layer instability (if not thick enough) and rolls up into ring vortices. This of course later breaks down into turbulence. The SPL associated with engine noise is proportional to the jet speed (to a high power) therefore, even modest reductions in exhaust velocity will see a large reduction in Jet Noise.

Noise from aircraft systems

Cockpit and cabin pressurisation and conditioning systems are often a major contributor within cabins of both civilian and military aircraft. However, one of the most significant sources of cabin noise from commercial jet aircraft other than the engines is the Auxiliary Power Unit (or APU). An Auxiliary Power Unit is an on-board generator used in aircraft to start the main engines, usually with compressed air, and to provide electrical power while the aircraft is on the ground. Other internal aircraft systems can also contribute, such as specialised electronic equipment in some military aircraft.

Health effects

There are health consequences of elevated sound levels. Elevated workplace or other noise can cause hearing impairment, hypertension, ischemic heart disease, annoyance, sleep disturbance, and decreased school performance. Although some hearing loss occurs naturally with age, in many developed nations the impact of noise is sufficient to impair hearing over the course of a lifetime. Elevated noise levels can create stress, increase workplace accident rates, and stimulate aggression and other anti-social behaviors.

A large-scale statistical analysis of the health effects of aircraft noise was undertaken in the late 2000s by Bernhard Greiser for the Umweltbundesamt, Germany's central environmental office. The health data of over one million residents around the Cologne airport were analysed for health effects correlating with aircraft noise. The results where then corrected for other noise influences in the residential areas, and for socioeconomic factors, to reduce possible skewing of the data. The study concluded that aircraft noise clearly and significantly impairs health, with, for example, a day-time average sound pressure level of 60 decibel increasing coronary heart disease by 61% in men and 80% in women. As another indicator, a night-time average sound pressure level of 55 decibel increased the risk of heart attacks by 66% in men and 139% in women. Statistically significant health effects did however start as early as from an average sound pressure level of 40 decibel.

Noise mitigation programs

In the United States, since aviation noise became a public issue in the late 1960s, governments have enacted legislative controls. Aircraft designers, manufacturers, and operators have developed quieter aircraft and better operating procedures. Modern high-bypass turbofan engines, for example, are quieter than the turbojets and low-bypass turbofans of the 1960s. First, FAA Aircraft Certification achieved noise reductions classified as 'Stage 3' aircraft; which has been upgraded to 'Stage 4' noise certification resulting in quieter aircraft. This has resulted in lower noise exposures in spite of increased traffic growth and popularity.

In the 1980s the U.S. Congress authorized the FAA to devise programs to insulate homes near airports. While this does not address the external noise, the program has been effective for residential interiors. Some of the first airports at which the technology was applied were San Francisco International Airport and San Jose International Airport in California. A computer model is used which simulates the effects of aircraft noise upon building structures. Variations of aircraft type, flight patterns and local meteorology can be studied. Then the benefits of building retrofit strategies such as roof upgrading, window glazing improvement, fireplace baffling, caulking construction seams can be evaluated.

Night flying restrictions

At Heathrow, Gatwick and Stansted airports in the UK, and Frankfurt Airport in Germany, night flying restrictions apply to reduce noise exposure at night.

Chapter-6

Aerial Warfare

Aerial warfare is the use of military aircraft and other flying machines in warfare, including military airlift of cargo to further the national interests as was demonstrated in the Berlin Airlift. **Strategic air power** is the bombing of enemy resources (by bombers); **tactical air power** is the battle for control of the air space (by fighters); **close air support** is the direct support of ground units; **naval aviation** refers especially to the use of aircraft carriers.

Kite warfare

The earliest documented aerial warfare took place in ancient China, when a manned Kite was set off to spy for military intelligence and communication. Ancient Chinese soldiers also mounted massive aerial fire arrow attacks from war kites, where they would send a volley of flaming arrows from the war kite onto the ground target, carrying out the world's first-ever air attacks.

Balloon warfare

Balloon warfare in Ancient China

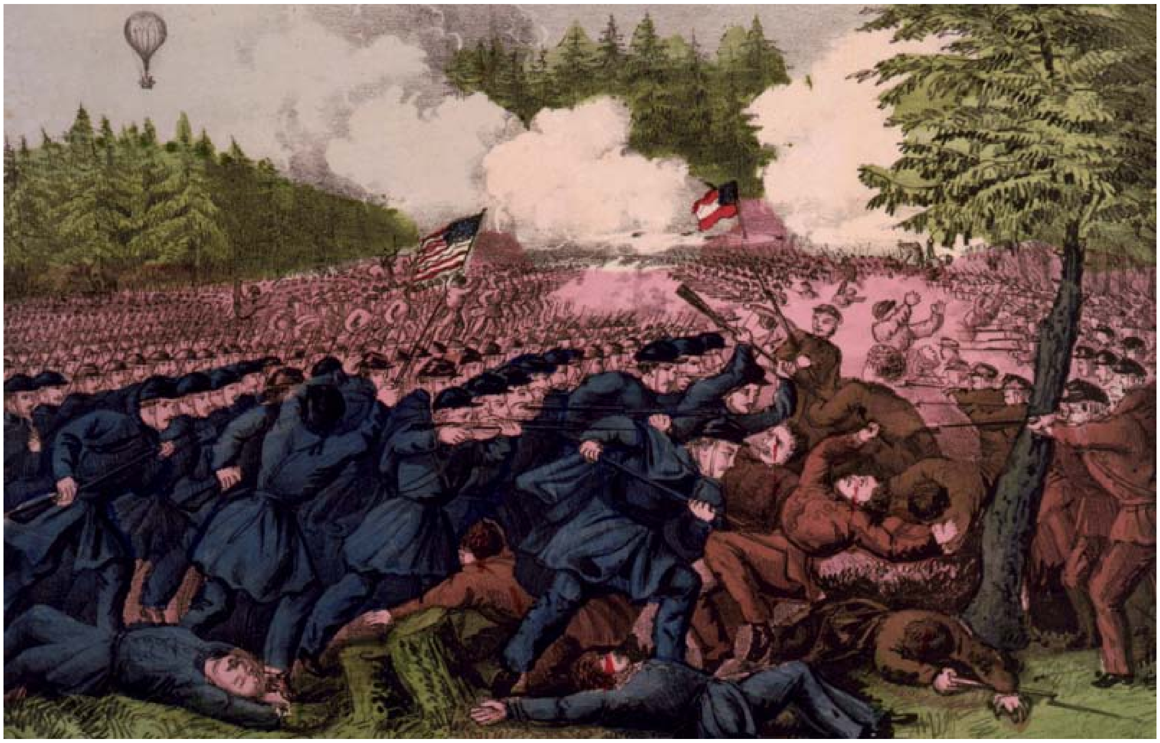
In or around the 2nd or 3rd century, a prototype Hot air balloon, the Kongming lantern was invented in China serving as military communication.

Balloon warfare in Europe

Some minor warfare use was made of balloons in the infancy of aeronautics. The first instance was by the French Aerostatic Corps at the Battle of Fleurus in 1794, who used a tethered balloon, *L'entreprenant*, to gain a vantage point.

Balloons had disadvantages. They could not fly in bad weather, fog, or high winds. They were at the mercy of the winds and were also very large targets.

American Civil War



Battle of Fair Oaks with one of Lowe's balloons in the background.

Union Army Balloon Corps

The American Civil War was the first war to witness significant use of aeronautics in support of battle.. Thaddeus Lowe made noteworthy contributions to the Union war effort using a fleet of balloons he created In June 1861 Professor Thaddeus S. C. Lowe left his work in the private sector as a scientist/balloonist and offered his services as an aeronaut to President Lincoln, who took some interest in the idea of an air war. Lowe's demonstration of flying his balloon *Enterprise* over Washington, DC, and transmitting a telegraph message to the ground was enough to have him introduced to the commanders of the Topographical Engineers; initially it was thought balloons could be used for preparing better maps.

Lowe's first action was at the First Battle of Bull Run in July 1861 with General Irvin McDowell and the Grand Army of the Potomac. *Enterprise* did a free flight observation of the Confederate positions.

In another demonstration, Lowe was called to Fort Corcoran by artillery General W. F. Smith. Lowe ascended to a given altitude in order to spot rebel encampments at Falls Church, Virginia. With flag signals he directed artillery fire onto the sleeping encampment. As the General put it, *"The signals from the balloon have enabled my gunners to hit with a fine degree of accuracy an unseen and dispersed target area."*

By October, Lowe had orders in hand to build four balloons with portable hydrogen gas generators for use in aerial reconnaissance. Working with several other prominent American balloonists he formed the Union Army Balloon Corps who never received commissions, working as civilian contractors, This was of great concern should the aeronauts be shot down over enemy lines, as civilian spying is summarily punishable by death. Therefore Lowe insisted on the strict use of tethered (as opposed to free) flight. By attaining altitudes from 1,000 feet (300 m) to as much as 3½ miles, an expansive view of the battle field and beyond could be had.

Lowe built seven balloons: *Eagle*, his first; *Constitution*, one of the smaller balloons; its sister, *Washington*; *Intrepid*, a larger balloon and his favorite; a sister, *Union*; *Excelsior*; and *AMERICA*, which never came out of storage.

As the Confederates retreated toward Richmond, the War turned into the Peninsular Campaign. Due to the heavy forests on the peninsula, the balloons were unable to follow on land. Lowe was introduced to *George Washington Parke Custis*, a coal barge converted to operate balloons. The balloons and their gas generators were loaded aboard and taken down the Potomac, where reconnaissance of the peninsula could continue. *Custis* was taken up the Pawmunkey River, where Lowe was reunited with McClellan's army.

Prof. Lowe ascending in *Intrepid* to observe the Battle of Fair Oaks

Lowe's most dramatic action came in the Battle of Fair Oaks, where he was able to view the advancing of Lee's army onto the isolated detachment of General Heintzelman. Working from two balloon camps, one at Mechanicsville and one at Gaine's Farm, Lowe galloped six miles (10 km) twice daily to keep up with the reconnaissance reports. McClellan was sure the rebels were feigning an attack, but Lowe could see differently. Heintzelman was left stranded on the other side of the Chickahominy River with the bridges having been taken out overnight by the swollen waters. Lowe sent a dispatch of utmost urgency to have the bridge repaired immediately and reserves sent to Heintzelman's aid. He then sent dispatch from Mechanicsville to Gaine's Farm calling for the immediate inflation of the large balloon *Enterprise*, which would aid him in overlooking the imminent battle.

When Lowe arrived at Gaine's Farm, *Intrepid* will still far from being inflated. In a quick work of inventive ingenuity, Lowe had the bottom of a camp kettle cut out and joined the valve ends of the *Intrepid* and the partially inflated *Constitution* hooked together, thereby transferring the gas from the latter into the former. Within 15 minutes he was in the air to oversee the battle.

Lowe fell prey to malaria during Fair Oaks and was out of commission for more than a month. On his return he found the Balloon Corps had been stripped of horses and wagons and left out of service for Antietam. Lowe was called back into service at Sharpsburg and later responded to Gen. Burnside's army at Vicksburg. The ensuing defeat of the Union Army in what was referred to as the "Mud March" led to Gen. Joseph Hooker relieving Burnside. By this time, the Balloon Corps had been assigned to the Engineers Corps, and a newly promoted Captain Comstock cut Lowe's pay dramatically.

Lowe tendered his resignation and was released from military duty in May 1863. The Balloon Corps continued to operate with Lowe's handlers, but Union generals' continuing ignoring and mistrust of ballooning resulted in balloon-intelligence not being utilized. By August, the Union Army Balloon Corps was disbanded.

Silk Dress Balloons

Due to the effectiveness of the Union Army Balloon Corps, the Confederates felt compelled to incorporate balloons as well. As coke gas was not always available in Richmond, the first balloons were made of the Montgolfier rigid style, cotton stretched over wood framing and filled with hot smoke from fires made of oil-soaked pinecones. They were piloted by Captain John R. Bryant for use at Yorktown. Though Bryant's performance was not all that bad, his handlers were poorly experienced and his balloon was left in the air spinning like a top. Another incident had one of the handlers becoming entangled in the ascending tether rope which had to be chopped loose, leaving the Captain free-flying over his own Confederate positions whose troops threatened to shoot him down.

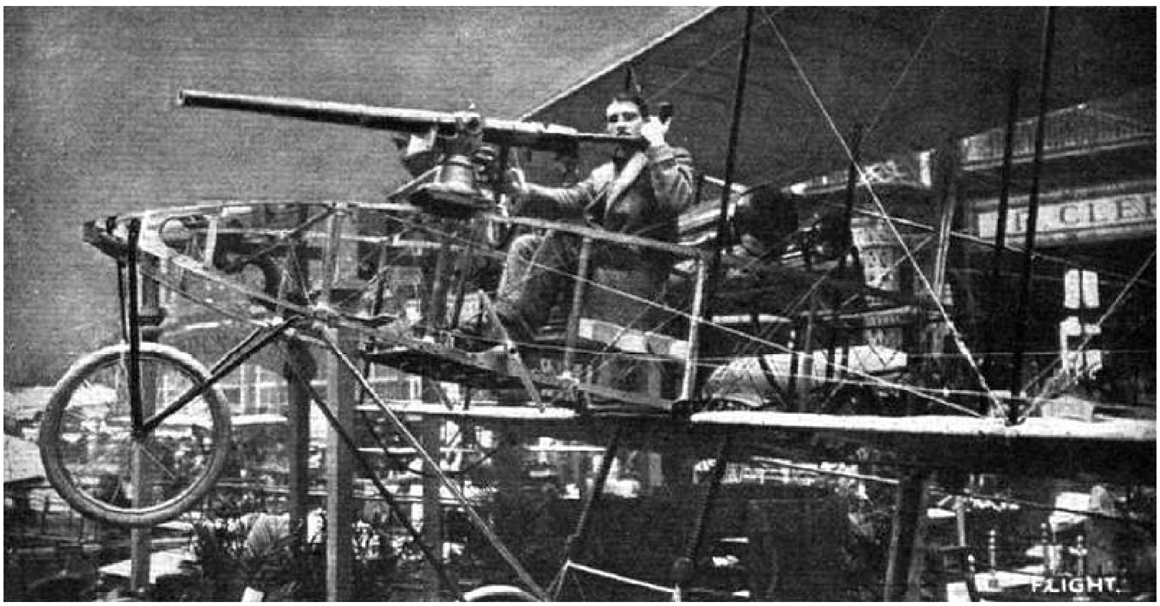
Attempts at making gas-filled silk balloons were hampered by the South's inability to obtain any imports at all. They did fashion a balloon from dress silk (purportedly silk for making dresses, not from silk dresses themselves). The inflated spheres appeared as multi-colored orbs over Richmond and were piloted by Captain Landon Cheeves. Before the first balloon could be used it was captured during transportation on the James River by the crew of the Monitor. A second balloon did see action until summer 1863, when it was blown from its mooring and taken by Union forces only to be divided up as souvenirs for members of the Federal Congress. As the Union Army reduced its use of balloons, so did the Confederates—much to their relief.

Zeppelins, airships and blimps

As powered aircraft with wings dominated military aviation during World War I, rigid dirigibles and zeppelins were used by the Germans to attack cities. After World War I, the United States Navy researched the use of airships, including their use as a base for fighter aircraft, but efforts were cancelled after losses in storms. In World War II, barrage balloons were used as obstacles against aircraft, and blimps were used as observation and radar platforms.

Before World War I

The armies of many countries evaluated the use of aircraft for observation purposes. Naval aviation was pursued as well; several tests were made in which floatplanes were launched by catapult from ships at sea, and recovered later by crane.



A 1910 French experimental design by *Aéroplanes Voisin*, featuring a *mitrailleuse* gun fired by the passenger

The U.S. Navy had been interested in naval aviation since the turn of the 20th century. In August 1910 Jacob Earl Fickel did the first experimenting with Glenn Curtiss shooting a gun from an airplane. In 1910–1911, the Navy conducted experiments which proved the practicality of carrier-based aviation. On November 14, 1910, near Hampton Roads, Virginia, civilian pilot Eugene Ely took off from a wooden platform installed on the scout cruiser *USS Birmingham* (CL-2). He landed safely on shore a few minutes later. Ely proved several months later that it was also possible to land on a ship. On January 18, 1911, he landed on a platform attached to the American cruiser *USS Pennsylvania* (ACR-4) in San Francisco harbor.

The first use of airplanes in an actual war occurred in the 1911 Italo-Turkish War with the Italian Army Air Corps bombing a Turkish camp at Ain Zara, Libya. In the First Balkan War (1912) the Bulgarian Air Force bombed Turkish positions at Adrianople, while the Greek Aviation performed, over the Dardanelles, the first naval air co-operation mission in history. Airplanes were also used by the U.S. against Pancho Villa. Air reconnaissance was carried out in both wars too. The air-dropped bomb was extensively used during the First Balkan War (including in the first ever night bombing on 7 November 1912), and subsequently shared with the Imperial German Air Service during World War I.

World War I

RAF Sopwith Camel during World War I

Initially during that war both sides made use of tethered balloons and airplanes for observation purposes, both for information gathering and directing of artillery fire. A desire to prevent enemy observation led to airplane pilots attacking other airplanes and balloons, initially with small arms carried in the cockpit, but due to the technology of the time pilots couldn't have forward facing machine guns.

Although the addition of deflector plates to the back of propellers by French pilot Roland Garros and designer Raymond Saulnier in the Morane-Saulnier monoplane was the first example of an aircraft able to fire through its propeller, it wasn't until the Dutch aircraft designer Anthony Fokker developed the gun synchronizer in 1915 that it became possible to aim the gun and the airplane at the same time, resulting in German *Leutnant* Kurt Wintgens scoring the first known victory for a synchronized gun-equipped fighter aircraft, on July 1, 1915.

The Allies were able to capture a Fokker *Eindecker* with a Fokker-designed *Stangensteuerung* synchronizer mechanism intact and reverse engineer it, leading to the birth of *aerial combat*, more commonly known as the dogfight. Tactics for dogfighting evolved by trial and error. The German ace Oswald Boelcke created eight essential rules of dogfighting, the *Dicta Boelcke*.

Both sides also made use of aircraft for bombing, strafing, sea reconnaissance, antisubmarine warfare, and dropping of propaganda. The German military made use of Zeppelins and, later on, bombers such as the Gotha, to drop bombs on Britain. By the end of the war airplanes had become specialized into bombers, fighters, and observation (reconnaissance) aircraft.

Between the wars

Between 1918 and 1939 aircraft technology developed very rapidly. In 1918 most aircraft were biplanes with wooden frames, canvas skins, wire rigging and air-cooled engines. Biplanes continued to be the mainstay of air forces around the world and were used extensively in conflicts such as the Spanish Civil War. Most industrial countries also created air forces separate from the army and navy. However, by 1939 military biplanes were in the process of being replaced with metal framed monoplanes, often with stressed skins and liquid cooled engines. Top speeds had tripled; altitudes doubled; ranges and payloads of bombers increased enormously.

Some theorists, especially in Britain, considered that aircraft would become the dominant military arm in the future. They imagined that a future war would be won entirely by the destruction of the enemy's military and industrial capability from the air. The Italian general Giulio Douhet, author of *The Command of the Air*, was a seminal theorist of this school, which has been associated with Stanley Baldwin's statement that "the bomber will always get through"; that is, regardless of air defences, sufficient raiders will survive to rain destruction on the enemy's cities. This led to what would later be called a strategy of deterrence and a "bomber gap", as nations measured air force power by number of bombers.

Others, such as General Billy Mitchell in the United States, saw the potential of air power to augment the striking power of naval surface fleets. German and British pilots had experimented with aerial bombing of ships and air-dropped torpedoes during World War I with mixed results. The vulnerability of capital ships to aircraft was demonstrated on 21 July 1921 when a squadron of bombers commanded by General Mitchell sank the ex-German battleship SMS *Ostfriesland* with aerial bombs; although the *Ostfriesland* was stationary and defenseless during the exercise, its destruction demonstrated the potency of air planes against ships.

It was during the Banana Wars, while fighting bandits, freedom fighters and insurgents in places like Haiti, the Dominican Republic and Nicaragua, that United States Marine Corps aviators would begin to experiment with air-ground tactics making the support of their fellow Marines on the ground their primary mission. It was in Haiti that Marines began to develop the tactic of dive bombing and in Nicaragua where they began to perfect it. While other nations and services had tried variations of this technique, Marine aviators were the first to embrace it and make it part of their tactical doctrine

Germany was banned from possessing an air force by the terms of the World War I armistice. The German military continued to train its soldiers as pilots clandestinely until

Hitler was ready to openly defy the ban. This was done by forming the *Deutscher Luftsportverband*, a flying enthusiast's club and training pilots as civilians, and some German pilots were even sent to the Soviet Union for secret training; a trained air force was thus ready as soon as the word was given. This was the beginning of the *Luftwaffe*.

World War II

Military aviation came into its own during the Second World War. The increased performance, range, and payload of contemporary aircraft meant that air power could move beyond the novelty applications of World War I, becoming a central striking force for all the combatant nations.

Over the course of the war, several distinct roles emerged for the application of air power.

Strategic bombing

Strategic bombing of civilian targets from the air was first proposed by the Italian theorist General Giulio Douhet. In his book *The Command of the Air* (1921), Douhet argued future military leaders could avoid falling into bloody World War I–style trench stalemates by using aviation to strike past the enemy's forces directly at their vulnerable civilian populations. Douhet believed such strikes would cause these populations to force their governments to surrender.

Douhet's ideas were paralleled by other military theorists who emerged from World War I, including Sir Hugh Trenchard in Britain. In the interwar period, Britain and the United States became the most enthusiastic supporters of the strategic bombing theory, with each nation building specialized heavy bombers specifically for this task.

Chinese baby crying in the ruins of Shanghai South Railway Station after a bombing by the Imperial Japanese Navy Air Service on 28 August 1937

Imperial Japanese Air Service

Shōwa strategic bombing was independently conducted during the Second Sino-Japanese war and World War II by the Imperial Japanese Navy Air Service and the Imperial Japanese Army Air Service.

Bombing efforts mostly targeted large Chinese cities such as Shanghai, Wuhan and Chonging. The bombing of Nanjing and Canton, which began on 22 and 23 September 1937, called forth widespread protests culminating in a resolution by the Far Eastern Advisory Committee of the League of Nations.

There were also air raids on Philippines and northern Australia (Bombing of Darwin, 19 February 1942). The Imperial Japanese Navy Air Service used tactical bombing against enemy airfields and military positions, as at Pearl Harbor. The Imperial Japanese Army Air Service also attacked enemy ships and military installations.

Luftwaffe

In the early days of World War II, the Luftwaffe launched devastating air attacks against the besieged cities of Warsaw and Rotterdam. In the case of Warsaw, the bombings had little effect, but in the case of Rotterdam, the psychological effect of the bombings did have the intended effect—a relatively rapid ending of Dutch resistance (Buckley 129).

During the Battle of Britain, the *Luftwaffe*, frustrated in its attempts to gain air superiority in preparation for the planned invasion, turned to bombing of London and other large English cities. However, the *Luftwaffe* found these raids did not have the effect predicted by prewar airpower theorists.

Royal Air Force

The Spitfire played a vital part for British victory in the Battle of Britain.

The British, started in kind - using a strategic bombing campaign in 1940 that was to last for the rest of the war. Early British bombers were all twin-engined designs and were lacking in defensive armament. Therefore, RAF Bomber Command quickly turned to a policy of night bombing, for which the crews were untrained; their inaccuracy meant they were forced to adopt area bombing and were unable to hit specific targets such as factories or power plants until later in the war when pathfinder tactics, radio location plus ground mapping radar (OBOE and H2S) and very low-level bombing such as that used by the Dambusters in Operation Chastise were developed.

Soviet Red Air Force

Although the rapid industrialization the Soviet Union experienced in the 1930s had the *potential* to enable the Voyenno-vozdushnyye sily (VVS) to be effective against the Luftwaffe, Stalin's purges left the organization intellectually and morally weakened. However, when Germany invaded in June 1941 (Operation Barbarossa), the massive size of the VVS, in both planes and people, allowed it to absorb "horrendous" casualties and still maintain capability.

Despite the near collapse of both the Red Army and Red Air Force in 1941, they survived, as German forces outran their supply lines and the Americans and British provided Lend Lease assistance.

Fundamental flaws in the Luftwaffe were exposed during Germany's war with the Soviet Union. Although strategic bombing requires that the enemy's industrial war capacity be neutralized, some Soviet war factories were moved as much as 1,000 miles (1,600 km) east—far out of reach of the Luftwaffe's bombers Because the Luftwaffe's resources were needed for more critical duty in supporting the German army. The Luftwaffe became overstretched, and even victorious battles damaged the overall capability of Germany's air force due to attrition.

By 1943, the Soviets had fully rebounded from the defeats of 1941, and they were able to produce considerably more airplanes than their German rivals; for example, at Kursk, the VVS had twice the number of airplanes that the Luftwaffe had. The VVS's fighter-capability rested on the Yakovlev Yak-9 and Lavochkin La-5, and its primary bombers were the Ilyushin 2 Shturmovik and Petlyakov Pe-2. Utilizing overwhelming numerical superiority, Soviet forces were able to drive the Germans out of Soviet territory and take the war to Germany.

U.S. Army Air Force

When the U.S. Eighth Air Force arrived in England in 1942, the Americans were convinced they could carry out successful daylight raids. The Eighth was equipped with B-17 Flying Fortresses and B-24 Liberators, both high-altitude four-engined designs. The new bombers also featured the strongest defensive armament yet seen - up to 13 .50 caliber machine guns, depending on the version, most of them in power-operated turrets. Flying in daylight in large, close formations, U.S. doctrine held tactical formations of heavy bombers would be sufficient to gain air superiority in the absence of escort fighters. The intended raids would hit hard on chokepoints in the German war economy such as oil refineries or ball bearing factories.

Part of a USAAF stream of over 1,000 B-17 bombers.

The U.S.A.A.F. was compelled to change its doctrine since bombers alone, no matter how heavily armed, could not achieve air superiority against single-engined fighters. Loss rates rose from five to twenty percent in a series of missions between August 17 and October 14, 1943, when raids against Regensburg and Schweinfurt, penetrating beyond the range of fighter cover, resulted in the loss of 60 bombers on one mission.

Air superiority

During the Battle of Britain, many of the best *Luftwaffe* pilots had been forced to bail out over British soil, where they were captured. As the quality of the *Luftwaffe* fighter arm decreased, the Americans introduced the long-range P-38 Lightning and P-51 Mustang escort fighters, carrying drop tanks. Newer, inexperienced German pilots—flying potentially superior aircraft, such as the Focke-Wulf Fw 190, Heinkel He 162, and the Messerschmitt Me 262—gradually became less and less effective at thinning the late-war bomber streams. Adding fighters to the daylight raids gave the bombers much-needed protection and greatly improved the impact of the strategic bombing effort.

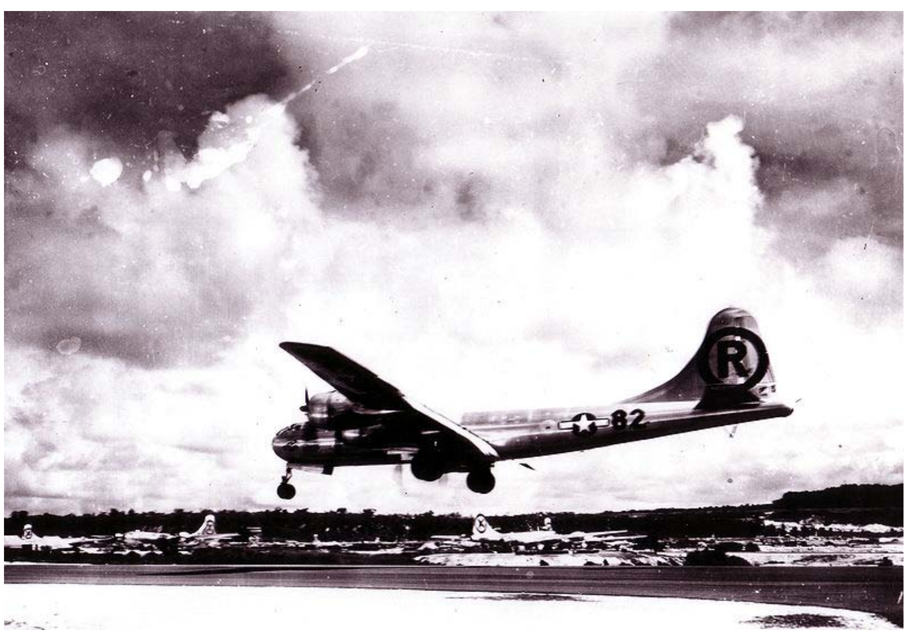
Over time, from 1942 to 1944, the Allies' air forces became stronger and stronger while the Luftwaffe became weaker and weaker. During 1944, the Luftwaffe experienced a 78 percent reduction in its strength, and Germany's air force lost control over Germany's skies. As a result *nothing* in Germany could be securely protected—not stationary army units, nor moving army units, nor war factories, nor their workers, nor civilians in cities such as Hamburg and Dresden, nor the nation's capital—Berlin. Germans had to watch as their soldiers and civilians began to be slaughtered in the thousands by aerial bombardment—much as the Germans had done to Poland, Rotterdam, Britain, and the Soviet Union.

Effectiveness

Strategic bombing by non-atomic means did not win the war for the Allies, nor did it succeed in breaking the will to resist of the German (and Japanese) people. But in the words of the German armaments minister Albert Speer, it created "a second front in the air." Speer succeeded in increasing the output of armaments right up to mid-1944 in spite of the bombing. Still, the war against the British and American bombers demanded enormous amounts of resources: antiaircraft guns, day and night fighters, radars, searchlights, manpower, ammunition, and fuel.

On the Allied side, strategic bombing diverted material resources, equipment (such as radar) aircraft, and manpower away from the Battle of the Atlantic (where even a couple of squadrons of B-24s could be priceless) and Allied armies. As a result, German army groups in Russia, Italy, and France rarely saw friendly aircraft and constantly ran short of tanks, trucks, and anti-tank weapons. The only option left was to create World War I–style slit trench defenses quite unlike the *blitzkrieg*s of 1939–1941.

U.S. Bombing of Japan



Enola Gay, a Silverplate version of the Boeing B-29 Superfortress landing after delivering Little boy over Hiroshima

The long-range Boeing B-29 was used to bomb Japan. On 15 June 1944, 47 B-29s launched from Chengdu, China, bombed the Imperial Iron and Steel Works at Yawata Japan. This raid was the first attack on Japanese islands since the Doolittle Raid in April 1942. The entire B-29 effort was gradually shifted to the new bases in the Marianas Islands in the Central Pacific.

The first mission against Japan from bases in the Marianas was flown on 24 November 1944, with 111 B-29s sent to attack Tokyo. From that point, increasingly intense raids were launched regularly until the end of the war. Tactics evolved from high-altitude to lower altitude attacks, largely removing most defensive guns and switching to incendiary bombs. These attacks succeeded in devastating almost all large Japanese cities.

The most famous B-29 was the *Enola Gay*, which dropped the atomic bomb 'Little Boy' on Hiroshima on 6 August 1945. *Bockscar*, another B-29, dropped 'Fat Man' on Nagasaki three days later. Although the ethics of nuclear warfare remain controversial, these two actions, along with the Soviet invasion of Manchuria on 9 August 1945, brought about the Japanese surrender, and the official end of World War II.

Tactical air support

By contrast with the British strategists, the primary purpose of the *Luftwaffe* was to support the Army. This accounted for the presence of large numbers of dive bombers on strength and the scarcity of long-range heavy bombers. This 'flying artillery' greatly assisted in the successes of the German Army in the Battle of France (1940). Hitler determined air superiority was essential for the invasion of Britain. When this was not achieved in the Battle of Britain, the invasion was canceled, making this the first major battle whose outcome was determined primarily in the air.

The war in Russia forced the Luftwaffe to devote the majority of its resources to providing tactical air support for the beleaguered German army. In that role, the Luftwaffe used the Junkers Ju 87, Henschel Hs 123 and modified fighters—Bf 109 and FW 190.

The Red Air Force was also primarily used in the tactical support role, and towards the end of the war was very effective in the support of the Red Army in its advance across Eastern Europe. An aircraft of importance to the Soviets was the *Ilyushin Il-2 Sturmovik*—appropriately called "flying artilery"; the Il-2 was able to make life very difficult for panzer crews, and the Il-2 was an important part of the Soviet victory at Kursk—one of the biggest tank battles in history.

Military transport aviation and use of airborne troops

Military transport aviation was invaluable to all sides in maintaining supply and communications of ground troops, and was used on many notable occasions such as resupply of German troops in and around Stalingrad after Operation Uranus, and employment of airborne troops. After the first trials in use of airborne troops by the Red

Army displayed in the early 1930s many European nations and Japan also formed the airborne troops, and these saw extensive service on in all Theatres of the Second World War.

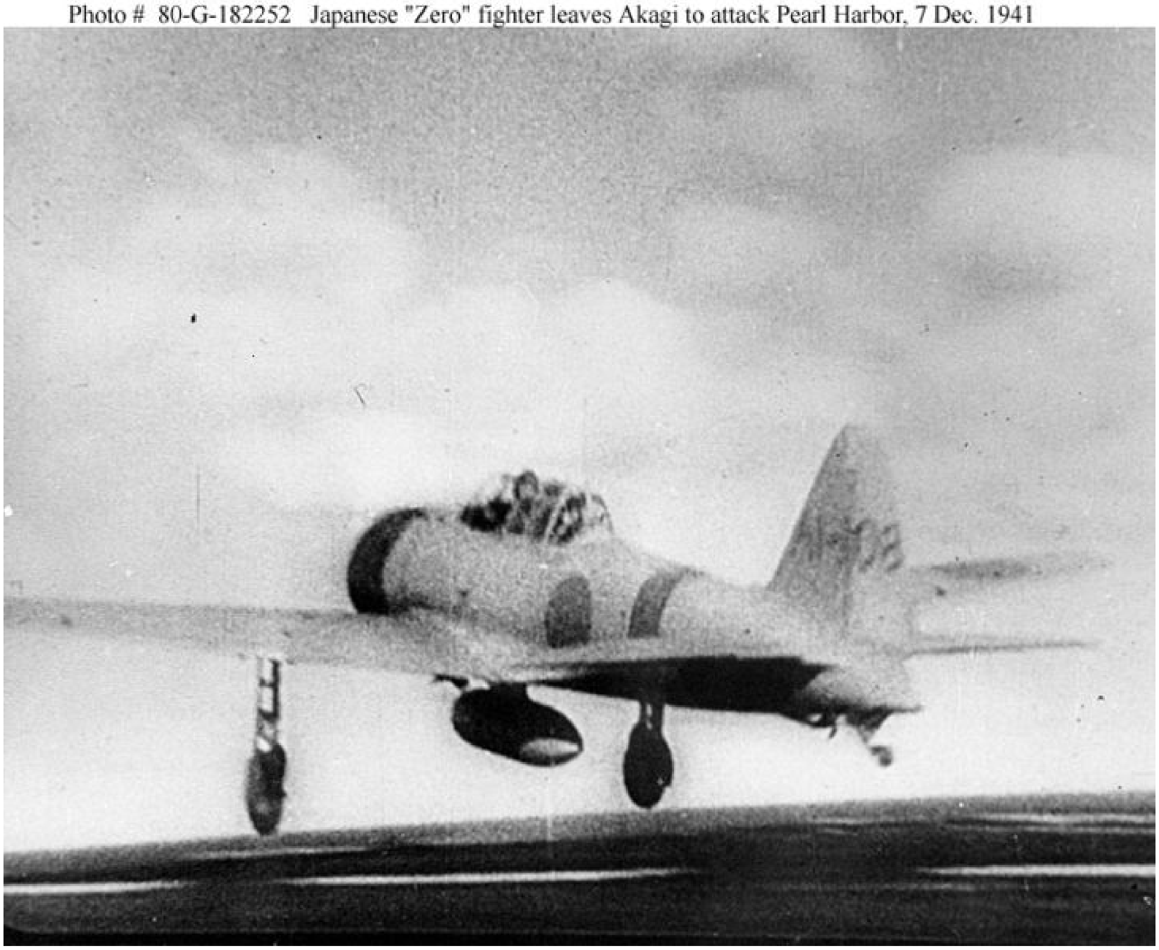
However their effectiveness as shock troops employed to surprise enemy static troops proved to be of limited success. Most airborne troops served as light infantry by the end of the war despite attempts at massed use in the Western Theatre by US and Britain during the Operation Market Garden.

Naval aviation

Aircraft and the aircraft carrier first became important in naval battles in World War II. Carrier based aircraft are specialized as dive bombers, torpedo bombers, and fighters, evolving from biplanes such as the Swordfish and fighters such as the F4F Wildcat which were based on biplanes to the F4U Corsair which outperformed many land based types, and the TBF Avenger which had an enclosed gun turret.

Surface based aircraft such as the PBY Catalina help find submarines and surface fleets. The aircraft carrier replaces the battleship as the most powerful naval offensive weapons system as battles between fleets are fought entirely out of gun range by aircraft. The Yamato, the most powerful battleship ever built is first turned back by light escort carrier aircraft, and later sunk lacking its own air cover.

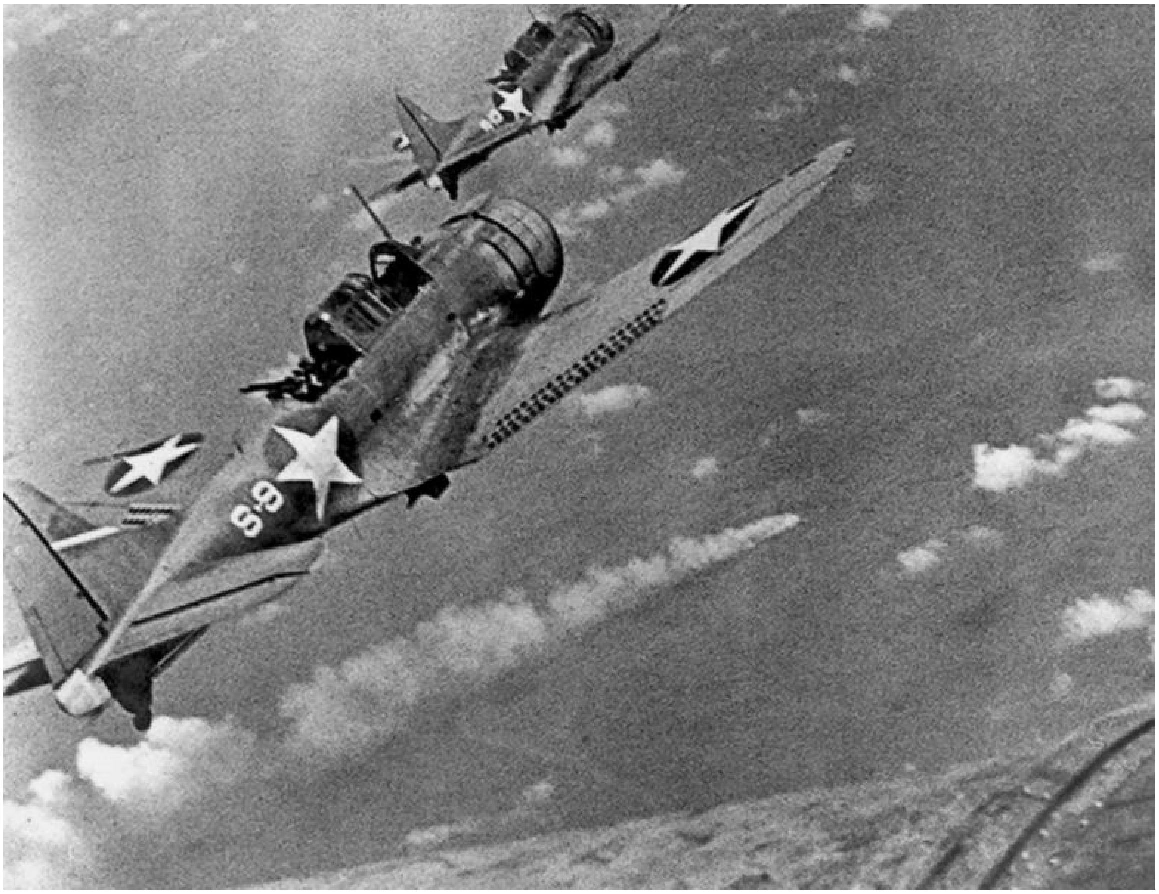
Photo # 80-G-182252 Japanese "Zero" fighter leaves Akagi to attack Pearl Harbor, 7 Dec. 1941



A Japanese Mitsubishi A6M2 "Zero" fighter

In the Doolittle Raid, the US launches normally land-based B-25 Mitchell bombers from carriers in a raid against Tokyo and other Japanese mainland targets. Small escort carriers and light carriers are built in large numbers to escort slow cargo convoys or supplement fast carriers. Aircraft for observation or light raids are also carried by battleships and cruisers, while blimps are used to search for attack submarines.

- Battle of the Atlantic, aircraft carried by low-cost escort carriers are used for antisubmarine patrol, defense, and attack
- Battle of Taranto
- Attack of Pearl Harbor First attack on US territory is carried out entirely by carrier based aircraft, destroying or sinking most US battleships, but not finding any US carriers in port.
- Sinking of *Prince of Wales* and *Repulse*, the first time a battleship underway was sunk solely by aircraft
- Battle of the Coral Sea, the first where neither fleet was in visual contact with the other and all fighting was carried out by aircraft



Douglas Dauntless SBD dive-bomber in Battle of Midway.

- Battle of Midway
- Battle of the Bismarck Sea
- Battle of the Philippine Sea
- Battle of Leyte Gulf, with the first appearance of kamikazes, perhaps the largest naval battle in history. Japan's last carriers and pilots are deliberately sacrificed as a decoy, the super battleship *Musashi* is sunk by aircraft. The Japanese Navy ceases to be an effective fighting force.
- Battle off Samar A powerful fleet led by the Japanese battleship Yamato catches the light escort carrier "Taffy" task forces within gun range. Although largely unprepared to attack armored ships, aircraft and screening "tin-can" destroyers caused enough damage, sinking or forcing the scuttling of 3 cruisers and 1 destroyer, to turn the Japanese force back.
- Operation Ten-Go The sinking of a fleet with the Yamato and nine other warships with no air cover demonstrated U.S. air supremacy in the Pacific theater by this stage in the war and the vulnerability of surface ships without air cover to aerial attack.

Cold War

Military aviation in the post-war years was dominated by the needs of the Cold War. The post-war years saw the almost total conversion of combat aircraft to jet power, which resulted in enormous increases in speeds and altitudes of aircraft. Until the advent of the Intercontinental Ballistic Missile major powers relied on high-altitude bombers to deliver their newly developed nuclear deterrent; each country strove to develop the technology of bombers and the high-altitude fighters that could intercept them. The concept of air superiority began to play a heavy role in aircraft designs for both the United States and the Soviet Union.

The Americans developed and made extensive use of the high-altitude observation aircraft for intelligence-gathering. The U-2, and later the SR-71 Blackbird were developed in great secrecy. The U-2 at its time was supposed to be invulnerable to defensive measures, due to its extreme altitude. It therefore came as a great shock when the Soviets downed one piloted by Gary Powers with a surface-to-air missile.

Air combat was also transformed through increased use of air-to-air guided missiles with increased sophistication in guidance and increased range. In the 70s and 80s it became clear that speed and altitude was not enough to protect a bomber against air defences. The emphasis shifted therefore to maneuverable attack aircraft that could fly 'under the radar', at altitudes of a few hundred feet.

Korean War

MiG-15 shot down by an F-86 over MiG Alley

Over the course of the war, at least 16 B-29 bombers were shot down by communist aircraft.

The Korean War was best remembered for jet combat, but was one of the last major wars where propeller-powered fighters such as the P-51 Mustang, F4U Corsair and aircraft carrier-based Hawker Sea Fury and Supermarine Seafire were used. Turbojet fighter aircraft such as F-80s, F-84 Thunderjets and F9F Panthers came to dominate the skies, overwhelming North Korea's propeller-driven Yakovlev Yak-9s and Lavochkin La-9s.

From 1950, North Koreans flew the Soviet-made MiG-15 jet fighters which introduced the near-sonic speeds of swept wings to air combat. Though an open secret during the war, the most formidable pilots today now admit that they were experienced Soviet Air Force pilots, a *casus bell* deliberately overlooked by the UN allied forces who suspected the use of Russians but were reluctant to engage in open war with the Soviet Union and the People's Republic of China.

At first, UN jet fighters, which also included Royal Australian Air Force Gloster Meteors, had some success, but straight winged jets were soon outclassed in daylight by the superior speed of the MiGs. At night, however, radar-equipped Marine Corps F3D Skynight night fighters claimed five MiG kills with no losses of their own, and no B-29s under their escort were lost to enemy fighters.

In December 1950, the U.S. Air Force rushed in their own swept-wing fighter, the F-86 Sabre. The MiG could fly higher, 50,000 vs. 42,000 feet (12,800 m), offering a distinct advantage at the start of combat. In level flight, their maximum speeds were comparable — about 660 mph (1,060 km/h). The MiG could climb better, while the Sabre could turn and dive better with an all-flying tailplane. For weapons, the MiG carried two 23 mm and one 37 mm cannon, compared to the Sabre’s six .50 (12.7 mm) caliber machine guns. The American .50 caliber machine guns, while not packing the same punch, carried many more rounds and were aimed with a more accurate radar-ranging gunsight. The U.S. pilots also had the advantage of G-suits, which were used for the first time in this war.

Even after the Air Force introduced the advanced F-86, its pilots often struggled against the jets piloted by Soviet pilots, dubbed "honchos". The UN gradually gained air superiority over most of Korea that lasted until the end of the war — a decisive factor in helping the UN first advance into the north, and then resist the Chinese invasion of South Korea.

After the war, the USAF claimed 792 MiG-15s and 108 additional aircraft shot down by Sabres for the loss of 78 Sabres, a ratio in excess of 10:1, though some other studies show a gap of close to 2:1 against the best Russian pilots. Some post-war research has been able to confirm only 379 victories, although the USAF continues to maintain its official credits and the debate is possibly irreconcilable.

The Soviets claimed about 1,100 air-to-air victories and 335 combat MiG losses at that time. China's official losses were 231 planes shot down in air-to-air combat (mostly MiG-15) and 168 other losses. The number of losses of the North Korean Air Force was not revealed. It is estimated that it lost about 200 aircraft in the first stage of the war, and another 70 aircraft after Chinese intervention.

Soviet claims of 650 victories over the Sabres, and China's claims of another 211 F-86s, are considered to be exaggerated by the USAF. According to a recent U.S. publication, the number of F-86s ever present in the Korean peninsula during the war totaled only 674 and the total F-86 losses from all causes were about 230.

Helicopters like this H-19 were used in the Korean war.

The Korean war was the first time the helicopter was used extensively in a conflict. While helicopters such as the YR-4 were used in World War II, their use was rare, and Jeeps like the Willys MB were the main method of removing an injured soldier. In the Korean war helicopters like the H-19 partially took over in the non combat Medevac area.

India-Pakistan War of 1965

The war saw the Indian Air Force and the Pakistani Air Force being involved in full scale combat for the first time since independence. Though the two forces had previously faced off in the First Kashmir War during the late 1940s, it was limited in scale compared to the '65 conflict.

Both countries hold highly contradictory claims on combat losses during the war and hardly any neutral sources have thoroughly verified the claims of both countries' claim. PAF claimed it had shot down 104 IAF planes losing only 19 in the process. India meanwhile claimed that 35 IAF planes were lost while shooting down 73 PAF aircraft.

Pakistan's main strike force comprised the U.S. made F-86 Sabre jets, which claimed a fair share of Indian planes, though remaining vulnerable to the dimunitive Folland Gnat, nicknamed "Sabre Slayer". The PAF's F-104 Starfighter was by far the fastest fighter on the subcontinent at that time. On the other hand, the Indian Air Force relied largely on the Hawker Hunter for attacks. Unlike the PAF, whose strength largely comprised American craft, IAF flew an assortment of planes from de Havilland Vampires to Dassault Mysteres, many of which were outdated in comparison to PAF planes, with even Gnats and Hunters being outmatched by Sabres and Starfighters.

Some of the fiercest dogfights occurred over Sargodha, which was PAF's main base housing the bulk of its planes; IAF planes attacked the base but PAF was able to repulse the attacks. PAF responded by attacking Indian bases with some success, especially in air to ground attacks but were soon forced to back off, in order to provide cover for its ground troops elsewhere. In one incident, the Gujarat Chief Minister, Balawant Rai Mehta's civilian craft was shot down by PAF Sabres inside Indian territory, killing him and the crew. By the end of the war, neither the numerically larger IAF, nor the PAF which possessed a qualitative advantage, achieved air superiority.

Vietnam War

UH-1Ds during early "Air Cav" operations, 1966.

The South Vietnamese Air Force (VNAF) was originally equipped with helicopters such as the CH-21 and propeller powered aircraft such as the T-28 Trojan when jet aircraft were disallowed by treaty. As US involvement increased, most airpower was directly flown by US forces.

Large scale use of helicopters by the US Army in Vietnam led to a new class of airmobile troops, and the introduction of "Air Cavalry" in the U.S, culminating in extensive use of the UH-1 Huey helicopter which would become a symbol of that war, while the CH-54 Tarhe "Skycrane" and CH-47 Chinook lifted heavier loads such as vehicles or artillery. Troops were able to land unexpectedly, strike, and leave again, and evacuate wounded. The specialized AH-1 Cobra was developed from the Huey for escort and ground support duties, The later Soviet campaign in Afghanistan would also see widespread use of helicopters as part of the Air Assault brigades and regiments.

US forces provided close support of ground force over South Vietnam, and strategic bombing of targets over North Vietnam. Many types flying close support or COIN (Counter Insurgency Warfare) missions were propeller powered types such as the O-1 and OV-10 Bronco FAC spotters, A-1 Skyraider, B-26 Invader, and AC-47 "Spooky" gunship. C-123 Provider and C-130 Hercules transports flew supplies into battlefields such as Khe Sanh.

"Fast movers" included the supersonic F-100 Super Sabre, while the giant B-52 Stratofortress would be modified to unload a massive high explosive payload on enemy troop concentrations. The AC-130 would become the ultimate gunship, while the AX specification to replace the Skyraider would evolve into the A-10 Thunderbolt II.

The USAF F-105 Thunderchiefs flew the bulk of strike missions against North Vietnam in Operation Rolling Thunder, while carrier-based A-4 Skyhawks were flown by the Navy. That first campaign was marred by carefully measured regulations that prohibited attacks against SAM missile sites and fighter bases, and frequent bombing halts, and produced little in political results. Rolling Thunder saw the first combat use of electronic computers aboard PIRAZ ships to display comprehensive real-time aircraft position information for force commanders.

A F-105D shoots down a MiG-17, 1967.

Lessons learned were applied to the later Operation Linebacker which employed Phantoms, B-52s, swing-wing F-111s, A-7 Corsairs and all-weather A-6 Intruders was more successful in bringing North Vietnam to the negotiating table after a massive ground invasion. North Vietnam effectively combined Soviet and Chinese anti-aircraft artillery, SA-2 guided missiles, and MiG fighters to create the most heavily defended airspace up to that time.

US air strikes would combine the use of airbone radar platforms such as the EC-121 Warning Star, KC-135 Stratotankers for air refueling, radar jamming aircraft and specialized "Wild Weasel" units to attack SAM missile sites. Jolly Green Giant helicopter crews escorted by A-1 "Sandy"s would retrieve downed pilots over hostile territory.With the use of "smart" guided bombs late in the war, this would set the model for future US air operations.

Experts were surprised when advanced F-105s were shot down in its first encounter against the elderly but nimble MiG-17. Dogfights were thought to be obsolete in the age of missiles, but pilots now needed maneuverability. The F-4 Phantom was quickly tasked with protecting against MiGs, but sorely lacked a built-in gun when missiles were often unreliable. Air combat training schools such as TOPGUN would improve kill ratios, but combat experience started programs that would produce agile air superiority fighters with guns such as the F-15 Eagle by the 1970s.

South Vietnam fell without US air support when faced with a massive assault in 1975. The VNAF South Vietnamese Air Force was never supplied with powerful fighters and bombers such as the Phantom and B-52 which could strike at North Vietnam.

Middle East

In the Six-Day War of 1967, the Israeli Air Force launched pre-emptive strikes which destroyed opposing Arab air forces on the ground. The Yom Kippur War of 1973 saw the Arab deployment of mobile SA-6 missiles which proved effective against low-flying Israeli aircraft until they were neutralized by ground forces.

Post Cold War

USS *Abraham Lincoln* rides out a storm in the Arabian Sea while on station in support of Operation Southern Watch and Operation Enduring Freedom.

The collapse of the Soviet Union in 1991 forced Western air forces to undergo a shift from the massive numbers felt to be necessary during the Cold War to smaller numbers of multi-role aircraft. The closure of several military bases overseas and the U.S. Base Realignment and Closure program have served to highlight the effectiveness of aircraft carriers in the absence of dedicated military or air forces bases, as the Falklands war and U.S. operations in the Persian Gulf have highlighted.

The advent of precision-guided munitions have allowed for strikes at arbitrary surface targets once proper reconnaissance is performed (network-centric warfare). In some cases such as the NATO Operation Allied Force effort against Serbian operations in Kosovo, air power was the deciding factor with ground forces mostly securing the area afterwards. However in most cases the standard military doctrine still applies: wars against third-world regional entities still cannot be won through air power alone.

Operation: Desert Storm

The role of air power in modern warfare was dramatically demonstrated during the Gulf War in 1991. Behind-the-lines air attacks were made on Iraqi command and control centers, communications facilities, supply depots, and reinforcement forces. Air superiority over Iraq was gained before major ground combat began.

The initial strikes were composed of Tomahawk cruise missiles launched from battleships situated in the Persian Gulf, F-117A Nighthawk stealth bombers with an armament of laser-guided smart bombs, and F-4G Wild Weasel aircraft armed with HARM anti-radar missiles. These first attacks allowed F-14, F-15, F-16, and F/A-18 fighter bombers to gain air superiority over the country and then continue to drop TV and laser-guided bombs.

Armed with a gatling gun and heat-seeking or optically guided Maverick missiles, A-10 Thunderbolts bombed and destroyed Iraqi armored forces, supporting the advance of US ground troops. The AH-64 Apache and AH-1 Cobra attack helicopters, fired laser guided Hellfire missiles and TOW missiles which were guided to tanks by ground observers or scout helicopters. The allied air fleet also made use of the E-3A Airborne Warning and Control Systems (AWACS) and a fleet of B-52 bombers.

The aerial strike force was made up of over 2,250 combat aircraft, which included 1,800 US aircraft, which fought against an Iraqi force of about 500 Soviet-built MiG-29 and French-made Mirage F-1 fighters. More than 88,000 combat missions had been flown by allied forces with over 88,000 tons of bombs dropped by the end of the fifth week.

Operation: Iraqi Freedom

An F-15E Strike Eagle from the 391st Expeditionary Fighter Squadron at Bagram Air Base, Afghanistan, launches heat decoys during a close-air-support mission over Afghanistan, 15 December 2008.

During the 2003 invasion of Iraq led by US and British forces putatively to defeat the regime of Saddam Hussein, aerial warfare continued to be decisive. The US-British alliance began its air campaign on March 19 with limited nighttime bombing on the Iraqi capital of Baghdad. Several days later, intensive bombardment began. About 14,000 sorties were flown, and at a cost of $1 million dollars each, 800 Tomahawk cruise missiles were fired at numerous targets in Iraq from March 19 until mid-April 2003. By this time Iraqi resistance had largely ended.

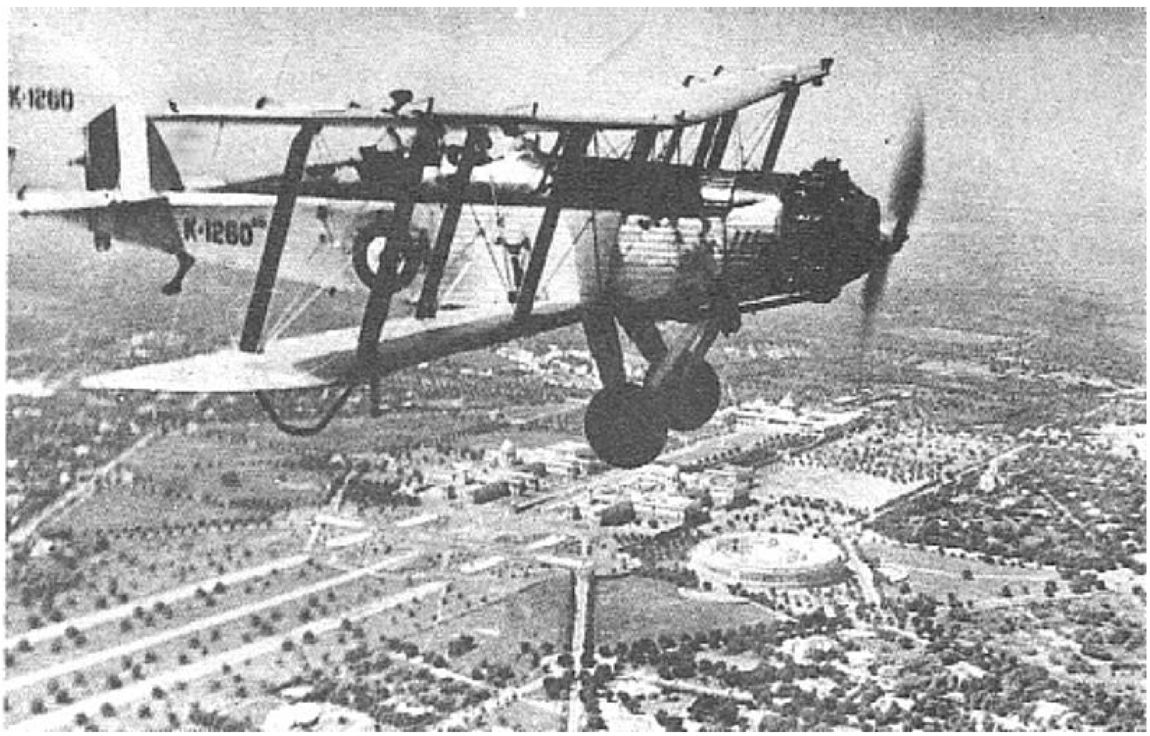
Iraqi anti-aircraft weapons were unable to open fire on high-altitude US bombers such as the B-52 or stealth aircraft such as the B-2 bomber and the F-117A. US and British aircraft used radar-detecting devices and aerial reconnaissance to locate Iraqi anti-aircraft weapons. Bunker buster bombs, designed to penetrate and destroy underground bunkers, were dropped on Iraqi command and control centers. Iraqi ground forces could not seriously challenge the American ground forces because of their air supremacy. By mid-April 2003, US-British forces controlled all of Iraq's major cities and oil fields.

2006 Lebanon War

In the beginning of the 2006 Lebanon War Israel utilized an intensive aerial campaign aimed to eliminate Hezbollah and destroy its military, as stated by Israeli prime minister Ehud Olmert. It also aimed to return kidnapped Israeli soldiers. The campaign started by destroying Lebanese infrastructure and Hezbollah targets. This continued during the 33 days of the war.

Taking into consideration the results of the 1991 and 2003 wars on Iraq and the 1999 war on the former Yugoslavia, the Israeli air force was unable to accomplish its objectives as completely. This partly results from the military doctrine that Hezbollah used in the war which proved effective. There have also been reports during the conflict that a Hezbollah-operated flying drone penetrated Israeli airspace, and returned to Lebanese territory.

Indian Air Force-IAF



A Westland Wapiti, one of the first aircraft of the Indian Air Force.

The Indian Air Force was established in British India as an auxiliary air force of the Royal Air Force with the enactment of the Indian Air Force Act 1932 on 8 October that year and adopted the Royal Air Force uniforms, badges, brevets and insignia. On 1 April 1933, the IAF commissioned its first squadron, No.1 Squadron, with four Westland Wapiti biplanes and five Indian pilots. The Indian pilots were led by Flight Lieutenant (later Air Vice Marshal) Cecil Bouchier. Until 1938, No. 1 Squadron remained the only squadron of the IAF, though two more flights were added.

During World War II, the red blob was removed from the IAF roundel to eliminate confusion with the Japanese Red Sun Emblem. The Air Force grew to seven squadrons in 1943 and to nine squadrons in 1945. The IAF helped in blocking the advance of the Japanese army in Burma, where its first air strike was on the Japanese military base in Arakan. It also carried out strike missions against the Japanese airbases at Mae Hong Son, Chiang Mai and Chiang Rai in northern Thailand. In recognition of the crucial role played by the IAF, King George VI conferred it the prefix "Royal" in 1945. During the war, many youth joined the Indian National Army. Forty five of them (known as the Tokyo Boys) were sent to train as fighter pilots at the Imperial Japanese Army Air Force Academy in 1944 by Subhas Chandra Bose. After the war, they were interned by the Allies and were court-martialled. After Indian independence, some of them rejoined the IAF for service.

Sukhoi Su-30MKI

IAF MiG-29 at Aero India 2009.

A few other spans of conflicts opened up the use of aerial warfare in recent times. In 1999, India and Pakistan were involved in a brief conflict over Kashmir. The Indian Air Force used Mirage 2000 fighter jet effectively to carry out ground assault sorties against Pakistani positions. The air operations were notable given the high altitude terrain of Kashmir. When British India was granted its independence in 1947, it was partitioned into the new states of the Union of India and the Dominion of Pakistan. The armed forces were similarly divided. India's air force retained the name of the Royal Indian Air Force, but three of the ten operational squadrons and facilities, located within the new borders of Pakistan, were transferred to the Royal Pakistan Air Force. The RIAF Roundel was changed to an interim 'Chakra' roundel derived from the Ashoka Chakra.

When India became a republic in 1950, the prefix 'Royal' was dropped from the Indian Air Force. At the same time, the current IAF roundel was adapted.

Around the same time, conflict broke out between them over the control of the princely state of Jammu & Kashmir. With Pakistani forces moving into the state, its Maharaja decided to accede to India in order to receive military help. The day after instrument of accession was signed, the RIAF was called upon to transport troops into the war-zone. This led to the eruption of full scale war between India and Pakistan, though there was no formal declaration of war. During the war, the RIAF did not engage the Pakistan Air

Force in air-to-air combat; however, it did provide effective transport and close air support to the Indian troops. In 1962, border disagreements between China and India escalated to a war when China mobilised its troops across the Indian border. During the Sino-Indian War, India's military planners failed to deploy and effectively use the IAF against the invading Chinese forces. This resulted in India losing a significant amount of territory to the Chinese; especially in Jammu and Kashmir. By late 1971, the intensification of the independence movement in erstwhile East Pakistan lead to the Bangladesh Liberation War between India and Pakistan. On 22 November 1971, 10 days before the start of a full-scale war, four PAF F-86 Sabre jets attacked Indian and Mukti Bahini positions at Garibpur, near the international border. Three of the four PAF Sabres were shot down by the IAF's Folland Gnats. On 3 December, India formally declared war against Pakistan following massive preemptive strikes by the PAF against Indian Air Force installations in Srinagar, Ambala, Sirsa, Halwara and Jodhpur. However, the IAF did not suffer significantly because the leadership had anticipated such a move and precautions were taken. The Indian Air Force was quick to respond to Pakistani air strikes, following which the PAF carried out mostly defensive sorties.

Within the first two weeks, the IAF had carried out almost 2,000 sorties over East Pakistan and also provided close air support to the advancing Indian Army. IAF also assisted the Indian Navy in its operations against the Pakistani Navy and Maritime Security Agency in the Bay of Bengal and Arabian Sea. On the western front, the IAF destroyed more than 29 Pakistani tanks, 40 APCs and a railway train during the Battle of Longewala. The IAF undertook strategic bombing of West Pakistan by carrying out raids on oil installations in Karachi, the Mangla Dam and a gas plant in Sindh. Similar strategy was also deployed in East Pakistan and as the IAF achieved complete air superiority on the eastern front, the ordnance factories, runways, and other vital areas of East Pakistan were severely damaged. By the time Pakistani forces surrendered, the IAF claimed that 94 PAF aircraft, including 54 F-86 Sabres had been shot down. The IAF had flown over 6,000 sorties on both East and West fronts; including sorties by transport aircraft and helicopters. Towards the end of the war, IAF's transport planes dropped leaflets over Dhaka urging the Pakistani forces to surrender, demoralising Pakistani troops in East Pakistan.

Three years after the Sino-Indian conflict, in 1965, India went to war with Pakistan again over Kashmir in what came to be known as the Second Kashmir War. Learning from the experiences of the Sino-Indian war, India used its air force extensively during the war. This was the first time the IAF actively engaged an enemy air force. However, instead of providing close air support to the Indian Army, the IAF carried out independent raids against PAF bases. These bases were situated deep inside Pakistani territory, making IAF fighters vulnerable to anti-aircraft fire. During the course of the conflict, the PAF enjoyed qualitative superiority over the IAF as most of the jets in IAF's fleet were of post World War II vintage. Despite this, the IAF was able to prevent the PAF from gaining air superiority over conflict zones. By the time the conflict had ended, Pakistan claimed to have shot down 113 IAF aircraft while the Indians claimed 73 PAF aircraft were downed. More than 60% of IAF's air combat losses took place during the battles over Kalaikunda and Pathankot; where most of the aircraft were destroyed while parked on the ground.

Kargil War (1999)

IAF MiG-21s were used extensively in the Kargil war.

On 11 May 1999, the Indian Air Force was called in to provide close air support to the Indian Army at the height of the ongoing Kargil conflict with the use of helicopters. The IAF strike was code named Operation Safed Sagar. The first strikes were launched on the 26 May, when the Indian Air Force struck infiltrator positions with fighter aircraft and helicopter gunships.. The initial strikes saw MiG-27s carrying out offensive sorties, with MiG-21s and later MiG-29s providing fighter cover. The IAF also deployed its radars and the MiG-29 fighters in vast numbers to keep check on Pakistani military movements across the border. Srinagar Airport was at this time closed to civilian air-traffic and dedicated to the Indian Air Force.

During the Kargil conflict IAF Mirage 2000Hs carried out strike missions.

On 27 May, the first fatalities were suffered when a MiG-21 and a MiG-27 jets were lost over Batalik Sector to enemy action and mechanical failure, respectively. The following day, a Mi-17 was lost- with the loss of all four of the crew- when it was hit by three stingers while on an offensive sortie.. These losses forced the Indian Air Force to reassess its strategy. The helicopters were immediately withdrawn from offensive roles as a measure against the man-portable missiles in possession of the infiltrators. On 30 May, the Indian Air Force called into operation the Mirage 2000 which was deemed the best aircraft capable of optimum performance under the conditions of high-altitude seen in the zone of conflict. Mirage 2000s not only had better defence equipment compared to the MiGs, but also gave IAF the ability to carry out aerial raids at night. The MiG-29s were used extensively to provide fighter escort to the Mirage 2000. The Mirages successfully targeted enemy camps and logistic bases in Kargil and within days, their supply lines were severely disrupted. Mirage 2000s were used for strikes on Muntho Dhalo and the heavily defended Tiger Hill and paved the way for their early recapture. At the height of the conflict, the IAF was conducting over forty sorties daily over the Kargil region. By 26 July, the Indian forces had successfully liberated Kargil from Pakistani forces.

Soviet Mi-24 epitomized combat helicopter usage in aerial warfare during the Russo-Afghan war in the '80s

Chapter-7

Military Aviation

Simple balloons were used as surveillance aircraft as early as the 18th century. Over the years, military aircraft have been built to meet ever increasing capability requirements. Manufacturers of military aircraft compete for contracts to supply their government's arsenal. Aircraft are selected based on factors like cost, performance, and the speed of production.

The Lockheed SR-71 remains unsurpassed in many areas of performance.

Types of military aviation

Fighter aircraft

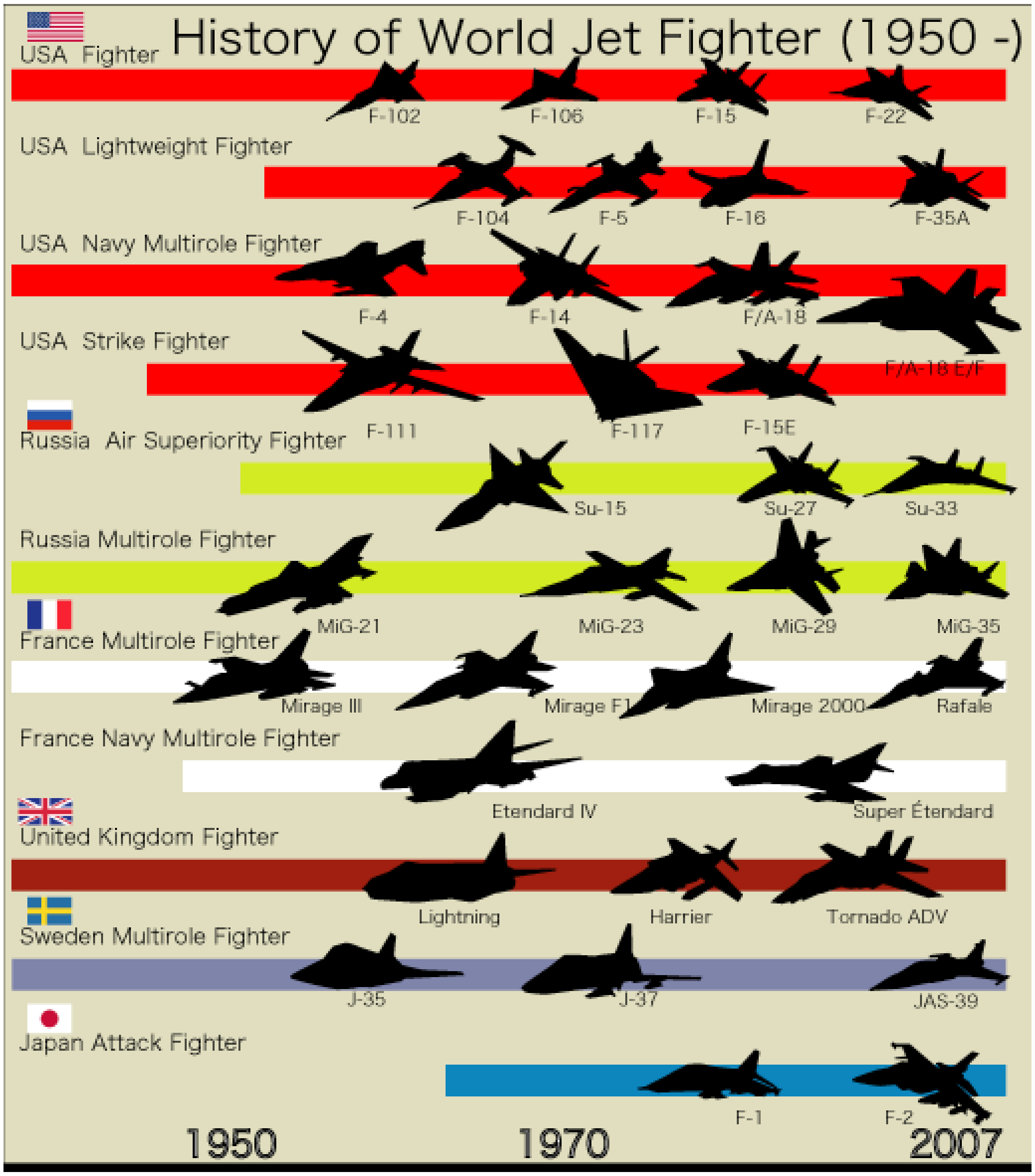
An A-10 Thunderbolt II, F-86 Sabre, P-38 Lightning and P-51 Mustang fly in formation during an air show at Langley Air Force Base, Virginia. The formation displays two generations of U.S. Air Force fighter aircraft, and an attack aircraft (the A-10).

A **fighter aircraft** is a military aircraft designed primarily for air-to-air combat with other aircraft, as opposed to a bomber, which is designed primarily to attack ground targets by dropping bombs. Fighters are small, fast, and maneuverable. Many fighters have secondary ground-attack capabilities, and some are dual-roled as fighter-bombers; the term "fighter" is also sometimes used colloquially for dedicated ground-attack aircraft. Fighter aircraft are the primary means by which armed forces gain air superiority over their opponents in battle. Since at least World War II, achieving and maintaining air superiority has been a key component of victory in warfare, particularly conventional warfare between regular armies (as opposed to guerrilla warfare). The purchase, training and maintenance of a fighter fleet represent a very substantial proportion of defense budgets for modern militaries.

Terminology

Royal Flying Corps recruiting poster

The word "fighter" did not become the official English term for such aircraft until after World War I. In Great Britain's Royal Flying Corps – later the Royal Air Force – these aircraft continued to be called "scouts" into the early 1920s. The U.S. Army called their fighters "pursuit" aircraft (reflected by their designation in the "P" series) from 1916 until the late 1940s. In the French, Portuguese and German languages the term used (and still in use) literally means "hunter". This has been followed in most other languages, an exception being Russian, in which the fighter is called "истребитель" (pronounced "istrebitel"), meaning "The Fighter".



Examples of jet fighter aircraft, sorted by time, country and role

Although the term "fighter" technically refers to aircraft designed to shoot down other aircraft, such designs are often also useful as multirole fighter-bombers and sometimes lighter, fighter-sized tactical ground-attack aircraft. For example, in World War II the US Navy would later favor fighters over dedicated dive bombers, and the P-47 Thunderbolt would be favored for ground attack. The controversial F-111 would be employed as a strike bomber as the fighter variant was abandoned. Bombers generally refer to long-range strategic or theater bombing roles. This blurring follows the use of fighters from their earliest days for "attack" or "strike" operations against enemy troops, field positions, vehicles, and facilities by means of strafing or dropping of bombs or incendiaries.

Some of the most expensive fighters such as the F-14 Tomcat, F-22 Raptor and F-15 Eagle were employed as all-weather interceptors as well as air superiority combat aircraft, only developing air-to-ground roles late in their careers. Multirole fighter-bombers such as the F/A-18 Hornet are often less expensive and tasked (and in this case, given an F/A designation) with ground attack as part of a "high-low mix", or in the case of the Super Hornet, replacing a range of specialized aircraft types.

Introduction

F-16 Fighting Falcon is a fighter aircraft

Fighters were developed in response to the fledgling use of aircraft and dirigibles in World War I for reconnaissance and ground-attack roles. Early fighters were very small and lightly armed by later standards, and were mostly biplanes. As aerial warfare became increasingly important, so did control of the airspace. By World War II, fighters were predominantly all-metal monoplanes with wing-mounted batteries of cannons or machine guns. By the end of the war, turbojet engines were already beginning to replace piston engines as the means of propulsion, and increasingly sophisticated refinements to armament were already appearing.

Modern jet fighters are predominantly powered by one or two turbofan engines, and are equipped with a radar as the primary method of target acquisition. Armament consists primarily of air-to-air missiles (from as few as two on some lightweight day fighters to as many as eight or twelve on air superiority fighters like the Sukhoi Su-27 or Boeing F-15 Eagle), with a cannon as backup armament (typically between 20 and 30 mm in caliber); however, they can also employ air-to-surface missiles, as well as guided and unguided bombs.

Piston engine fighters

World War I

Vickers F.B.5 Gunbus

The word "fighter" was first used to describe a two-seater aircraft with sufficient lift to carry a machine gun and its operator as well as the pilot. The first such "fighters" belonged to the "gunbus" series of experimental gun carriers of the British Vickers company which culminated in the Vickers F.B.5 Gunbus of 1914. The main drawback of this type of aircraft was its lack of speed. It was quickly realized that an aircraft intended to destroy its kind in the air needed at least to be fast enough to catch its quarry.

Fortunately another type of military aircraft already existed, which was to form the basis for an effective "fighter" in the modern sense of the word. It was based on the small fast aircraft developed before the war for such air races as the Gordon Bennett Cup and Schneider Trophy. The military **scout** airplane was not expected to be able to carry serious armament, but rather to rely on its speed to be able to reach the location it was required to "scout" or reconnoiter and then return quickly to report – while at the same time making itself a difficult target for anti-aircraft artillery or enemy gun-carrying aircraft. British scout aircraft in this sense included the Sopwith Tabloid and Bristol Scout; French equivalents included the light, fast Morane-Saulnier N.

In practice, soon after the actual commencement of the war, the pilots of small scout aircraft began to arm themselves with pistols, carbines, grenades, and an assortment of improvised weapons with which to attack enemy aircraft. It was inevitable that sooner or later means of effectively arming "scouts" would be devised. One method was to build a "pusher" scout such as the Airco DH.2, with the propeller mounted behind the pilot. The main drawback was that the high drag of a pusher type's tail structure meant that it was bound to be slower than an otherwise similar "tractor" aircraft. The other approach was to mount the machine gun armament on a tractor-type airplane in a manner that enabled the gun to fire outside the arc of the propeller.

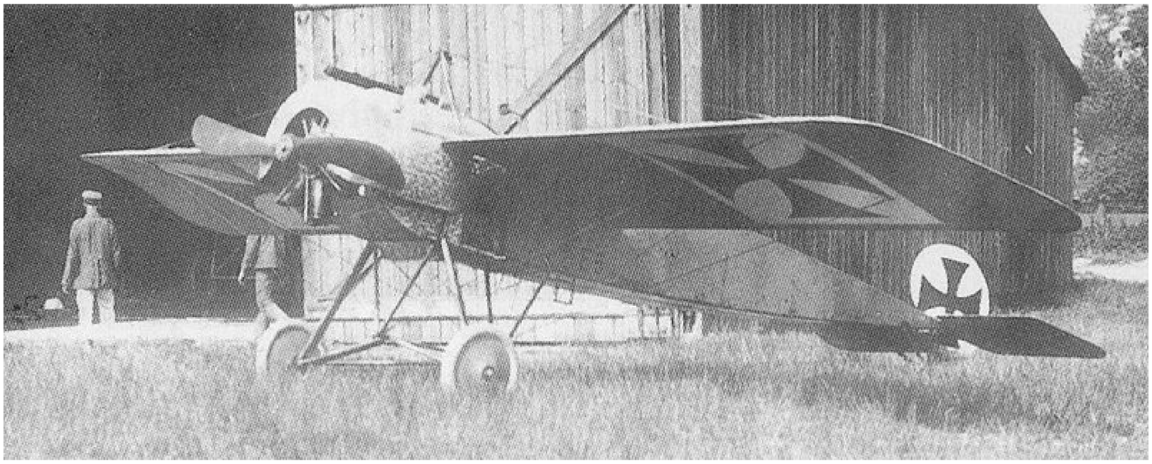
Airco DH.2 "pusher" scout

Only two configuration options were practical initially for tractor aircraft. One involved having a second crew member added behind the pilot to aim and fire a swivel-mounted machine gun at enemy airplanes. However, this limited the area of coverage chiefly to the rear hemisphere, and the inability to effectively coordinate the pilot's maneuvering with the gunner's aiming, which reduced the accuracy and efficacy of the gunnery. This option was chiefly employed as a defensive measure on two seater reconnaissance aircraft from 1915 on. The alternative configuration mounted a gun on the upper wing to fire over the propeller arc. While more effective for offensive combat, since the pilot could move and aim the guns as a unit, this placement made determining the proper aim point more difficult. Furthermore, this location made it nearly impossible for a pilot to maneuver his aircraft and have access to the gun's breech – a very important consideration, given the tendency of early machine guns to jam – hence this was a stopgap solution. Nevertheless, a machine gun firing over the propeller arc did have some advantages, and was to remain in service from 1915 (Nieuport 11) until 1918 (Royal Aircraft Factory S.E.5). The British Foster mounting was specifically designed for this kind of application.

A captured Morane-Saulnier Type L with German insignia

The need to arm a tractor scout with a forward-firing gun whose bullets passed through the propeller arc was evident even before the outbreak of war, and its approach motivated inventors in both France and Germany to devise a practical synchronization gear that could time the firing of the individual rounds to when the propeller was not in the way. Franz Schneider, a Swiss engineer, had patented such a device in Germany in 1913, but his original work was not followed up. French aircraft designer Raymond Saulnier patented a practical device in April 1914, but trials were unsuccessful because of the propensity of the machine gun employed to hang fire due to unreliable ammunition.

In December 1914, French aviator Roland Garros asked Saulnier to install his synchronization gear on Garros' Morane-Saulnier Type L. Unfortunately the gas-operated Hotchkiss machine gun had a firing cycle which caused the bullet to leave the weapon too late to effectively and consistently synchronize the gunfire with a spinning propeller. Because of this, the propeller blades were armored, and Garros' mechanic, Jules Hue, fitted metal wedges to the blades to protect the pilot from ricochets. Garros' modified monoplane was first flown in March 1915 and he began combat operations soon thereafter. Firing 8 mm (.323 in) solid copper bullets, Garros scored three victories in three weeks before he himself was shot down on 18 April and his airplane – along with its synchronization gear and propeller – was captured by the Germans.



The actual aircraft used by Wintgens in his pioneering aerial engagement, his Fokker M.5K/MG with IdFlieg military serial number "E.5/15", as it appeared at the time of the engagement.

However, the synchronization gear (called the *Zentralsteuerung* in German) devised by the engineers of Anthony Fokker's firm was the first gear to attract official sponsorship, and this would make the pioneering Fokker *Eindecker* monoplane a feared name over the Western Front, despite its being an adaptation of an obsolete pre-war French Morane-Saulnier racing airplane, with a mediocre performance and poor flight characteristics. The first victory for the *Eindecker* came on 1 July 1915, when *Leutnant* Kurt Wintgens, flying with the *Feldflieger Abteilung 6* unit on the Western Front, forced down a Morane-Saulnier Type L two-seat "parasol" monoplane just east of Luneville. Wintgens' aircraft, one of the five Fokker M.5K/MG production prototype examples of the *Eindecker*, was armed with a synchronized, air-cooled aviation version of the Parabellum MG14 machine gun, which did not require armored propellers. In some respects, this was the first "true" fighter victory of military aviation history.

German Fokker Triplanes of *Jasta* 26 in War World I

The success of the *Eindecker* kicked off a competitive cycle of improvement among the combatants, building ever more capable single-seat fighters. The Albatros D.I of late 1916, designed by Robert Thelen, set the classic pattern followed by almost all such aircraft for about twenty years. Like the D.I, they were biplanes (only very occasionally monoplanes or triplanes). The strong box structure of the biplane wing allowed for a rigid wing that afforded accurate lateral control, which was essential for fighter-type maneuvers. They had a single crew member, who flew the aircraft and also operated its armament. They were armed with two Maxim-type machine guns – which had proven much easier to synchronize than other types – firing through the propeller arc. The gun breeches were typically right in front of the pilot's face. This had obvious implications in case of accidents, but enabled jams (to which Maxim-type machine guns always remained liable) to be cleared in flight and made aiming much easier.

Replica of the Fokker Dr.I, the "Red Baron's" triplane, at the ILA 2006 air show

The use of metal in fighter aircraft was pioneered in World War I by Germany, as Anthony Fokker used chrome-molybdenum steel tubing (a close chemical cousin to stainless steel) for the fuselage structure of all his fighter designs, and the innovative German engineer Hugo Junkers developed two all-metal, single-seat fighter monoplane designs with cantilever wings: the strictly experimental Junkers J 2 private-venture aircraft, made with steel, and some forty examples of the Junkers D.I, made with corrugated duralumin, all based on his experience in creating the pioneering Junkers J 1 all-metal airframe technology demonstration aircraft of late 1915.

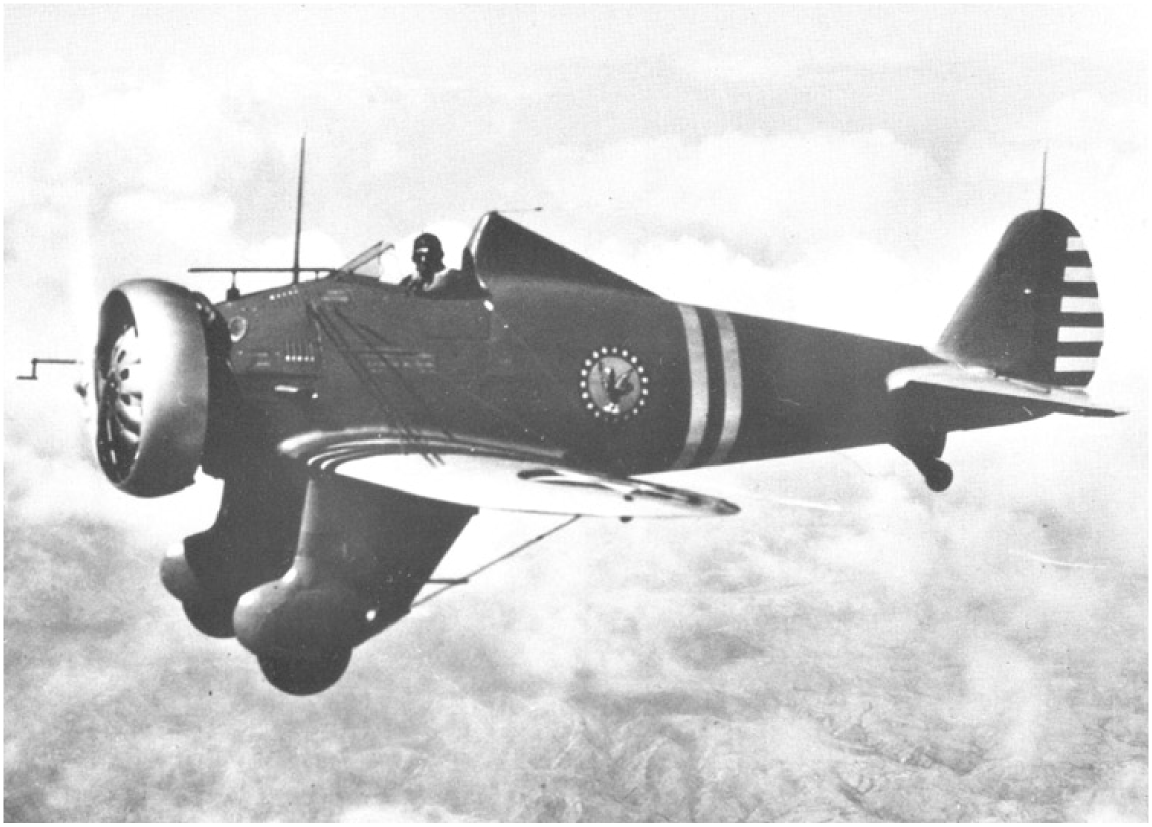
A Sopwith Camel 2F1 biplane at the Imperial War Museum in London

As collective combat experience grew, the more successful pilots such as Oswald Boelcke, Max Immelmann, and Edward Mannock developed innovative tactical formations and maneuvers to enhance their air units' combat effectiveness and accelerate the learning – and increase the expected lifespan – of newer pilots reaching the front lines.

Allied and – until 1918 – German pilots of World War I were not equipped with parachutes, so most cases of an aircraft catching fire, or structurally breaking up in flight were fatal. Parachutes were well-developed by 1918, and were adopted by the German flying services during the course of that year (the famous "Red Baron" was wearing one when he was killed), but the allied command continued to oppose their use, on various grounds.

Interwar period (1919–38)

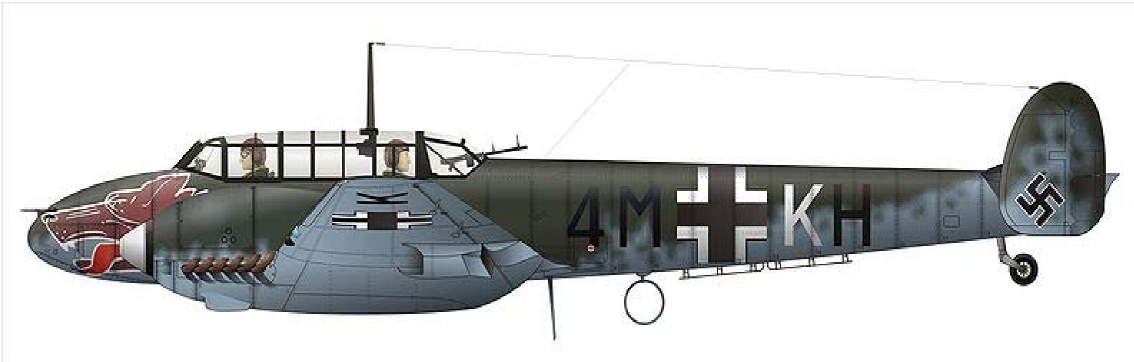
Fighter development slowed between the wars, with the most significant change coming late in the period, when the classic World War I type machines started to give way to metal monocoque or semi-monocoque monoplanes, with cantilever wing structures. Given limited defense budgets, air forces tended to be conservative in their aircraft purchases, and biplanes remained popular with pilots because of their agility. Designs such as the Gloster Gladiator, Fiat CR.42, and Polikarpov I-15 were common even in the late 1930s, and many were still in service as late as 1942. Up until the mid-1930s, the vast majority of fighter aircraft remained fabric-covered biplanes.



An early monoplane fighter: the Boeing P-26 Peashooter which first flew in 1932

Fighter armament eventually began to be mounted inside the wings, outside the arc of the propeller, though most designs retained two synchronized machine-guns above the engine (which were considered more accurate). Rifle-caliber guns were the norm, with .50 caliber (12.7 mm) machine guns and 20 mm cannons deemed "overkill." Considering that many aircraft were constructed similarly to World War I designs (albeit with aluminum frames), it was not considered unreasonable to use World War I-style armament to counter them. There was insufficient aerial combat during most of the period to disprove this notion.

The rotary engine, popular during World War I, quickly disappeared, replaced chiefly by the stationary radial engine. Aircraft engines increased in power several-fold over the period, going from a typical 180 hp (130 kW) in the 1918 Fokker D.VII to 900 hp (670 kW) in the 1938 Curtiss P-36. The debate between the sleek in-line engines versus the more reliable radial models continued, with naval air forces preferring the radial engines, and land-based forces often choosing in-line units. Radial designs did not require a separate (and vulnerable) cooling system, but had increased drag. In-line engines often had a better power-to-weight ratio, but there were radial engines that kept working even after having suffered significant battle damage.



Messerschmitt Bf 110 *Zerstörer* "heavy fighter"

Some air forces experimented with "heavy fighters" (called "destroyers" by the Germans). These were larger, usually two-engined aircraft, sometimes adaptations of light or medium bomber types. Such designs typically had greater internal fuel capacity (thus longer range) and heavier armament than their single-engine counterparts. In combat, they proved ungainly and vulnerable to more nimble single-engine fighters.

The primary driver of fighter innovation, right up to the period of rapid rearmament in the late thirties, were not military budgets, but civilian aircraft races. Aircraft designed for these races pioneered innovations like streamlining and more powerful engines that would find their way into the fighters of World War II.

At the very end of the inter-war period came the Spanish Civil War. This was just the opportunity the German *Luftwaffe*, Italian *Regia Aeronautica*, and the Soviet Union's Red Air Force needed to test their latest aircraft designs. Each party sent several aircraft to back their side in the conflict. In the dogfights over Spain, the latest Messerschmitt fighters (Bf 109) did well, as did the Soviet Polikarpov I-16. The German design, however, had considerable room for development and the lessons learned in Spain led to greatly improved models in World War II. The Russians, whose side lost in the conflict, nonetheless determined that their planes were sufficient for their immediate needs. I-16s were later slaughtered *en masse* by these improved German models in World War II, although they remained the most common Soviet front-line fighter until well into 1942. For their part, the Italians were satisfied with the performance of their Fiat CR.42 biplanes, and being short on funds, continued with this design even though it was obsolescent.

The Spanish Civil War also provided an opportunity for updating fighter tactics. One of the innovations to result from the aerial warfare experience this conflict provided was the development of the "finger-four" formation by the German pilot Werner Mölders. Each fighter squadron (German: *Staffel*) was divided into several flights (*Schwärme*) of four aircraft. Each *Schwarm* was divided into two *Rotten* which was a pair of aircraft. Each *Rotte* was composed of a leader and a wingman. This flexible formation allowed the pilots to maintain greater situational awareness, and the two *Rotten* could split up at any time and attack on their own. The finger-four would become widely adopted as the fundamental tactical formation over the course of World War II.

World War II

C.200 in the markings of 372° Sq. *Regia Aeronautica*

Messerschmitt Bf 109G-2/Trop 'Black 6'

The Mitsubishi A6M Zero typified the highly maneuverable, but lightly armored, fighter design

Aerial combat formed an important part of World War II military doctrine. The ability of aircraft to locate, harass, and interdict ground forces was an instrumental part of the German combined-arms doctrine, and their inability to achieve air superiority over Britain made a German invasion unfeasible. German Field Marshal Erwin Rommel noted the effect of airpower: "Anyone who has to fight, even with the most modern weapons, against an enemy in complete command of the air, fights like a savage against modern European troops, under the same handicaps and with the same chances of success."

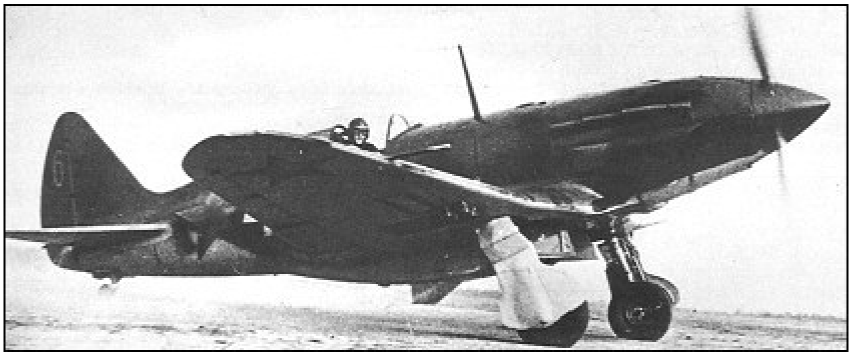
During the 1930s, two different streams of thought about air-to-air combat began to emerge, resulting in two different approaches to monoplane fighter development. In Japan and Italy especially, there continued to be a strong belief that lightly armed, highly maneuverable single-seat fighters would still play a primary role in air-to-air combat. Aircraft such as the Nakajima Ki-27, Nakajima Ki-43 and the Mitsubishi A6M Zero in Japan, and the Fiat G.50 and Macchi C.200 in Italy epitomized a generation of monoplanes designed to this concept.

This Supermarine Spitfire XVI was typical of World War II fighters optimized for high level speeds and good climb rates

The other stream of thought, which emerged primarily in Britain, Germany, the Soviet Union, and the United States was the belief that the high speeds of modern combat aircraft and the *g*-forces imposed by aerial combat meant that dogfighting in the classic World War I sense would be impossible. Fighters such as the Messerschmitt Bf 109, the Supermarine Spitfire, the Yakovlev Yak-1 and the Curtiss P-40 Warhawk were all designed for high level speeds and a good rate of climb. Good maneuverability was desirable, but it was not the primary objective.

The 1939 Soviet-Japanese Battle of Khalkhyn Gol and the initial German invasion of Poland that same year were too brief to provide much feedback to the participants for further evolution of their respective fighter doctrines. During the Winter War, the greatly outnumbered Finnish Air Force, which had adopted the German finger-four formation, bloodied the noses of Russia's Red Air Force, which relied on the less effective tactic of a three-aircraft delta formation.

European theater (Eastern Front)



Russian Mikoyan-Gurevich MiG-3

On the Eastern Front, the strategic surprise of Operation Barbarossa demonstrated that Soviet air defense preparations were woefully inadequate, and the Great Purge rendered any lessons learned by the Red Air Force command from previous experience in Spain and Finland virtually useless. During the first few months of the invasion, Axis air forces were able to destroy large numbers of Red Air Force aircraft on the ground and in one-sided dogfights. However, by the winter of 1941–1942, the Red Air Force was able to put together a cohesive air defense of Moscow, successfully interdict attacks on Leningrad, and begin production of new aircraft types in the relocated semi-built factories in the Urals, Siberia, Central Asia and the Caucasus. These facilities produced more advanced monoplane fighters, such as the Yak-1, Yak-3, LaGG-3, and MiG-3, to wrest air superiority from the *Luftwaffe*. However, Soviet aircrew training was hasty in comparison to that provided to the *Luftwaffe*, so Soviet pilot losses continued to be disproportionate until a growing number of survivors were matched to more effective machines.

Beginning in 1942, significant numbers of British, and later U.S., fighter aircraft were also supplied to aid the Soviet war effort, with the Bell P-39 Airacobra proving particularly effective in the lower-altitude combat typical of the Eastern Front. Also from that time, the Eastern Front became the largest arena of fighter aircraft use in the world; fighters were used in all of the roles typical of the period, including close air support, interdiction, escort and interception roles. Some aircraft were armed with weapons as large as 45 mm cannon (particularly for attacking enemy armored vehicles), and the Germans began installing additional smaller cannons in under-wing pods to assist with ground-attack missions.

Pacific theatre

Grumman F4F-3 Wildcat on patrol in early 1942

Lockheed P-38 Lightnings flying in formation

In the Pacific Theater, the Allies had the sturdy P-38 Lightning which was used most extensively and successfully in the Pacific theater, where it proved ideally suited, combining excellent performance with very long range. But the experienced Japanese used their latest Mitsubishi A6M "Zero" to clear the skies of all opposition. Allied air forces – often flying obsolete aircraft, as the Japanese were not deemed as dangerous as the Germans – were caught off-guard and driven back until the Japanese became overextended. While the Japanese entered the war with a cadre of superbly trained airmen, they were never able to adequately replace their losses with pilots of the same quality, resulting in zero leave for experienced pilots and sending pilots with minimal skill into battle, while the British Commonwealth Air Training Plan and U.S. schools produced thousands of competent airmen, compared to one hundred Japanese that graduated a year before the war. Japanese fighter planes were also optimized for agility and range, and in time Allied airmen developed tactics that made better use of the superior armament and protection in their Grumman F4F Wildcats and Curtiss P-40s. From mid-1942, newer Allied fighter models were faster and better-armed than the Japanese fighters. Improved tactics such as the Thach weave helped counter the more agile Zeros and Nakajima Ki-43 'Oscars'. Japanese industry was not up to the task of mass-producing fighter designs equal to the latest Western models, and Japanese fighters had been largely driven from the skies by mid-1944.

Technological innovations

A Curtiss P-40, painted with the shark-face emblem of the Flying Tigers and the 12-point sun roundel of the Chinese Air Force

P-51D-5NA *44-13357* of 8th AF / 361st FG / 374th FS

Piston-engine power increased considerably during the war. The Curtiss P-36 Hawk had a 900 hp (670 kW) radial engine but was soon redesigned as the P-40 Warhawk with a 1100 hp (820 kW) in-line engine. By 1943, the latest P-40N had a 1300 hp (970 kW) Allison engine. At war's end, the German Focke-Wulf Ta 152 interceptor could achieve 2050 hp (1530 kW) with an MW-50 (methanol-water injection) supercharger and the American P-51H Mustang fitted with the Packard V-1650-9 could achieve 2218 hp (1650 kW) under war emergency power. The Spitfire Mk I of 1939 was powered by a 1030 hp (770 kW) Merlin II; its 1945 successor, the Spitfire F.Mk 21, was equipped with the 2035 hp (1520 kW) Griffon 61. Likewise, the radial engines favored for many fighters also grew from 1,100 hp (820 kW) to as much as 2090 hp (1560 kW) during the same timeframe.

The first turbojet-powered fighter designs became operational in 1944, and clearly outperformed their piston-engined counterparts. New designs such as the Messerschmitt Me 262 and Gloster Meteor demonstrated the effectiveness of the new propulsion system. (Rocket-powered interceptors – most notable the Messerschmitt Me 163 – appeared at the same time, but proved less effective.) Many of these fighters could do over 660 km/h (410 mph) in level flight, and were fast enough in a dive that they started encountering the transonic buffeting experienced near the speed of sound; such turbulence occasionally resulted in a jet breaking up in flight due to the heavy load placed on an aircraft near the so-called "sound barrier". Dive brakes were added to jet fighters late in World War II to minimize these problems and restore control to fighter pilots.

Focke-Wulf Fw 190D-9 fighter-bomber

More powerful armament became a priority early in the war, once it became apparent that newer stressed-skin monoplane fighters could not be easily shot down with rifle-caliber machine guns. The Germans' experiences in the Spanish Civil War led them to put 20 mm cannons on their fighters. The British soon followed suit, putting cannons in the wings of their Hurricanes and Spitfires. The Americans, lacking a native cannon design, instead chose to place multiple .50 caliber (12.7 mm) machine guns on their fighters. Armaments continued to increase over the course of the war, with the German Me 262 jet having four 30 mm cannons in the nose. Cannons fired explosive shells, and could blast a hole in an enemy aircraft rather than relying on kinetic energy from a solid bullet striking a critical subsystem (fuel line, hydraulics, control cable, pilot, etc.). A debate existed over the merits of high rate-of-fire machine guns versus slower-firing, but more devastating, cannon.

German Bf 110G-4 night fighter at the RAF Museum in London

A P-61 'Black Widow' of 419th Night Fighter Squadron

With the increasing need for close air support on the battlefield, fighters were increasingly fitted with bomb racks and used as fighter-bombers. Some designs, such as the German Fw 190, proved extremely capable in this role – though the designer Kurt Tank had designed it as a pure interceptor. While carrying air-to-surface ordnance such as bombs or rockets beneath the aircraft's wing, its maneuverability is decreased because of lessened lift and increased drag, but once the ordnance is delivered (or jettisoned), the aircraft is again a fully capable fighter aircraft. By their flexible nature, fighter-bombers offer the command staff the freedom to assign a particular air group to air superiority or ground-attack missions, as need requires.

Rapid technology advances in radar, which had been invented shortly prior to World War II, would permit their being fitted to some fighters, such as the Messerschmitt Bf 110, Bristol Beaufighter, de Havilland Mosquito, Grumman F6F Hellcat and Northrop P-61 Black Widow, to enable them to locate targets at night. The Germans developed several night-fighter types as they were under constant night bombardment by RAF Bomber Command. The British, who developed the first radar-equipped night fighters in 1940–1941, lost their technical lead to the *Luftwaffe*. Since the radar of the era was fairly primitive and difficult to use, larger two- or three-seat aircraft with dedicated radar operators were commonly adapted to this role.

Post-World War II period

Lavochkin La-9 'Fritz'

An FR-1 Fireball of VF-66 at NAS North Island, 1945.

Several prototype fighter programs begun early in 1945 continued on after the war and led to advanced piston-engine fighters that entered production and operational service in 1946. A typical example is the Lavochkin La-9 'Fritz', which was an evolution of the successful wartime Lavochkin La-7 'Fin'. Working through a series of prototypes, the La-120, La-126 and La-130, the Lavochkin design bureau sought to replace the La-7's wooden airframe with a metal one, as well as fit a laminar-flow wing to improve maneuver performance, and increased armament. The La-9 entered service in August 1946 and was produced until 1948; it also served as the basis for the development of a long-range escort fighter, the La-11 'Fang', of which nearly 1200 were produced 1947–1951. Over the course of the Korean War, however, it became obvious that the day of the piston-engined fighter was coming to a close and that the future would lie with the jet fighter.

This period also witnessed experimentation with jet-assisted piston engine aircraft. La-9 derivatives included examples fitted with two underwing auxiliary pulsejet engines (the La-9RD) and a similarly mounted pair of auxiliary ramjet engines (the La-138); however, neither of these entered service. One which did enter service – with the U.S. Navy in March 1945 – was the Ryan FR-1 Fireball; production was halted with the war's end on

VJ-Day, with only 66 having been delivered, and the type was withdrawn from service in 1947. The USAAF had ordered its first 13 mixed turboprop-turbojet-powered pre-production prototypes of the Consolidated Vultee XP-81 Silver Bullet fighter, but this program was also canceled by VJ Day, with 80% of the engineering work completed.

Rocket-powered fighters

The Messerschmitt Me 163 was the fastest aircraft of WWII and the only mass-produced rocket-powered fighter

The first rocket-powered aircraft was the Lippisch Ente, which made a successful maiden flight in March 1928. The only pure rocket aircraft ever to be mass-produced was the Messerschmitt Me 163 in 1944, one of several German World War II projects aimed at developing rocket-powered aircraft. Later variants of the Me 262 (C-1a and C-2b) were also fitted with rocket powerplants, while earlier models were fitted with rocket boosters, but were not mass-produced with these modifications.

The USSR experimented with a rocket-powered interceptor in the years immediately following World War II, the Mikoyan-Gurevich I-270. Only two were built.

In the 1950s, the British developed mixed-power jet designs employing both rocket and jet engines to cover the performance gap that existed in existing turbojet designs. The rocket was the main engine for delivering the speed and height required for high-speed interception of high-level bombers and the turbojet gave increased fuel economy in other parts of flight, most notably to ensure the aircraft was able to make a powered landing rather than risking an unpredictable gliding return. The Saunders-Roe SR.53 was a successful design and was planned to be developed into production when economics forced curtailment of most British aircraft programs in the late 1950s. Furthermore, rapid advancements in jet engine technology had rendered mixed-power aircraft designs like Saunders-Roe's SR.53 (and its SR.177 maritime variant) obsolete. The American XF-91 Thunderceptor (which was the first U.S. fighter to exceed Mach 1 in level flight) met a similar fate for the same reason, and no hybrid rocket-and-jet-engine fighter design has ever been placed into service. The only operational implementation of mixed propulsion was Rocket-Assisted Take Off (RATO), a system rarely used in fighters.

Jet-powered fighters

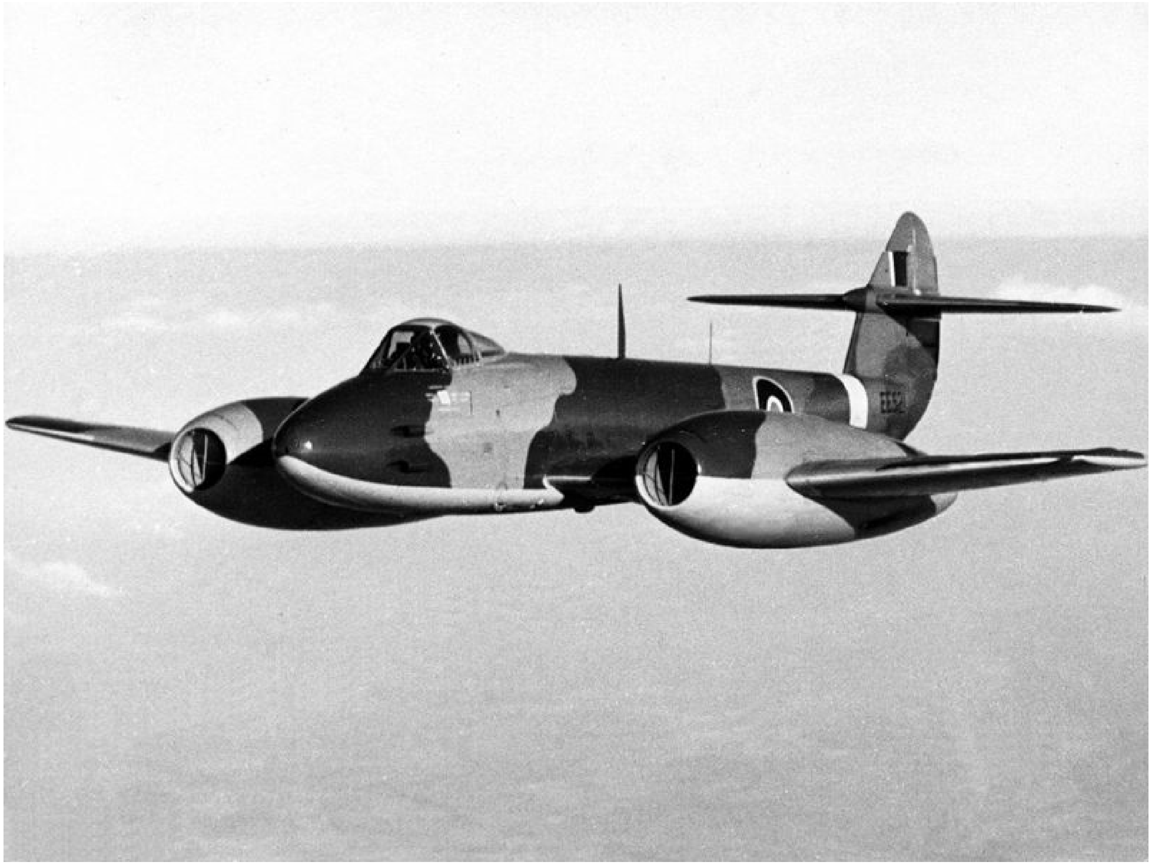
It has become common in the aviation community to classify jet fighters by "generations" for historical purposes. There are no official definitions of these generations; rather, they represent the notion that there are stages in the development of fighter design approaches, performance capabilities, and technological evolution.

The timeframes associated with each generation are inexact and are only indicative of the period during which their design philosophies and technology employment enjoyed a prevailing influence on fighter design and development. These timeframes also encompass the peak period of service entry for such aircraft.

First generation subsonic jet fighters (mid-1940s to mid-1950s)

Messerschmitt Me 262A at the National Museum of the United States Air Force

The first generation of jet fighters comprises the initial, subsonic jet fighter designs introduced late in World War II and in the early post-war period. They differed little from their piston-engined counterparts in appearance, and many employed unswept wings. Guns remained the principal armament. The impetus for the development of turbojet-powered aircraft was to obtain a decisive advantage in maximum speed. Top speeds for fighters rose steadily throughout World War II as more powerful piston engines were developed, and had begun approaching the transonic flight regime where the efficiency of piston-driven propellers drops off considerably.



RAF Gloster Meteor

The first jets were developed during World War II and saw combat in the last two years of the war. Messerschmitt developed the first operational jet fighter, the Me 262. It was considerably faster than contemporary piston-driven aircraft, and in the hands of a competent pilot, was quite difficult for Allied pilots to defeat. The design was never deployed in numbers sufficient to stop the Allied air campaign, and a combination of fuel shortages, pilot losses, and technical difficulties with the engines kept the number of sorties low. Nevertheless, the Me 262 indicated the obsolescence of piston-driven aircraft. Spurred by reports of the German jets, Britain's Gloster Meteor entered production soon after and the two entered service around the same time in 1944. Meteors were commonly used to intercept the V-1 "buzz bomb", as they were faster than available piston-engined fighters. By the end of the war almost all work on piston-powered fighters had ended. A few designs combining piston and jet engines for propulsion – such as the Ryan FR Fireball – saw brief use, but by the end of the 1940s virtually all new combat aircraft were jet-powered.

Lockheed P-80Bs Shooting Star at Langley AFB.

Despite their advantages, the early jet fighters were far from perfect, particularly in the opening years of the generation. Their operational lifespans could be measured primarily in hours; the engines themselves were fragile and bulky, and power could be adjusted only slowly. Many squadrons of piston-engined fighters were retained until the early-to-mid 1950s, even in the air forces of the major powers (though the types retained were the best of the World War II designs). Innovations including ejector seats and all-moving tailplanes were introduced in this period.

The Americans were one of the first to begin using jet fighters post-war. The Lockheed P-80 Shooting Star (soon re-designated F-80) was less elegant than the swept-wing Me 262, but had a cruise speed (660 km/h [410 mph]) as high as the combat maximum of many piston-engined fighters. The British designed several new jets, including the iconic de Havilland Vampire which was sold to the air forces of many nations.

F-86 Sabres in Pakistani markings

The British transferred the technology of the Rolls-Royce Nene jet engine technology to the Soviets, who soon put it to use in their advanced Mikoyan-Gurevich MiG-15 fighters which were the first to introduce swept wings in combat, an innovation first proposed by German research which allowed flying much closer to the speed of sound than straight-winged designs such as the F-80. Their top speed of 1,075 km/h (668 mph) proved quite a shock to the American F-80 pilots who encountered them over Korea, along with their armament of two 23 mm cannons and a single 37 mm cannon compared to machine guns. Nevertheless, in the first jet-versus-jet dogfight in history, which occurred during the Korean War on 8 November 1950, an F-80 (as the P-80 had been redesignated) intercepted two North Korean MiG-15s near the Yalu River and shot them down.

A US Navy F2H-2 Banshee over Wonsan, North Korea, 1952

The Americans responded by rushing their own swept-wing F-86 squadrons to battle against the MiGs which had similar trans-sonic performance. The two aircraft had different strengths, but were similar enough that the superior technology such as a radar ranging gunsight and skills of the veteran United States Air Force pilots allowed them to prevail.

The world's navies also transitioned to jets during this period, despite the need for catapult-launching of the new aircraft. Grumman's F9F Panther was adopted by the U.S. Navy as their primary jet fighter in the Korean War period, and it was one of the first jet fighters to employ an afterburner. The de Havilland Sea Vampire was the Royal Navy's first jet fighter. Radar was used on specialized night fighters such as the F3D Skyknight which also downed MiGs over Korea, and later fitted to the F2H Banshee and swept wing F7U Cutlass and F3H Demon as all-weather / night fighters. Early versions of Infra-red (IR) air-to-air missiles (AAMs) such as the AIM-9 Sidewinder and radar guided missiles such as the AIM-7 Sparrow which would be developed into the 21st century were first introduced on swept wing subsonic Demon and Cutlass naval fighters.

Second generation jet fighters (mid-1950s to early 1960s)

English Electric Lightning

The development of second-generation fighters was shaped by technological breakthroughs, lessons learned from the aerial battles of the Korean War, and a focus on conducting operations in a nuclear warfare environment. Technological advances in aerodynamics, propulsion and aerospace building materials (primarily aluminium alloys) permitted designers to experiment with aeronautical innovations, such as swept wings, delta wings, and area-ruled fuselages. Widespread use of afterburning turbojet engines made these the first production aircraft to break the sound barrier, and the ability to sustain supersonic speeds in level flight became a common capability amongst fighters of this generation.

Dassault Mirage III

Fighter designs also took advantage of new electronics technologies that made effective radars small enough to be carried aboard smaller aircraft. Onboard radars permitted detection of enemy aircraft beyond visual range, thereby improving the handoff of targets by longer-ranged ground-based warning and tracking radars. Similarly, advances in guided missile development allowed air-to-air missiles to begin supplementing the gun as the primary offensive weapon for the first time in fighter history. During this period, passive-homing infrared-guided (IR) missiles became commonplace, but early IR missile sensors had poor sensitivity and a very narrow field of view (typically no more than 30°), which limited their effective use to only close-range, tail-chase engagements. Radar-guided (RF) missiles were introduced as well, but early examples proved unreliable. These semi-active radar homing (SARH) missiles could track and intercept an enemy aircraft "painted" by the launching aircraft's onboard radar. Medium- and long-range RF air-to-air missiles promised to open up a new dimension of "beyond-visual-range" (BVR) combat, and much effort was placed in further development of this technology.

MiG-21F interceptor

The prospect of a potential third world war featuring large mechanized armies and nuclear weapon strikes led to a degree of specialization along two design approaches: interceptors (like the English Electric Lightning and Mikoyan-Gurevich MiG-21F) and fighter-bombers (such as the Republic F-105 Thunderchief and the Sukhoi Su-7). Dogfighting, per se, was de-emphasized in both cases. The interceptor was an outgrowth of the vision that guided missiles would completely replace guns and combat would take place at beyond visual ranges. As a result, interceptors were designed with a large missile payload and a powerful radar, sacrificing agility in favor of high speed, altitude ceiling and rate of climb. With a primary air defense role, emphasis was placed on the ability to intercept strategic bombers flying at high altitudes. Specialized point-defense interceptors often had limited range and little, if any, ground-attack capabilities. Fighter-bombers could swing between air superiority and ground-attack roles, and were often designed for a high-speed, low-altitude dash to deliver their ordnance. Television- and IR-guided air-to-surface missiles were introduced to augment traditional gravity bombs, and some were also equipped to deliver a nuclear bomb.

Third-generation jet fighters (early 1960s to circa 1970)

McDonnell Douglas F-4E Phantom II

The third generation witnessed continued maturation of second-generation innovations, but it is most marked by renewed emphases on maneuverability and traditional ground-attack capabilities. Over the course of the 1960s, increasing combat experience with guided missiles demonstrated that combat would devolve into close-in dogfights. Analog avionics began to be introduced, replacing older "steam-gauge" cockpit instrumentation. Enhancements to improve the aerodynamic performance of third-generation fighters included flight control surfaces such as canards, powered slats, and blown flaps. A number of technologies would be tried for Vertical/Short Takeoff and Landing, but thrust vectoring would be successful on the Harrier jump jet.

Growth in air combat capability focused on the introduction of improved air-to-air missiles, radar systems, and other avionics. While guns remained standard equipment (early models of F-4 being a notable exception), air-to-air missiles became the primary weapons for air superiority fighters, which employed more sophisticated radars and medium-range RF AAMs to achieve greater "stand-off" ranges, however, kill probabilities proved unexpectedly low for RF missiles due to poor reliability and improved electronic countermeasures (ECM) for spoofing radar seekers. Infrared-homing AAMs saw their fields of view expand to 45°, which strengthened their tactical usability. Nevertheless, the low dogfight loss-exchange ratios experienced by American fighters in the skies over Vietnam led the U.S. Navy to establish its famous "TOPGUN" fighter weapons school, which provided a graduate-level curriculum to train fleet fighter pilots in advanced Air Combat Maneuvering (ACM) and Dissimilar Air Combat Training (DACT) tactics and techniques.

This era also saw an expansion in ground-attack capabilities, principally in guided missiles, and witnessed the introduction of the first truly effective avionics for enhanced ground attack, including terrain-avoidance systems. Air-to-surface missiles (ASM) equipped with electro-optical (E-O) contrast seekers – such as the initial model of the widely used AGM-65 Maverick – became standard weapons, and laser-guided bombs (LGBs) became widespread in effort to improve precision-attack capabilities. Guidance for such precision-guided munitions (PGM) was provided by externally mounted targeting pods, which were introduced in the mid-1960s.

It also led to the development of new automatic-fire weapons, primarily chain-guns that use an electric engine to drive the mechanism of a cannon; this allowed a single multi-barrel weapon (such as the 20 mm Vulcan) to be carried and provided greater rates of fire and accuracy. Powerplant reliability increased and jet engines became "smokeless" to make it harder to visually sight aircraft at long distances.

Saab 37 Viggen

Dedicated ground-attack aircraft (like the Grumman A-6 Intruder, SEPECAT Jaguar and LTV A-7 Corsair II) offered longer range, more sophisticated night attack systems or lower cost than supersonic fighters. With variable-geometry wings, the supersonic F-111 introduced the Pratt & Whitney TF30, the first turbofan equipped with afterburner. The ambitious project sought to create a versatile common fighter for many roles and services. It would serve well as an all-weather bomber, but lacked the performance to defeat other fighters. The McDonnell F-4 Phantom was designed around radar and missiles as an all-weather interceptor, but emerged as a versatile strike bomber nimble enough to prevail in air combat, adopted by the U.S. Navy, Air Force and Marine Corps.

Despite numerous shortcomings that would be not be fully addressed until newer fighters, the Phantom claimed 280 aerial kills, more than any other U.S. fighter over Vietnam. With range and payload capabilities that rivaled that of World War II bombers such as B-24 Liberator, the Phantom would became a highly successful multirole aircraft.

Fourth generation jet fighters (circa 1970 to mid-1990s)

Panavia Tornado ADV

Fourth-generation fighters continued the trend towards multirole configurations, and were equipped with increasingly sophisticated avionics and weapon systems. Fighter designs were significantly influenced by the Energy-Maneuverability (E-M) theory developed by Colonel John Boyd and mathematician Thomas Christie, based upon Boyd's combat experience in the Korean War and as a fighter tactics instructor during the 1960s. E-M theory emphasized the value of aircraft specific energy maintenance as an advantage in fighter combat. Boyd perceived maneuverability as the primary means of getting "inside" an adversary's decision-making cycle, a process Boyd called the "OODA loop" (for "Observation-Orientation-Decision-Action"). This approach emphasized aircraft designs that were capable of performing "fast transients" – quick changes in speed, altitude, and direction – as opposed to relying chiefly on high speed alone.

F-16 Fighting Falcon

E-M characteristics were first applied to the F-15 Eagle, but Boyd and his supporters believed these performance parameters called for a small, lightweight aircraft with a larger, higher-lift wing. The small size would minimize drag and increase the thrust-to-weight ratio, while the larger wing would minimize wing loading; while the reduced wing loading tends to lower top speed and can cut range, it increases payload capacity and the range reduction can be compensated for by increased fuel in the larger wing. The efforts of Boyd's "Fighter Mafia" would result in General Dynamics' (now Lockheed Martin's) F-16 Fighting Falcon.

The F-16's manoeuvrability was further enhanced by its being designed to be slightly aerodynamically unstable. This technique, called "relaxed static stability" (RSS), was made possible by introduction of the "fly-by-wire" (FBW) flight control system (FLCS), which in turn was enabled by advances in computers and system integration techniques. Analog avionics, required to enable FBW operations, became a fundamental requirement and began to be replaced by digital flight control systems in the latter half of the 1980s. Likewise, Full Authority Digital Engine Controls (FADEC) to electronically manage powerplant performance were introduced with the Pratt & Whitney F100 turbofan. The F-16's sole reliance on electronics and wires to relay flight commands, instead of the usual cables and mechanical linkage controls, earned it the sobriquet of "the electric jet". Electronic FLCS and FADEC quickly became essential components of all subsequent fighter designs.

Sukhoi Su-27 'Flanker'

Other innovative technologies introduced in fourth-generation fighters include pulse-Doppler fire-control radars (providing a "look-down/shoot-down" capability), head-up displays (HUD), "hands on throttle-and-stick" (HOTAS) controls, and multi-function displays (MFD), all of which have become essential equipment. Composite materials in the form of bonded aluminum honeycomb structural elements and graphite epoxy laminate skins began to be incorporated into flight control surfaces and airframe skins to reduce weight. Infrared search-and-track (IRST) sensors became widespread for air-to-ground weapons delivery, and appeared for air-to-air combat as well. "All-aspect" IR AAM became standard air superiority weapons, which permitted engagement of enemy aircraft from any angle (although the field of view remained relatively limited). The first long-range active-radar-homing RF AAM entered service with the AIM-54 Phoenix, which solely equipped the Grumman F-14 Tomcat, one of the few variable-sweep-wing fighter designs to enter production. Even with the tremendous advancement of Air to Air missiles in this era, internal guns were standard equipment.

Dassault Mirage 2000

Another revolution came in the form of a stronger reliance on ease of maintenance, which led to standardisation of parts, reductions in the numbers of access panels and lubrication points, and overall parts reduction in more complicated equipment like the engines. Some early jet fighters required 50 man-hours of work by a ground crew for every hour the aircraft was in the air; later models substantially reduced this to allow faster turn-around times and more sorties in a day. Some modern military aircraft only require 10 man-hours of work per hour of flight time, and others are even more efficient.

Aerodynamic innovations included variable-camber wings and exploitation of the vortex lift effect to achieve higher angles of attack through the addition of leading-edge extension devices such as strakes.

Chengdu J-10

Unlike interceptors of the previous eras, most fourth-generation air-superiority fighters were designed to be agile dogfighters (although the Mikoyan MiG-31 and Panavia Tornado ADV are notable exceptions). The continually rising cost of fighters, however, continued to emphasize the value of multirole fighters. The need for both types of fighters led to the "high/low mix" concept which envisioned a high-capability and high-cost core of dedicated air-superiority fighters (like the F-15 and Su-27) supplemented by a larger contingent of lower-cost multi-role fighters (such as the F-16 and MiG-29).

HAL Tejas

Most fourth-generation fighter-bombers, such as the Boeing F/A-18 Hornet and Dassault Mirage 2000, are true multirole warplanes, designed as such from the start. This was facilitated by multimode avionics which could switch seamlessly between air and ground modes. The earlier approaches of adding on strike capabilities or designing separate models specialized for different roles generally became *passé* (with the Panavia Tornado being an exception in this regard). Dedicated attack roles were generally assigned either to interdiction strike aircraft such as the Sukhoi Su-24 and Boeing F-15E Strike Eagle or to armored "tank-plinking" close air support (CAS) specialists like the Fairchild-Republic A-10 Thunderbolt II and Sukhoi Su-25.

Perhaps the most novel technology to be introduced for combat aircraft was "stealth", which involves the use of special "low-observable" (L-O) materials and design techniques to reduce the susceptibility of an aircraft to detection by the enemy's sensor systems, particularly radars. The first stealth aircraft to be introduced were the Lockheed F-117 Nighthawk attack aircraft (introduced in 1983) and the Northrop Grumman B-2 Spirit bomber (which first flew in 1989). Although no stealthy fighters per se appeared amongst the fourth generation, some radar-absorbent coatings and other L-O treatments developed for these programs are reported to have been subsequently applied to fourth-generation fighters.

4.5th generation jet fighters (1990s to the present)

Mitsubishi F-2.

The end of the Cold War in 1991 led many governments to significantly decrease military spending as a "peace dividend". Air force inventories were cut, and research and development programs intended to produce what was then anticipated to be "fifth-generation" fighters took serious hits; many programs were canceled during the first half of the 1990s, and those which survived were "stretched out". While the practice of slowing the pace of development reduces annual investment expenses, it comes at the penalty of increased overall program and unit costs over the long-term. In this instance, however, it also permitted designers to make use of the tremendous achievements being made in the fields of computers, avionics and other flight electronics, which had become possible largely due to the advances made in microchip and semiconductor technologies in the 1980s and 1990s. This opportunity enabled designers to develop fourth-generation designs – or redesigns – with significantly enhanced capabilities. These improved designs have become known as "Generation 4.5" fighters, recognizing their intermediate nature between the 4th and 5th generations, and their contribution in furthering development of individual fifth-generation technologies.

MiG-35

The primary characteristics of this sub-generation are the application of advanced digital avionics and aerospace materials, modest signature reduction (primarily RF "stealth"), and highly integrated systems and weapons. These fighters have been designed to operate in a "network-centric" battlefield environment and are principally multirole aircraft. Key weapons technologies introduced include beyond-visual-range (BVR) AAMs; Global Positioning System (GPS)-guided weapons, solid-state phased-array radars; helmet-mounted sights; and improved secure, jamming-resistant datalinks. Thrust vectoring to further improve transient maneuvering capabilities have also been adopted by many 4.5th generation fighters, and uprated powerplants have enabled some designs to achieve a degree of "supercruise" ability. Stealth characteristics are focused primarily on frontal-aspect radar cross section (RCS) signature-reduction techniques including radar-absorbent materials (RAM), L-O coatings and limited shaping techniques.

"Half-generation" designs are either based on existing airframes or are based on new airframes following similar design theory as previous iterations; however, these modifications have introduced the structural use of composite materials to reduce weight, greater fuel fractions to increase range, and signature reduction treatments to achieve lower RCS compared to their predecessors. Prime examples of such aircraft, which are based on new airframe designs making extensive use of carbon-fibre composites, include the Eurofighter Typhoon, Dassault Rafale, and Saab JAS 39 Gripen NG.

Boeing F/A-18E Super Hornet

Apart from these fighter jets, most of the 4.5 generation aircraft are actually modified variants of existing airframes from the earlier fourth generation fighter jets. Such fighter jets are generally heavier and examples include the Boeing F/A-18E/F Super Hornet which is an evolution of the 1970s F/A-18 Hornet design, the F-15E Strike Eagle which is a ground-attack variant of the Cold War-era F-15 Eagle, the Sukhoi Su-30MKI which is a further development of the Su-30 fighter and the Mikoyan MiG-29M/35, an upgraded version of the 1980s MiG-29. The Su-30MKI and MiG-35 use two- and three-dimensional thrust vectoring engines respectively so as to enhance maneuvering. Most 4.5 generation aircraft are being retrofitted with Active Electronically Scanned Array (AESA) radars and other state-of-the art avionics such as electronic counter-measure systems and forward looking infrared.

4.5 generation fighters first entered service in the early 1990s, and most of them are still being produced and evolved. It is quite possible that they may continue in production alongside fifth-generation fighters due to the expense of developing the advanced level of stealth technology needed to achieve aircraft designs featuring very low observables (VLO), which is one of the defining features of fifth-generation fighters. Of the 4.5th generation designs, only the Super Hornet, Strike Eagle, and the Rafale have seen combat action.

The United States Government defines 4.5 generation fighter aircraft as those that "(1) have advanced capabilities, including— (A) AESA radar; (B) high capacity data-link; and (C) enhanced avionics; and (2) have the ability to deploy current and reasonably foreseeable advanced armaments."

Fifth generation jet fighters (2005 to the present)

Lockheed Martin F-22 Raptor

The fifth generation was ushered in by the Lockheed Martin/Boeing F-22 Raptor in late 2005. Currently the cutting edge of fighter design, fifth-generation fighters are characterized by being designed from the start to operate in a network-centric combat environment, and to feature extremely low, all-aspect, multi-spectral signatures employing advanced materials and shaping techniques. They have multifunction AESA radars with high-bandwidth, low-probability of intercept (LPI) data transmission capabilities. The Infra-red search and track sensors incorporated for air-to-air combat as well as for air-to-ground weapons delivery in the 4.5th generation fighters are now fused in with other sensors for Situational Awareness IRST or SAIRST, which constantly tracks all targets of interest around the aircraft so the pilot need not guess when he glances. These sensors, along with advanced avionics, glass cockpits, helmet-mounted sights (not currently on F-22), and improved secure, jamming-resistant LPI datalinks are highly integrated to provide multi-platform, multi-sensor data fusion for vastly improved situational awareness while easing the pilot's workload. Avionics suites rely on extensive use of very high-speed integrated circuit (VHSIC) technology, common modules, and high-speed data buses. Overall, the integration of all these elements is claimed to provide fifth-generation fighters with a "first-look, first-shot, first-kill capability".

The AESA radar offers unique capabilities for fighters (and it is also quickly becoming a *sine qua non* for Generation 4.5 aircraft designs, as well as being retrofitted onto some fourth-generation aircraft). In addition to its high resistance to ECM and LPI features, it enables the fighter to function as a sort of "mini-AWACS," providing high-gain electronic support measures (ESM) and electronic warfare (EW) jamming functions.

Lockheed Martin F-35 Lightning II

Other technologies common to this latest generation of fighters includes integrated electronic warfare system (INEWS) technology, integrated communications, navigation, and identification (CNI) avionics technology, centralized "vehicle health monitoring" systems for ease of maintenance, fiber optics data transmission, and stealth technology even hovering capabilities.

Maneuver performance remains important and is enhanced by thrust-vectoring, which also helps reduce takeoff and landing distances. Supercruise may or may not be featured; it permits flight at supersonic speeds without the use of the afterburner – a device that significantly increases IR signature when used in full military power.

A key attribute of fifth-generation fighters is very-low-observables stealth. Great care has been taken in designing its layout and internal structure to minimize RCS over a broad bandwidth of detection and tracking radar frequencies; furthermore, to maintain its VLO signature during combat operations, primary weapons are carried in internal weapon bays that are only briefly opened to permit weapon launch. Furthermore, stealth technology has advanced to the point where it can be employed without a tradeoff with aerodynamics performance, in contrast to previous stealth efforts. Some attention has also been paid to reducing IR signatures, especially on the F-22. Detailed information on these signature-reduction techniques is classified, but in general includes special shaping approaches, thermoset and thermoplastic materials, extensive structural use of advanced composites, conformal sensors, heat-resistant coatings, low-observable wire meshes to cover intake and cooling vents, heat ablating tiles on the exhaust troughs (seen on the Northrop YF-23), and coating internal and external metal areas with radar-absorbent materials and paint (RAM/RAP).

Sukhoi T-50

The expense of developing such sophisticated aircraft is as high as their capabilities. The U.S. Air Force had originally planned to acquire 650 F-22s, but it now appears that only 187 will be built. As a result, its unit flyaway cost (FAC) is reported to be around $140 million. To spread the development costs – and production base – more broadly, the Joint Strike Fighter (JSF) program enrolls eight other countries as cost- and risk-sharing partners. Altogether, the nine partner nations anticipate procuring over 3000 Lockheed Martin F-35 Lightning II fighters at an anticipated average FAC of $80–85 million. The F-35, however, is designed to be a family of three aircraft, a conventional take-off and landing (CTOL) fighter, a short take-off and vertical landing (STOVL) fighter, and a Catapult Assisted Take Off But Arrested Recovery (CATOBAR) fighter, each of which has a different unit price and slightly varying specifications in terms of fuel capacity (and therefore range), size and payload.

Other countries have initiated fifth-generation fighter development projects, with Russia's Sukhoi PAK FA anticipated to enter service circa 2012–2015. In October 2007, Russia and India signed an agreement for joint participation in a Fifth-Generation Fighter Aircraft Program (FGFA), which will give India responsibility for development of a two-seat model of the PAK-FA. India is also developing its own indigenous fifth generation aircraft named Medium Combat Aircraft. China is reported to be pursuing multiple fifth-generation projects under the western code name J-XX, while Japan is exploring their technical feasibility to produce fifth-generation fighters.

Ground-attack aircraft

An A-10 Thunderbolt II, a ground-attack aircraft, fires its 30 x 173mm GAU-8 Avenger seven-barreled cannon in 2007

Ground-attack aircraft are military aircraft designed to attack targets on the ground and are often deployed as close air support for, and in proximity to, their own ground forces. The proximity to friendly forces require precision strikes from these aircraft that are not possible with typical bomber aircraft. The resultant proximity to enemy targets also require aircraft that are more robust than other types of military aircraft. Examples include the American A-10 Thunderbolt II and the Russian Sukhoi Su-25 Frogfoot.

They are typically deployed as close air support to ground forces, their role is tactical rather than strategic, operating at the front of the battle rather than against targets deeper in the enemy's rear. As such, they are often attached to and in the direct command and control structures of army units as opposed to air force units, though tactical air forces attached to army formations are still an organic part of the air force and ultimately under air-force command. A number of names have or are used for ground-attack aircraft:

attack aircraft, **fighter-bomber**, **tactical fighter**, **tactical bomber**, **strafer**, **strike fighter**, **attack helicopter**, **gunship**, etc. A **light strike aircraft** is another category, based on adapted trainers or other light aircraft.

Definition

Like most combat aircraft classifications, the definition of ground attack is somewhat vague. A key difference between it and otherwise similar designs like *attack aircraft* is the expectation that they will receive small arms fire and are generally armored to protect the pilot against this threat. In general a ground-attack aircraft will also be smaller and less "fighter like" than designs like strike fighters, attack aircraft or interceptors. They will usually have less speed, range and BVR ordnance than fighters. More often they carry more powerful guns and other weapons than fighters.

In US service ground-attack aircraft have been identified by the prefix A- as in "A-6". British designations have included FB for fighter-bomber and more recently "G" for Ground as in "Harrier GR1".

The NATO reporting names for Soviet/Russian ground attack aircraft classified them as "fighters" instead of "bombers" possibly because they were often only variants of fighter aircraft, but always similar in size, range and weapons to fighters.

History

In the First World War Germany was the first country to produce dedicated ground attack aircraft such as the Junkers J.I, which pioneered the idea of a complete armored fuselage "bathtub" structure, that protected the engine and the aircraft's two crewmembers. The Allies experimented with attack planes such as the Sopwith Salamander and the Boeing GA-1 but the war ended before they could used in combat.

Between the World Wars, the United States Marine Corps Aviation pioneered ground attack and close air support tactics in the Banana Wars. Marine Aviators pioneered the technique of dive bombing during interventions in Haiti and Nicaragua.

At the start of World War II engine power was scarce and aircraft had to be tailored to individual roles. Ground attack aircraft during this era were generally created for the role, one that was considered largely unimportant and therefore saw little development. Perhaps the only early-war aircraft in this niche was the Henschel Hs 123, a biplane. The Germans worked on a suitable replacement and eventually delivered the Henschel Hs 129, which featured a steel-armored cockpit and windows made of bulletproof glass. Only small numbers were built, however, as the Germans widely used the more flexible Junkers Ju 87 *Stuka* dive-bomber in the ground attack role. A more famous example is the Soviet Ilyushin Il-2 *Shturmovik*, a light bomber that was designed expressly for the ground attack role with its own improved, armoured fuselage "bathtub" structure, powerful belt-fed heavy calibre anti-armor autocannon armament installations, and possibility of using air-to-ground rockets. More than 43,000 Ilyushin Il-2 were built through World War II. Stalin credited the Il-2 with winning the war.

P-47 Thunderbolt in flight firing rockets

As engine power improved, roughly doubling over the course of the war, even the average day fighter was more than capable enough to carry out the ground attack role, and some of the most successful designs were slight modifications of existing designs. One of the most successful of these was the RAF's Hawker Typhoons, although they deployed a variety of other aircraft due to changing availability. The Germans made a series of adapted versions of the Focke-Wulf Fw 190, the F and G series, serving roughly the same purpose. The same was true of the USAAF, who moved former front-line fighters into the ground attack role during the war, notably the P-38 Lightning and P-47 Thunderbolt, as newer aircraft took up the air superiority role.

While machine guns and cannon were sufficient against infantry and light vehicles, and one or two small bombs could be easily fitted to most fighters, for operations against tanks heavier weapons such as the 40 mm Vickers S gun or high explosive rockets (such as the RP-3 60 lb rocket) were needed. The former equipped the Hawker Hurricane to good effect in North Africa Campaign, the latter was used by many RAF aircraft among them the Typhoon. Both the US and Soviets also used a variety of rockets in this role. The Germans also deployed rockets, anti-tank cannons such as the *Bordkanone 3.7cm* or *Bordkanone 5.0cm*, as well as the first cluster bombs.

Post World War II

Su-22M4K in the markings of the 7th Tactical Sqn. of Polish Air Force

In the immediate post war era the piston engined ground attack aircraft remained useful - Royal Navy Hawker Sea Fury fighters and the US Vought F4U Corsair and Douglas A-1 Skyraider operated in the Korea with the latter plane effective into the Vietnam conflict. The long loiter times of the piston powered planes gave an advantage over fuel-thirsty jet planes.

In most of the post-World War II era air forces have been increasingly reluctant to develop combat aircraft specifically for ground attack. Although close air support and interdiction remain crucial to the modern battlefield, attack aircraft are less glamorous than fighters, and both pilots and military planners have a certain well-cultivated contempt for 'mud-movers.' More practically, the extra cost of a dedicated ground attack aircraft is harder to justify as opposed to having multi-role aircraft.

In the late 1960s the United States Air Force requested a dedicated air support plane that became the Fairchild Republic A-10 *Thunderbolt II*. It eventually became a primarily anti-armor weapon with limited capability in the interdiction and tactical bombing role, and even in the anti-tank role it was met with mixed feelings. However, the A-10's performance during Operation Desert Storm negated these criticisms. Current US doctrine increasingly emphasizes the use of United States Army helicopters for close air support and anti-tank missions. The Soviets' similar Sukhoi Su-25 (*Frogfoot*) found greater success in the flying artillery role, although it, too, shifted to anti-armor use in later versions and has largely been phased out in favour of 'fast mover' fighter-bomber versions of the MiG-29 and Su-27.

Examples of modern ground attack aircraft include the A-10 Thunderbolt II, Sukhoi Su-7, Sukhoi Su-17, Sukhoi Su-25 (*Frogfoot*), Nanchang Q-5. Ground attack has otherwise become the domain of converted trainers like the BAC Strikemaster, BAE Hawk, and Cessna A-37 and some trainers are already build with this task in mind, like the CASA 101.

Recent history

RAF Harrier GR7

U.S. experience in the Gulf War, Kosovo, Afghanistan, and Iraq War has resulted in renewed interest in fixed-wing ground-attack aircraft.

Under the Key West Agreement which governs the allocation of aircraft between the U.S. Army and the U.S. Air Force, fixed-wing ground-attack aircraft were generally allocated to the Air Force, while attack helicopters were generally allocated to the Army. The Army, wishing to have its own resources to support its troops in combat and faced with a lack of Air Force enthusiasm for the ground-attack role, developed the AH-64 Apache attack helicopter for ground-attack roles such as destroying enemy tanks and supporting troops in combat.

On January 17, 1991, Task Force Normandy began its attack on two Iraqi anti-aircraft missile sites. TF Normandy, under the command of LTC Richard A. "Dick" Cody, consisted of nine AH-64 Apaches, one UH 60 Black Hawk and four Air Force MH-53J Pave Low helicopters. The purpose of this mission was to create a safe corridor through the Iraqi air defense system. The attack was a huge success and cleared the way for the beginning of the Allied bombing campaign.

One concern involving the Apache arose when a unit of these helicopters was very slow to deploy during U.S. military involvement in Kosovo. According to the *Army Times*, the Army is shifting its doctrine to favour ground-attack aircraft over attack helicopters for deep strike attack missions because ground-attack helicopters have proved to be highly vulnerable to small-arms fire. The U.S. Marine Corps have noted similar problems.

Officially, the U.S. Air Force planned to replace the only dedicated ground-attack aircraft currently in U.S. service, the A-10, with its new "Joint Strike Fighter", the F-35 Lightning II. But, facing political concerns that the new fighters were not designed for the ground-attack role that had proven particularly useful in Iraq and Afghanistan, a plan to decommission the A-10 has been replaced with a plan to upgrade the existing aircraft with improved electronics, extending the service life of the planes until as late as 2028. The U.S. Air Force has not commissioned any new designs for this role (in part, out of concern for the F-35 program).

The UK is replacing its current ground attack aircraft with the F-35 (replacing the Harriers), and the Eurofighter Typhoon (Jaguars and Tornado GRs).

The other major complication to plans of military forces to purchase new ground-attack aircraft is uncertainty over the degree to which manned fixed wing aircraft may be replaced by unmanned combat drones in this role, a possibility illustrated by the armed Predator drone, which has been used in this capacity.

Surveillance aircraft

English Electric Canberra PR.9 photo reconnaissance aircraft

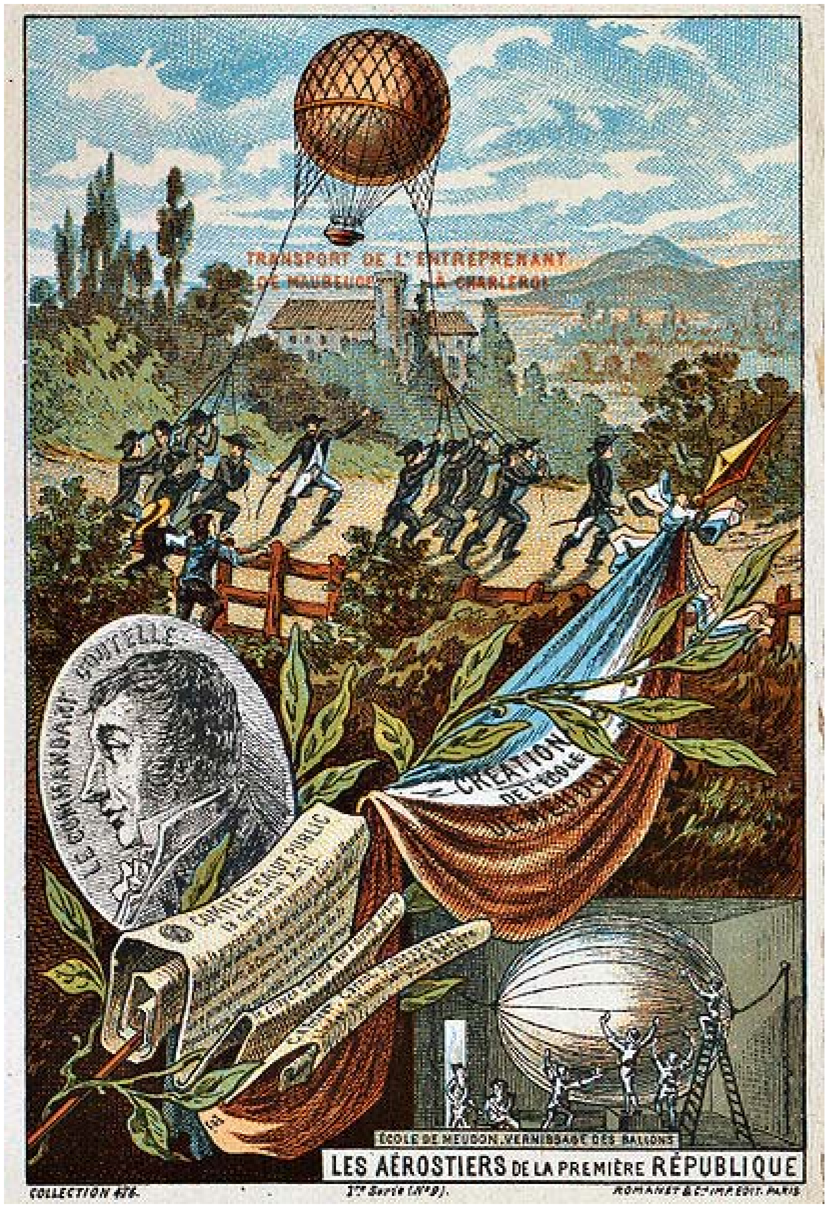
Lockheed U-2

Surveillance aircraft are military aircraft used for monitoring enemy activity, usually carrying no armament. Here we concentrates on military aircraft used in this role, though a major civilian aviation activity is reconnaissance and ground surveillance for mapping, traffic monitoring, science, and geological survey. In addition, civilian aircraft are used in many countries for border surveillance, fishery patrols or the prevention of smuggling and illegal migration.

A surveillance aircraft does not necessarily require high-performance capability or stealth characteristics. It may in fact be a modified civilian aircraft which has been disguised in order to look harmless. Technically, anything which can fly and make observations (dynamically or via recording equipment/sensors) of visual information or electronic emissions qualifies as a surveillance aircraft.

Such efforts long predate the invention of heavier-than-air flight, with experiments using balloons to provide targeting information for artillery beginning in France in 1794. Continued attempts throughout the 19th Century proved militarily useless, but aerostat-based radar platforms are now in use.

History



The first reconnaissance squad, *"les Aéreostiers"*, with the first surveillance balloon, *"l'Entreprenant"*, 1794. Illustration from the late 19th Century.

Airborne reconnaissance goes back to the early era of ballooning. After the French Revolution, the new rulers became interested in using the balloon to observe enemy manoeuvres and appointed scientist Charles Coutelle to conduct studies using *l'Entreprenant* -- its name literally meaning "The Undertaking," which was the first reconnaissance aircraft. The balloon found its first use in the 1794 conflict with Austria, where in the Battle of Fleurus the French Aerostatic Corps gathered information and the demoralizing effect on the Austrian troops ensured victory for the French troops.

The first reconnaissance flights with winged aircraft in combat conditions took place during the Balkan wars, on 5 October 1912 by Greek and on 16 October 1912 by Bulgarian (Albatros) aircraft.

One of the first aircraft used for surveillance was the Rumpler Taube during World War I, when aviators like Fred Zinn evolved entirely new methods of reconnaissance and photography. The translucent wings of the plane made it very difficult for ground based observers to detect a Taube at an altitude above 400 m. The French also called this plane "the Invisible Aircraft", and it is sometimes also referred to as the "world's very first stealth plane". German Taube aircraft were able to detect the advancing Russian army during the Battle of Tannenberg (1914).

Before World War II the conventional wisdom was to use converted bomber types for airborne photo reconnaissance, since these were the only aircraft with the long range needed for the reconnaissance missions. These bombers retained their defensive armament, which was vital since they were unable to avoid interception.

The Japanese designed a twin-engine purpose-built reconnaissance aircraft in 1939, the highly effective Mitsubishi Ki-46, armed with only one light gun facing rearward. It entered service in 1941. Allied airmen designated it the "Dinah".

In 1939 Flying Officer Maurice Longbottom was among the first to suggest that airborne reconnaissance may be a task better suited to fast, small aircraft which would use their speed and high service ceiling to avoid detection and interception. Although this seems obvious now, with modern reconnaissance tasks performed by fast, high flying aircraft, at the time it was radical thinking.

As a result, fighters such as the British Spitfire and Mosquito and the American P-38 Lightning and P-51 Mustang were adapted for photo-reconnaissance during World War II. Such craft were stripped of weaponry, painted in sky camouflage colours to make them difficult to spot in the air, and often had engines modified for higher performance at very high altitudes (well over 40,000 feet). Early in the war the British developed a warming system to allow photographs to be taken at very high altitudes. The collection and interpretation of such photographs became a considerable enterprise. One site claims that the British, at their peak, flew over 100 reconnaissance flights a day, yielding 50,000 images per day to interpret. Similar efforts were taken by other countries.

Immediately after World War II, long range aerial reconnaissance was once again taken up by adapted bombers, albeit with jet engines, enabling them to fly faster and higher than before. Examples of such aircraft include the English Electric Canberra, and its American development, the Martin B-57.

A De Havilland Chipmunk T10 - as used for "Operation Schooner" and "Operation Nylon" missions by BRIXMIS during the Cold War

In the 1950s, the first purpose-built jet covert surveillance aircraft, the Lockheed U-2 was constructed secretly for the United States. Designed for flights over Soviet territory, the plane remained an obscurity until one piloted by Gary Powers was shot down over the Soviet Union in 1960, leading to the U-2 Crisis. Modified versions of the U-2 remain in service in 2007, though its capabilities and operations remain secret. In the 1960s the SR-71 Blackbird, the fastest manned jet-propelled aircraft ever built, was constructed. However, as both the United States and Soviet Union possessed surveillance satellites, overt interest in new types of photo-reconnaissance aircraft declined.

There are claims that the US constructed a new, secret, hypersonic surveillance aircraft - dubbed the Aurora - in the late 1980s to replace the Blackbird, but no confirmation of this has ever emerged.

RAF Nimrod MR2 taxis for takeoff

Another category of surveillance aircraft that has been in vogue since World War II is the maritime patrol aircraft. These are typically large, slow machines capable of flying continuously for many hours, with a wide range of sensors and electronic equipments on board. Such aircraft include the Avro Shackleton, the Hawker-Siddeley Nimrod, the Breguet Atlantique, the Tupolev Tu-95, and from Lockheed, the Neptune and later the Orion. The latter type became famous when a Chinese interceptor collided with the wing of a US Navy example patrolling. The crew of the larger US aircraft made an emergency landing. The Orion was impounded by the Chinese authorities then dismantled and returned to the USA. The crew were questioned but released prior to the aircraft's return.

Current use

Camera bay of a reconnaissance Mirage III R

Several unmanned remotely-controlled reconnaissance aircraft (UAVs) have been recently deployed or are under development in many countries, including Israel, the UK, the United States, China, Pakistan and India. Currently under development are, amongst others, the RQ-4 Global Hawk, a high-altitude jet-propelled craft that resembles the U-2, and the smaller, medium-altitude MQ-1 Predator. Schweizer Aircraft Corporation are developing remotely-piloted versions of a light helicopter.

Most air forces around the world lack dedicated surveillance planes, but have the capability of adding reconnaissance cameras to combat and transport aircraft.

Another type of surveillance aircraft is the electronic surveillance aircraft. Whilst other military aircraft, including photo-reconnaissance aircraft, have been used for that purpose, several countries adapt aircraft for electronic intelligence (ELINT) gathering. The Beech RC-12 Super King Air and Boeing RC-135 Rivet Joint are examples of this military activity, which helps to reduce opportunities for surprise attack or the risks of training exercises being misunderstood by potential enemies.

As well as the development of UAVs, another recent trend in surveillance aircraft design has been the realization that, with the addition of lightweight sensors and communications gear, every fighter plane and ground attack plane can simultaneously be used to perform surveillance. Hence, the in-development F-35 Joint Strike Fighter multirole fighter plane will have extensive surveillance and communications capabilities built in.