



Encyclopedia of Airships and Rotorcrafts

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Chapter 1

Introduction to Airship



A modern airship

An **airship** or **dirigible** is a type of aerostat or "lighter-than-air aircraft" that can be steered and propelled through the air using rudders and propellers or other thrust mechanisms. Unlike aerodynamic aircraft such as fixed-wing aircraft and helicopters, which produce lift by moving a wing through the air, aerostatic aircraft, such as airships and hot air balloons, stay aloft by filling a large cavity with a lifting gas.

The main types of airship are non-rigid (or blimps), semi-rigid and rigid. Blimps are small airships without internal skeletons. Semi-rigid airships are slightly larger and have some form of internal support such as a fixed keel. Rigid airships with full skeletons, such as the huge Zeppelin transoceanic models, have nearly disappeared after several high-profile catastrophic accidents during the mid-20th century.

Airships were the first aircraft to enable controlled, powered flight, and were widely used before the 1940s, but their use decreased over time as their capabilities were surpassed by those of airplanes. Their decline continued with a series of high-profile accidents, including the 1937 burning of the hydrogen-filled *Hindenburg* near Lakehurst, New Jersey, and the destruction of the USS *Akron*. Airships are still used today in certain niche applications, such as advertising, freight transportation, tourism, camera platforms for sporting events, and aerial observation and interdiction platforms, where the ability to hover in one place for an extended period outweighs the need for speed and maneuverability.

Terminology

In some countries, airships are also known as *dirigibles* from the French (*diriger* to direct plus *-ible*), meaning "directable" or steerable. The first airships were called *dirigible balloons*. Over time, the word *balloon* was dropped from the phrase. In modern usage, balloon refers to any buoyant aircraft that generally relies on wind currents for horizontal movement, and usually has a mechanism to control vertical movement.



USS *Akron* (ZRS-4) in flight on 2 November 1931

The term *zeppelin* is a genericised trademark that originally referred to airships manufactured by the German Zeppelin Company. The word *Luftschiff*, German for "airship", usually prefixed their crafts' names.

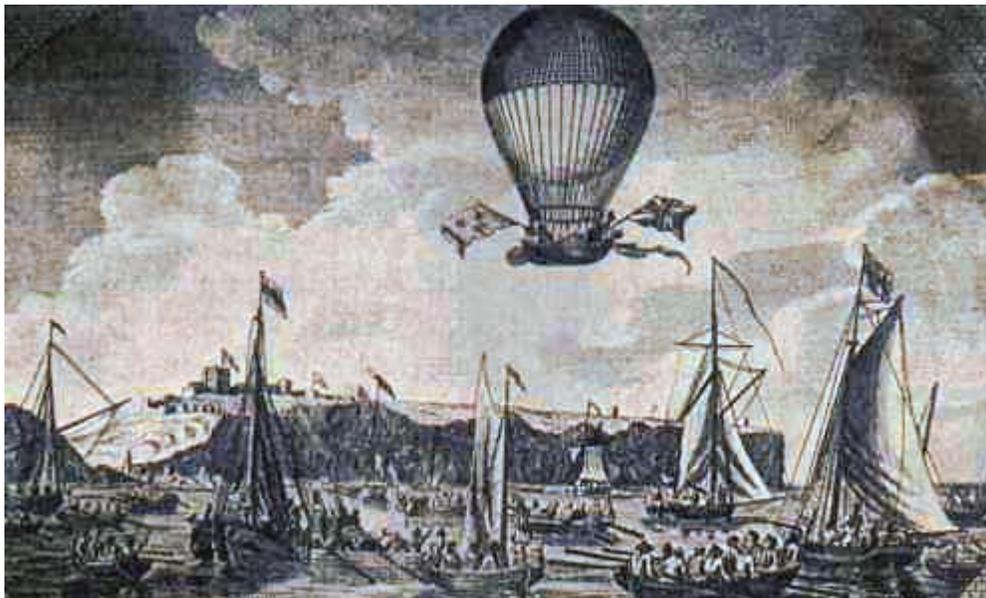
In modern common usage, the terms *Zeppelin*, *dirigible* and *airship* are used interchangeably for any type of rigid airship, with the term *blimp* alone used to describe non-rigid airships. Although the blimp also qualifies as a "dirigible", the term is seldom used with blimps. In modern technical usage, *airship* is the term used for all aircraft of this type, with *Zeppelin* referring only to aircraft of that manufacture, and *blimp* referring only to non-rigid airships.

There is some confusion around the term *aerostat* with regard to airships. This confusion arises because *aerostat* has two different meanings. One meaning of *aerostat* refers to all craft that remain aloft using buoyancy: here, airships are a type of *aerostat*. The narrower and more technical meaning of *aerostat* refers only to tethered or moored balloons: here, airships are distinct from *aerostats*. This airship/aerostat confusion is often exacerbated by the fact that both airships and aerostats have roughly similar shapes and comparable tail-fin configurations, although only airships have engines.

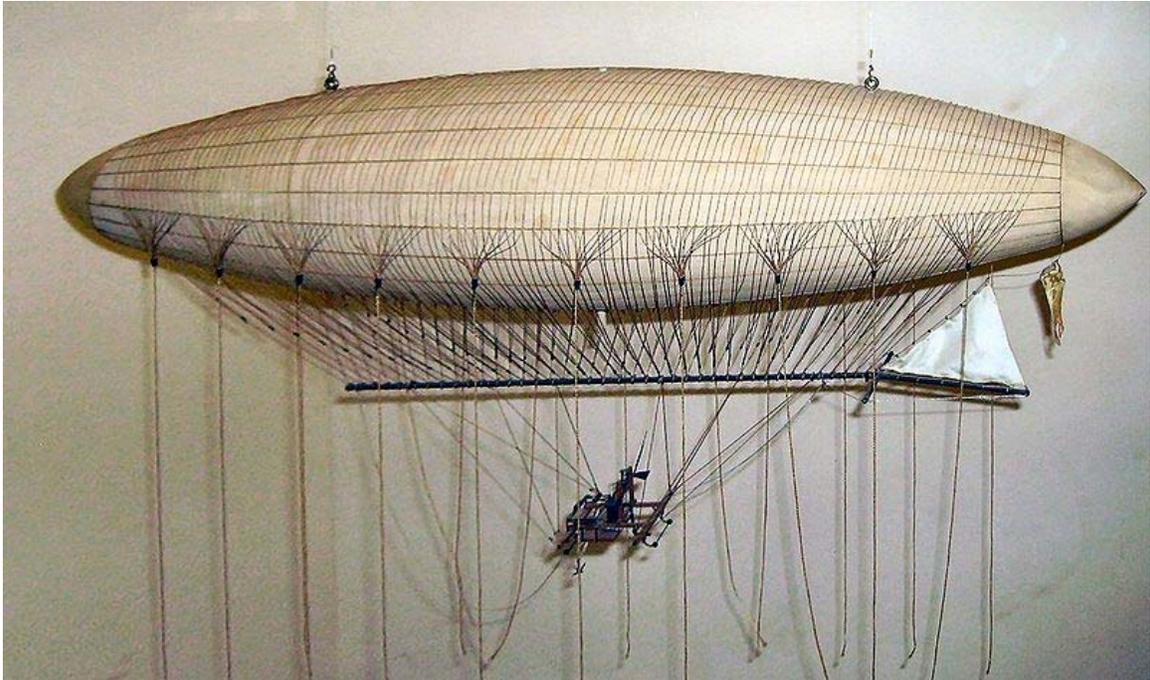
The term **gondola** is used to describe the passenger/instrument area of an airship. There may be one or more.

History

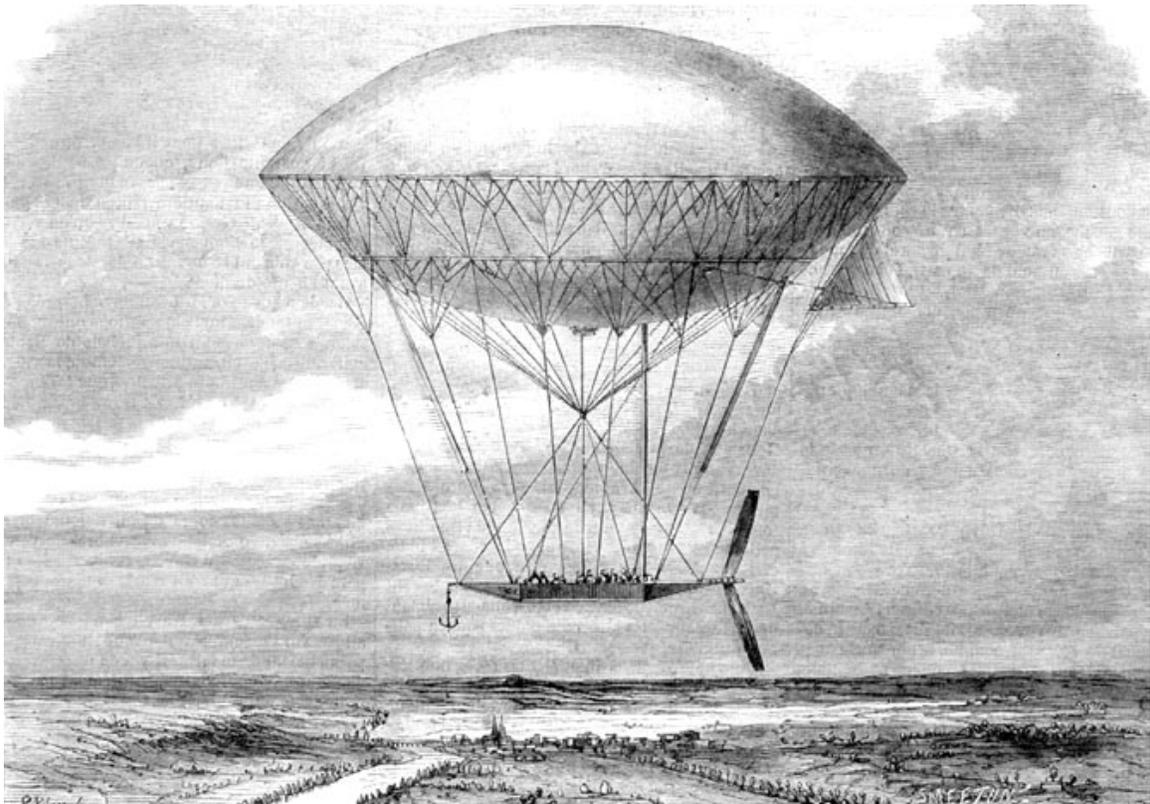
Early pioneers



Crossing of the English Channel by Blanchard in 1785



A model of the Giffard Airship at the London Science Museum



The navigable balloon developed by Henri Dupuy de Lôme in 1872

Francesco Lana de Terzi is referred to as the "Father of Aeronautics" in part for his theoretical design of a Vacuum airship circa 1670. Structural limitations have prevented this concept from taking flight.

The father of the dirigible was Lieutenant Jean Baptiste Marie Meusnier (1754–93). On 3 December 1783, he presented a historic paper to the French Academy: "*Memoire sur l'equilbre des Machines Aerostatique*" (Memorandum on the balance of aerostatic machines). The 16 water-colour drawings published the following year depicted a 260-foot-long (79 m) envelope with internal ballonets that could be used for regulating lift, and this was attached to a long carriage that could be used as a boat if the vehicle was forced to land in water. The airship was designed to be propelled in the air by three airscrew propellers and steered with a sail-like aft rudder. In 1784, Jean-Pierre Blanchard fitted a hand-powered propeller to a balloon, the first recorded means of propulsion carried aloft. In 1785, he crossed the English Channel with a balloon equipped with flapping wings for propulsion, and a bird-like tail for steerage.

The 19th century saw continued attempts at adding propulsion to balloons. The first aviation pioneer of Australia was Dr William Bland, a naval surgeon who was sentenced to seven years transportation in a Calcutta court after a duel in Bombay in 1813. In March 1851, Bland sent designs for his 'Atmotic Airship' to the Great Exhibition at the Crystal Palace in London where a model was displayed, this was the year before Henri Giffard flew the first steam-powered dirigible. His idea was to supply power to an elongated balloon with a steam engine installed in a car, Since the lift of the balloon was estimated at 5 tons and the car with the fuel weighed 3.5 tons, the payload was estimated at 1.5 tons. Bland believed that with two airscrews the machine could be driven at 80 km/h (50 mph) and could fly from Sydney to London in less than a week. The first person to make an engine-powered flight was Henri Giffard who, in 1852, flew 27 km (17 mi) in a steam-powered airship. Airships would develop considerably over the next two decades: there were reports that on 1 June 1863 Dr. Solomon Andrews had launched the *Aereon* comprising two horizontal cylindrical gas bags with no motor that "wheeled gracefully and headed back towards them" and that later, pilotless after Andrews had released all ballast, flew in "ascending spirals" and during this ascent that it "was apparent to everyone that the ship was moving with the wind and then against it" with a Herald reporter estimating the speed at 120 mph. In 1872, the French naval architect Dupuy de Lome launched a large limited navigable balloon, which was driven by a large propeller and the power of eight people. It was developed during the Franco-Prussian war, as an improvement to the balloons used for communications between Paris and the countryside during the Siege of Paris by German forces, but was completed only after the end of the war.

Paul Haenlein flew an airship with an internal combustion engine running on the coal gas used to inflate the envelope over Vienna, the first use of such an engine to power an aircraft in 1872. Charles F. Ritchel made a public demonstration flight in 1878 of his hand-powered one-man rigid airship, and went on to build and sell five of his aircraft.

In the 1880s a Serb named Ognoslav Kostovic Stepanovic also designed and built an airship. However, the craft was destroyed by fire before it flew. In 1883, the first electric-powered flight was made by Gaston Tissandier who fitted a 1.5 hp (1.1 kW) Siemens electric motor to an airship. The first fully controllable free-flight was made in a French Army airship, *La France*, by Charles Renard and Arthur Constantin Krebs in 1884. The 170 ft (52 m) long, 66,000 cu ft (1,900 m³) airship covered 8 km (5.0 mi) in 23 minutes with the aid of an 8.5 hp (6.3 kW) electric motor, and a 435 kilograms (960 lb) battery. In 1884 and 1885, it made seven flights.

In 1888, the Novelty Air Ship Company made the Air Ship for Professor Peter C. Campbell which was known as the Campbell Air Ship. The air ship was lost at sea in 1889 while being flown by Professor Hogan during an exhibition Flight.

In 1888–97, Dr. Frederich Wölfert built three airships powered by Daimler Motoren Gesellschaft-built petrol engines, the last of which caught fire in flight and killed both occupants in 1897. The 1888 version used a 2 hp one cylinder Daimler engine and flew 10 km (6 mi) from Canstatt to Kornwestheim.



Santos-Dumont#6 rounding the Eiffel Tower, winning the Deutsch Prize in 1901

In 1896, a rigid airship created by the Croatian engineer David Schwarz made its first flight at Tempelhof field in Berlin. After Schwarz's death, his wife, Melanie Schwarz, was paid 15,000 marks by Count Ferdinand von Zeppelin for information about the airship.

The wealthy Brazilian Alberto Santos-Dumont in France had a passion for flying. He designed 18 examples of balloons and dirigibles, and created 18 different examples of the latter before turning his attention to fixed winged aircraft in 1907. In 1901, in his airship *Number 6*, a small blimp, he won the Deutsch de la Meurthe prize of 100,000 francs for flying from the Parc Saint Cloud to the Eiffel Tower and back in under thirty minutes. Many inventors were inspired by Santos-Dumont's small airships and a veritable airship craze began worldwide. Many airship pioneers, such as the American Thomas Scott Baldwin financed their activities through passenger flights and public demonstration flights. Others, such as Walter Wellman and Melvin Vaniman set their sights on loftier goals, attempting two polar flights in 1907 and 1909, and two trans-atlantic flights in 1910 and 1912.

"The Golden Age"

The "Golden Age of Airships" began in July 1900 with the launch of the Luftschiff Zeppelin LZ1. This led to the most successful airships of all time: the Zeppelins. These were named after Count von Zeppelin who began experimenting with rigid airship designs in the 1890s leading to the badly-flawed *LZ1* (1900) and the more successful *LZ2* (1906). At the beginning of World War I the Zeppelin airships had a framework composed of triangular lattice girders, covered with fabric and containing separate gas cells. Multi-plane, later cruciform, tail fins were used for control and stability, and two engine/crew cars hung beneath the hull driving propellers attached to the sides of the frame by means of long drive shafts. Additionally, there was a passenger compartment (later a bomb bay) located halfway between the two cars.

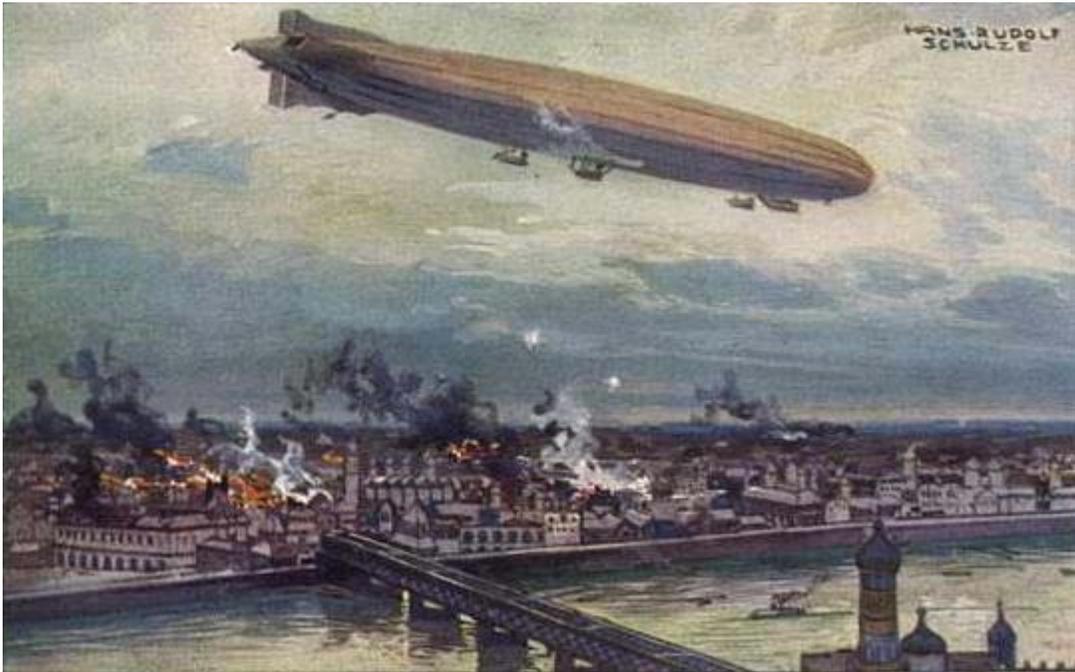
Other airship builders were also active before the war: The French company Lebaudy Frères specialised in semi-rigid airships from 1902 (e.g. the *Patrie* and the *République*), designed by their engineer Henri Julliot, who later worked for the American company Goodrich; the German firm Schütte-Lanz built the SL series from 1911; another German firm Luft-Fahrzeug-Gesellschaft built the *Parseval-Luftschiff* (PL) series from 1909, and Italian Enrico Forlanini's firm had built and flown the first two Forlanini airships.

In 1910 Walter Wellman unsuccessfully attempted the first aerial crossing of the Atlantic Ocean on airship *America*.

World War I

The prospect of airships as bombers had been recognised in Europe well before the airships were up to the task. H. G. Wells' *The War in the Air* (1908) described the obliteration of entire fleets and cities by airship attack. On 5 March 1912, Italian forces became the first to use dirigibles for a military purpose during reconnaissance west of

Tripoli behind Turkish lines. It was World War I, however, that marked the airship's real debut as a weapon.



German airship Schütte Lanz SL2 bombing Warsaw in 1914

Albert Caquot designed an Observation balloon for the French army in 1914. The tethered Type R Observation balloon was used by all the allied forces, including the British and United States Armies, at the end of the World War.

The Germans, French and Italians all operated airships in scouting and tactical bombing roles early in the war, and all learned that the airship was too vulnerable for operations over the front. The decision to end operations in direct support of armies was made by all in 1917.



Type "R" observation balloon at Arcadia Balloon School, Arcadia, Calif. 1921

Count Zeppelin and others in the German military believed they had found the ideal weapon with which to counteract British Naval superiority and strike at Britain itself. More realistic airship advocates believed the Zeppelin was a valuable long range scout/attack craft for naval operations. Raids began by the end of 1914, reached a first peak in 1915, and then were discontinued in August 1918. Zeppelins proved to be terrifying but inaccurate weapons. Navigation, target selection and bomb-aiming proved to be difficult under the best of conditions. The darkness, high altitudes and clouds that were frequently encountered by Zeppelin missions reduced accuracy even further. The physical damage done by the Zeppelins over the course of the war was trivial, and the deaths that they caused (though visible) amounted to a few hundred at most. The Zeppelins were initially immune to attack by aircraft and anti-aircraft guns: as the pressure in their envelopes was only just higher than ambient, holes had little effect. But once incendiary bullets were developed and used against them, their flammable hydrogen lifting gas made them vulnerable at lower altitudes. Several were shot down in flames by British defenders, and others crashed *en route*. They then started flying higher and higher above the range of other aircraft, but this made their bombing accuracy even worse and success harder to achieve.

In retrospect, advocates of the naval scouting role of the airship proved to be correct, and the land bombing campaign proved to be disastrous in terms of morale, men and material.

Many pioneers of the German airship service died in what was the first strategic bombing campaign in history.

Countermeasures by the British were sound detection equipment, search lights and anti-aircraft artillery, followed by night fighters in 1915. One method used early in the war when short range meant the airships had to fly from forward bases, and when the only Zeppelin production facilities were in Friedrichshafen, was bombing of airship sheds by the British Royal Naval Air Service. Late in the war, the development of the aircraft carrier led to the first successful carrier air strike in history. The morning of 19 July 1918, seven Sopwith 2F.1 Camels were launched from HMS *Furious* and struck the airship base at Tondern, destroying the Zeppelins *L 54* and *L 60*.



View from a French dirigible approaching a ship in 1918

Before the World War, the British Army was interested in blimps for scouting purposes. The Royal Navy, recognizing the potential threat that scouting Zeppelins might pose, decided in 1908 to produce an example of rigid airship so that the threat might be evaluated in practice instead of theory. The Royal Navy was to continue development of rigid airships until the end of the war. The British Army abandoned airship development in favour of aeroplanes by the start of the war, but the Royal Navy had recognised the need for small airships to counteract the submarine and mine threat in coastal waters. Beginning in February 1915, they began to deploy the SS (Sea Scout) class of blimp. These had a small envelope of 1,699-1,982 m³ (60–70,000 ft³) and at first used standard single engined planes (BE2c, Maurice Farman, Armstrong FK) shorn of wing and tail surfaces as control cars, as an economy measure. Eventually more advanced blimps with purpose built cars, such as the C (Coastal), C* (Coastal Star), NS (North Sea), SSP (Sea Scout Pusher), SSZ (Sea Scout Zero), SSE (Sea Scout Experimental) and SST (Sea Scout Twin) classes were developed. The NS class, after initial teething problems, proved to be

the largest and finest airships in British service. They had a gas capacity of 360,000 cu ft (10,000 m³), a crew of 10 and an endurance of 24 hours. Six 230 lb (100 kg) bombs were carried, as well as three to five machine guns.

British blimps were used for scouting, mine clearance, and submarine attack duties. During the war, the British operated 226 airships, mostly non-rigid, most of which were of indigenous construction, though some non-rigid airships operated were purchased from France and even Germany (before the war). Of that number several were sold to Russia, France, the US and Italy. Britain, in turn, purchased one M-type semi-rigid from Italy whose delivery was delayed until 1918. Nine rigid airships had been completed by the armistice, although several more were in an advanced state of completion by the war's end. The large number of trained crews, low attrition rate and constant experimentation in handling techniques meant that at the war's end Britain was the world leader in non-rigid airship technology.

Both France and Italy continued airships throughout the war. France preferred non-rigid types while Italy operated 49 semi-rigid airships in both the scouting and bombing roles.

Airplanes had essentially replaced airships as bombers by the end of the war, and Germany's remaining zeppelins were scuttled by their crews, scrapped or handed over to the Allied powers as spoils of war. The British rigid airship program, meanwhile, had been largely a reaction to the potential threat of the German one and was largely, though not entirely, based on imitations of the German ships.

Inter-war period

A number of nations operated airships between the two world wars. Many operated blimps. Britain, the United States and Germany were the main operators of rigid airships with Italy and France using them to a lesser extent. Italy, the Soviet Union, United States and Japan mainly concentrated on semi-rigid airships. On May 12, 1926, The Italian *Norge*, a semi-rigid airship, was the first aircraft confirmed to fly over the North Pole.

Photo # NH 69230 Rescuers working on wreckage of Airship R-38 (U.S. Navy ZR-2), 24 August 1921



Rescuers scramble across the wreckage of British R-38/USN ZR-2, 24 August 1921

The British *R33* and *R34* were near-identical copies of the German *L 33*, which crashed virtually intact in Yorkshire on 24 September 1916. Despite being almost three years out of date by the time they were launched in 1919, they were two of the most successful in British service. The creation of the Royal Air Force (RAF) in early 1918 created a hybrid British airship program. The RAF was not interested in airships and the Admiralty was, so a deal was made where the Admiralty would design any future military airships while the RAF would handle manpower, facilities and operations.

After the armistice, the airship program was rapidly wound down, and rigid airship operations were curtailed. On 2 July 1919, *R34* began the first double crossing of the Atlantic by an aircraft. It landed at Mineola, Long Island on 6 July after 108 hours in the air. The return crossing began on 8 July because of concerns about mooring the ship in the open, and took 75 hours. Impressed, British leaders began to contemplate a fleet of airships to link Britain to its far-flung colonies. But post-war economic conditions led to the scrapping of most airships and dispersion of trained personnel, until starting construction of the *R-100* and *R-101* in 1929. The major consequence of Britain's interest in establishing airship service to the empire was the effort to use the Allies' seizure of German airships and airship sheds to avoid competition from Germany. The US Navy

contracted to buy the British built R-38, but before that airship was turned over to the US, it was lost to structural failure due to both improper design and operation.



Construction of USS *Shenandoah* (ZR-1), 1923

The first American-built rigid airship was USS *Shenandoah*, christened on 20 August in Lakehurst, New Jersey. It flew in 1923, while the *Los Angeles* was under construction. It was the first ship to be inflated with the noble gas helium, which was still so rare that the *Shenandoah* contained most of the world's reserves. When the *Los Angeles* was delivered, the two airships had to share the limited supply of Helium, and thus alternated operating and overhauls.



US Navy Zeppelin USS *Macon* (ZRS-5) over Moffett Field in 1933

The United States Navy purchased what became the USS *Los Angeles* and paid with "war reparations" money, owed according to the Versailles Treaty, thus saving The Zeppelin works. The success of the *Los Angeles* encouraged the US Navy to invest in its own, larger airships. The *Los Angeles* flew successfully for 8 years.

Meanwhile Germany was building the *Graf Zeppelin* (LZ 127), the largest airship that could be built in the company's existing shed, and intended to stimulate interest in passenger airships. The *Graf Zeppelin* burned *blau gas*, similar to propane, stored in large gas bags below the hydrogen cells, as fuel. Since its density was similar to that of air, it avoided the weight change when fuel was used, and thus the need to valve hydrogen. The "Graf" was a great success and compiled an impressive safety record, flying over 1,600,000 km (990,000 mi) (including the first circumnavigation of the globe by air) without a single passenger injury.



USS *Akron* over Manhattan island circa 1932

The US Navy developed the idea of using airships as airborne aircraft carriers, although the British had experimented with a plane trapeze on their *R33* many years before. The USS *Los Angeles* was used to experiment with the project, followed by two other airships, the world's largest at the time, to test the principle—the USS *Akron* and *Macon*. Each carried four F9C Sparrowhawk fighters in its hangar, and could carry a fifth on the trapeze. The idea had mixed results. By the time the Navy started to develop a sound doctrine for using the ZRS-type airships, the last of the two built, USS *Macon*, was lost. The seaplane had become more mature, and was considered a better investment.

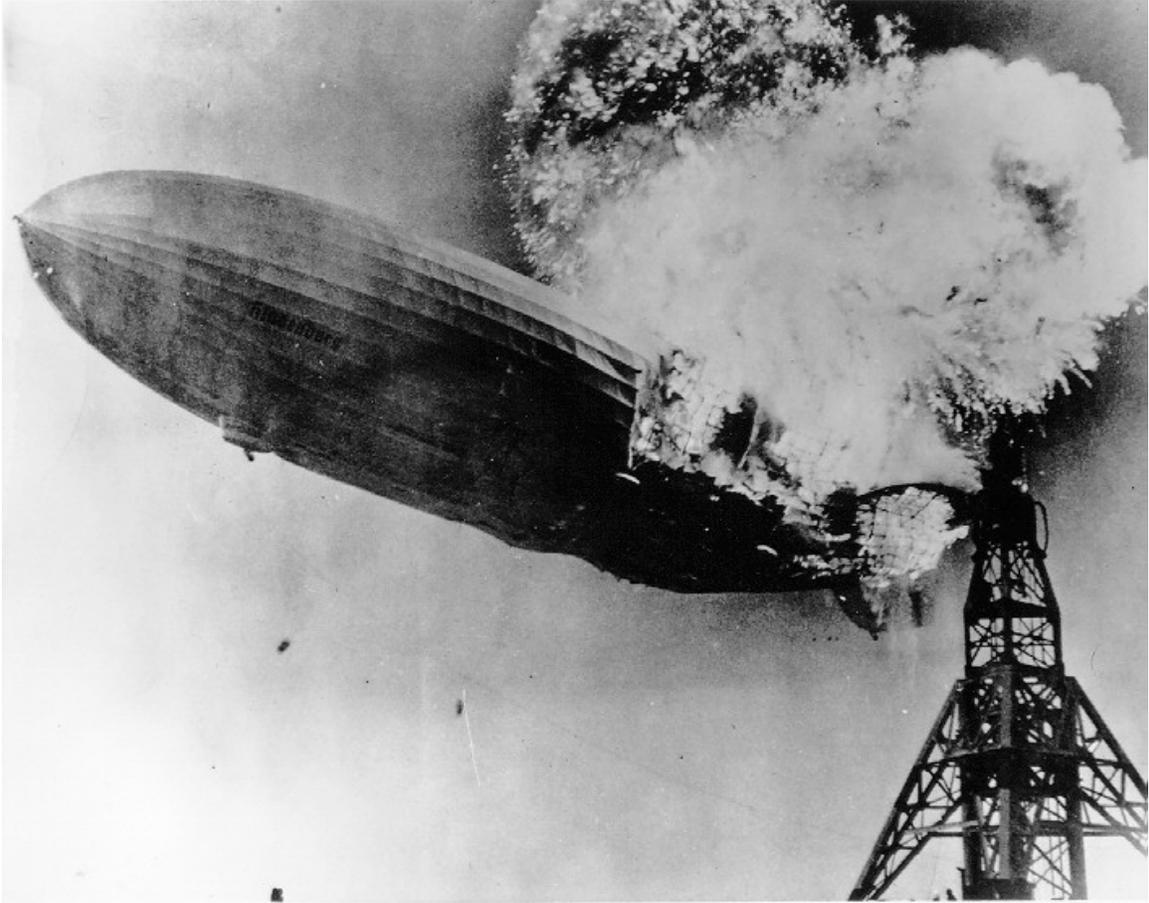
Eventually the US Navy lost all three American-built rigid airships to accidents. USS *Shenandoah* on a poorly planned publicity flight flew into a severe thunderstorm over Noble County, Ohio on 3 September 1925. It broke into pieces, killing 14 of its crew. USS *Akron* was caught in a severe storm and flown into the surface of the sea off the shore of New Jersey on 3 April 1933. It carried no life boats and few life vests, so 73 of its crew of 76 died from drowning or hypothermia. USS *Macon* was lost after suffering a structural failure off the shore of Point Sur Lightstation State Historic Park on 12 February 1935. The failure caused a loss of gas, which was made much worse when the aircraft was driven over pressure height causing it to lose too much helium to maintain

flight. Only 2 of its crew of 83 died in the crash thanks to the inclusion of life jackets and inflatable rafts after the *Akron* disaster.

Britain's Burney Scheme and decline in airships

In Britain during the 1920s, Sir Dennistoun Burney suggested a plan for air service throughout the Empire by airships (the Burney Scheme). Following the election of Ramsay MacDonald, the Burney scheme was transformed into a government-controlled program, the Imperial Airship Scheme, which contracted for two airships, one to be developed by the Airship Guarantee Company, the other by the Royal Airship Works. The two designs were radically different. The "capitalist" ship, the *R100*, was conservative, while the "socialist" ship, the *R101*, was wildly innovative. Construction was delayed, and the airships did not fly until 1929. Neither airship was capable of the service intended, though the *R100* did complete a proving flight to Canada and back in 1930, while the *R101* crashed on its maiden voyage to France at great loss of life.

In October 1930 there were rushed preparations to fly the *R101*, which had not been adequately tested and had serious deficiencies, on a flight to India carrying the Air Minister of the MacDonald government, Christopher Birdwell, Lord Thompson for an important Imperial conference. An air worthiness certificate was issued at the last moment. The *R101* left on the flight on 5 October but hours later crashed in France killing 48 of the 54 people aboard. Because of the bad publicity surrounding the crash, the Air Ministry grounded the competing *R100* in 1930 and sold it for scrap in 1931, ending the era of British rigid airships. The Empire State Building was completed in 1931 with a dirigible mast, in anticipation of passenger airship service. Various entrepreneurs experimented with commuting and shipping freight via airship.



The *Hindenburg* — moments after catching fire, 6 May 1937



Zeppelin Tower in Recife - The only one in the world preserved in its original structure.
2007 photo

By the mid-1930s only Germany still pursued the airship. The Zeppelin company continued to operate the *Graf Zeppelin* on passenger service between Frankfurt and Recife in Brazil, taking 68 hours. Even with the small *Graf Zeppelin*, the operation was almost profitable. In the mid-1930s work started to build an airship designed specifically to operate a passenger service across the Atlantic. The *Hindenburg* (LZ 129) completed a very successful 1936 season carrying passengers between Lakehurst, New Jersey and Germany. But 1937 started with the most spectacular and widely remembered airship accident. Approaching the mooring mast minutes before landing on 6 May 1937, the *Hindenburg* burst into flames and crashed. Of the 97 people aboard, 36 died: 13 passengers, 22 aircrew, and one American ground-crewman. The disaster happened

before a large crowd, was filmed and a radio news reporter was cutting a recording of his coverage of the arrival. This was a disaster which theater goers could see and hear the next day. On that same next day, the *Graf Zeppelin* landed at the end of its flight from Brazil, ending intercontinental passenger airship travel.

Hindenburg's sister ship, the *Graf Zeppelin II* (LZ 130), could not perform commercial passenger flights without helium, which the United States refused to sell. The *Graf Zeppelin* flew some test flights and conducted electronic espionage until 1939 when it was grounded due to the start of the war. The last two Zeppelins were scrapped in 1940.

Development of airships continued only in the United States, and in a small way, the Soviet Union. The Soviet Union had several semi-rigid and non-rigid airships. The semi-rigid SSSR-V6 OSOAVIAKhIM was among the largest of these craft, and set the longest endurance flight at the time of over 130 hours. However, it crashed into a mountain in 1938, killing 13 of the 19 people on board. While this was a severe blow towards the Russian airship programme, they continued to operate non-rigid airships until 1950.

World War II

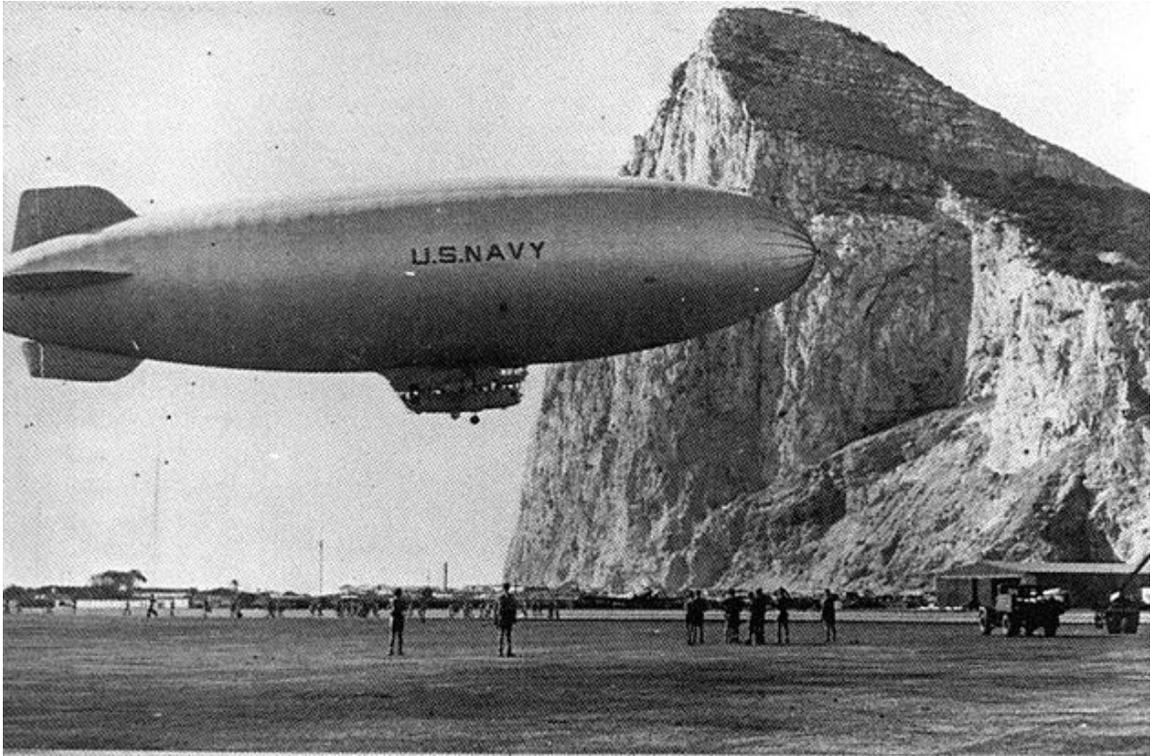
While Germany determined that airships were obsolete for military purposes in the coming war and concentrated on the development of airplanes, the United States pursued a program of military airship construction even though it had not developed a clear military doctrine for airship use. At the Japanese attack on Pearl Harbor on 7 December 1941 that brought the United States into World War II, it had 10 non-rigid airships:

- 4 *K*-class: *K-2*, *K-3*, *K-4* and *K-5* designed as patrol ships built from 1938.
- 3 *L*-class: *L-1*, *L-2* and *L-3* as small training ships, produced from 1938.
- 1 *G*-class built in 1936 for training.
- 2 *TC*-class that were older patrol ships designed for land forces, built in 1933. The US Navy acquired them from the United States Army in 1938.



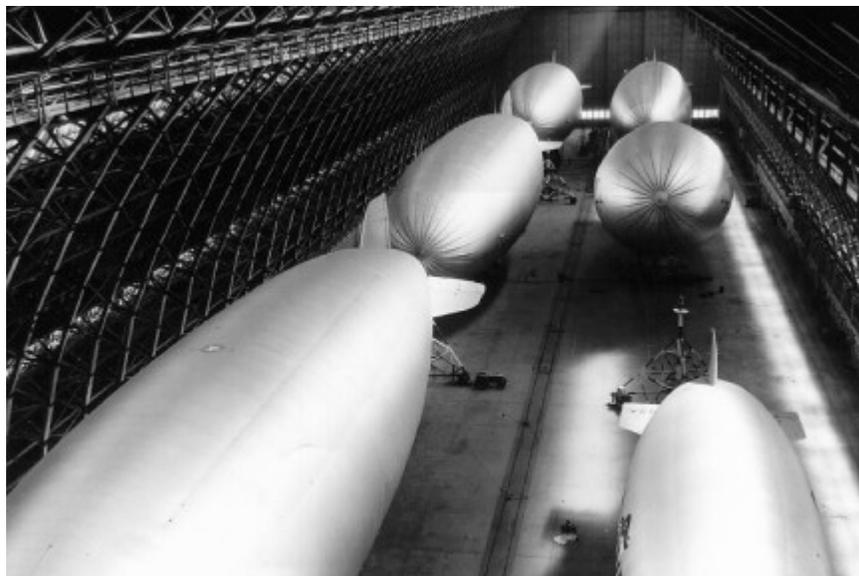
Control car of the Goodyear ZNPK (K-28) Puritan

Only *K*- and *TC*-class airships were suitable for combat and they were quickly pressed into service against Japanese and German submarines which were then sinking US shipping within visual range of the US coast. US Navy command, remembering the airship anti-submarine success from World War I, immediately requested new modern anti-submarine airships and on 2 January 1942 formed the ZP-12 patrol unit based in Lakehurst from the four *K* airships. The ZP-32 patrol unit was formed from two *TC* and two *L* airships a month later, based at NAS Moffett Field in Sunnyvale, California. An airship training base was created there as well. In December 1941 and the first months of 1942, the Goodyear blimp *Resolute* was operated as an anti-submarine privateer based out of Los Angeles. As the only US craft to operate under a Letter of Marque since the War of 1812, the *Resolute*, armed with a rifle and flown by its civilian crew, patrolled the seas for submarines.



This is the K-112--the first K-type airship to land on continental Europe. Commander Sullivan made two landings at Gibraltar 18 July in the initial service test of facilities established there for handling airships. The 1,396-foot "Rock" with its attendant wind "spill" coupled with the rudderman's ticklish job of avoiding neutral Spanish territory during the approach makes a Gibraltar landing a task for seasoned pilots. Fifty ratings from R.A.F. activities directed by an airship pilot and three L.T.A. enlisted men ground handled the ship. The landings were made successfully in a 19-knot cross-"Rock" wind and a British Vice Air Marshal taken for a short hop. A duty Blimp pilot is kept at Gibraltar for liason purposes.

K-class blimps of USN Blimp Squadron ZP-14 conducted antisubmarine warfare operations at the Strait of Gibraltar in 1944-45.



A view of six helium-filled blimps being stored in one of the two massive hangars located at NAS Santa Ana, during World War II.

In the years 1942–44, approximately 1,400 airship pilots and 3,000 support crew members were trained in the military airship crew training program and the airship military personnel grew from 430 to 12,400. The US airships were produced by the Goodyear factory in Akron, Ohio. From 1942 till 1945, 154 airships were built for the US Navy (133 *K*-class, 10 *L*-class, seven *G*-class, four *M*-class) and five *L*-class for civilian customers (serial numbers *L-4* to *L-8*).

The primary airship tasks were patrol and convoy escort near the US coastline. They also served as an organisation center for the convoys to direct ship movements, and were used in naval search and rescue operations. Rarer duties of the airships included aerophoto reconnaissance, naval mine-laying and mine-sweeping, parachute unit transport and deployment, cargo and personnel transportation. They were deemed quite successful in their duties with the highest combat readiness factor in the entire US air force (87%).

In 1944-45, the United States Navy moved an entire squadron of eight Goodyear K class blimps (K-123, K-130, K-109, K-134, K-101, K-112, K-89, & K-114) with flight and maintenance crews from Weeksville Naval Air Station in North Carolina to Port Lyautey, French Morocco. Their mission was to locate and destroy German U-boats in the relatively shallow waters around the Strait of Gibraltar where magnetic anomaly detection (MAD) was viable. PBV aircraft had been searching these waters but MAD required low altitude flying that was dangerous at night for these aircraft. The blimps were considered a perfect solution to establish a 24/7 MAD barrier (fence) at the Straits of Gibraltar with the PBVs flying the day shift and the blimps flying the night shift. The first two blimps (K-123 & K-130) left South Weymouth NAS on 28 May 1944 and flew to Argentia, Newfoundland, the Azores, and finally to Port Lyautey where they completed the first transatlantic crossing by non-rigid airships on 1 June 1944. The blimps of USN Blimp Squadron ZP-14 (Blimpron 14, aka *The Africa Squadron*) also

conducted mine-spotting and minesweeping operations in key Mediterranean ports and various escorts including the convoy carrying United States President Franklin D. Roosevelt and British Prime Minister Winston Churchill to the Yalta Conference in 1945.

During the war some 532 ships without airship escort were sunk near the US coast by enemy submarines. Only one ship, the tanker *Persephone*, of the 89,000 or so in convoys escorted by blimps was sunk by the enemy. Airships engaged submarines with depth charges and, less frequently, with other on-board weapons. They were excellent at driving submarines down, where their limited speed and range prevented them from attacking convoys. The weapons available to airships were so limited that until the advent of the homing torpedo they had little chance of sinking a submarine.

Only one airship was ever destroyed by U-boat: on the night of 18/19 July 1943, a K-class airship (*K-74*) from ZP-21 division was patrolling the coastline near Florida. Using radar, the airship located a surfaced German submarine. The K-74 made her attack run but the U-boat opened fire first. *K-74*'s depth charges did not release as she crossed the U-boat and the *K-74* received serious damage, losing gas pressure and an engine but landing in the water without loss of life. The crew was rescued by patrol boats in the morning, but one crewman, Aviation Machinist's Mate Second Class Isadore Stessel, died from a shark attack. The U-Boat, *submarine U-134*, was slightly damaged and the next day or so was attacked by aircraft sustaining damage that forced it to return to base. It was finally sunk on 24 August 1943 by a British Vickers Wellington near Vigo, Spain

Fleet Airship Wing One operated from Lakehurst, NJ, Glynco, GA, Weeksville, NC, South Weymouth NAS Massachusetts, Brunswick NAS and Bar Harbor ME, Yarmouth, Nova Scotia, and Argentia, Newfoundland.

Some US airships saw action in the European war theatre. The ZP-14 unit operating in the Mediterranean area from June 1944 completely denied the use of the Gibraltar Straits to Axis submarines. Airships from the ZP-12 unit took part in the sinking of the last U-Boat before German capitulation, sinking *U-881* on 6 May 1945 together with destroyers *Atherton* and *Mobery*.

Other airships patrolled the Caribbean, Fleet Airship Wing Two, Headquartered at NAS Richmond, Florida, covered the Gulf of Mexico from Richmond and Key West, FL, Houma, Louisiana, as well as Hitchcock and Brownsville, Texas. FAW 2 also patrolled the northern Caribbean from San Julian, the Isle of Pines (now called Isla de la Juventud) and Guantanamo Bay, Cuba as well as Vernam Field, Jamaica.

Navy blimps of Fleet Airship Wing Five, (ZP-51) operated from bases in Trinidad, British Guiana and Paramaribo, Dutch Guiana. Fleet Airship Wing Four operated along the coast of Brazil. Two squadrons, VP-41 and VP-42 flew from bases at Amapá, Igarape Assu, Sao Luiz, Fortaleza, Fernando de Noronha, Recife, Maceió, Ipitanga (near Salvador, Bahia), Caravellas, Vitoria and the hangar built for the *Graf Zeppelin* at Santa Cruz, Rio de Janeiro.

Fleet Airship Wing Three operated squadrons, ZP-32 from Moffett Field, ZP-31 at NAS Santa Ana, and ZP-33 at NAS Tillamook, Oregon. Auxiliary fields were at Del Mar, Lompoc, Watsonville and Eureka, CA, North Bend and Astoria, Oregon, as well as Shelton and Quillayute in Washington.

From 2 January 1942 till the end of war airship operations in the Atlantic, the airships of the Atlantic fleet made 37,554 flights and flew 378,237 hours. Of the over 70,000 ships in convoys protected by blimps, only one was sunk by a submarine while under blimp escort.

The Soviet Union used a single airship during the war. The *W-12*, built in 1939, entered service in 1942 for paratrooper training and equipment transport. It made 1432 runs with 300 metric tons of cargo until 1945. On 1 February 1945, the Soviets constructed a second airship, a *Pobeda*-class (*Victory*-class) unit (used for mine-sweeping and wreckage clearing in the Black Sea) which crashed on 21 January 1947. Another *W*-class - *W-12bis Patriot* - was commissioned in 1947 and was mostly used for crew training, parades and propaganda.

Modern use

Although airships are no longer used for passenger transport, they are still used for other purposes such as advertising, sightseeing, surveillance and research.



One of The Goodyear Tire and Rubber Company's blimp fleet

In the 1980s, Per Lindstrand and his team introduced the *GA-42* airship, the first airship to use fly-by-wire flight control which considerably reduced the pilot's workload.

The world's largest thermal airship (300,000 cubic feet/8,495 m³) was constructed by the Per Lindstrand company for French botanists in 1993. The *AS-300* carried an underslung raft, which was positioned by the airship on top of tree canopies in the rain forest, allowing the botanists to carry out their treetop research without significant damage to the

rainforest. When research was finished at a given location, the airship returned to pick up and relocate the raft.

In the spring of 2004, Lindstrand Technologies supplied the world's first fully-functional unmanned airship to the Ministry of Defense in Spain. This airship carried a 42 kilograms (93 lb) classified payload and its surveillance mission was also classified. Four years later, this airship, which is designated *GA-22*, still flies on an almost daily basis.

In June 1987, the US Navy awarded a US\$168.9 million contract to Westinghouse Electric and Airship Industries of the UK to demonstrate whether a blimp could be used as an airborne platform to detect the threat of sea-skimming missiles, such as the Exocet. At 2.5 million cubic feet, the Westinghouse/Airship Industries Sentinel 5000 (Redesignated YEZ-2A by the U. S. Navy) prototype design was to have been the largest blimp ever constructed. However, additional funding for the Naval Airship Program was killed in 1995 and development was discontinued.

The *CA-80* airship, which was launched in 2000 by Shanghai Vantage Airship Manufacture Co., Ltd., had a successful trial flight in September 2001. This model of airship was designed for the purpose of advertisement and propagation, air-photo, scientific test, tour and surveillance duties. It was certified as a grade 'A' Hi-Tech introduction program (No.20000186) in Shanghai, China. The CAAC authority granted a type design approval and certificate of airworthiness for the model *CA-80* airship, which has been published in the *Jane's All the World's Aircraft* for five times (2003–2008).

In recent years, the Zeppelin company has reentered the airship business. Their new model, designated the Zeppelin NT made its maiden flight on 18 September 1997. There are currently four NT aircraft flying, a fifth completed in March 2009 and an expanded NT-14 (14,000 cubic meters of helium, capable of carrying 19 passengers) also under construction. One was sold to a Japanese company, and was planned to be flown to Japan in the summer of 2004. But due to delays getting permission from the Russian government, the company decided to transport the airship to Japan by ship. One of the four NT craft is in South Africa carrying diamond detection equipment from De Beers, an application at which the very stable low vibration NT platform excels. Some adaptations to the design for high heat operation and desert climate were part of that project. A separate mooring mast and a very heavy truck to moor the vehicle is also part of the technology. NT-4 belongs to Airship Ventures of Moffett Field, Mountain View in the San Francisco Bay Area, and provides sight-seeing tours

Blimps are used for advertising and as TV camera platforms at major sporting events. The most iconic of these are the Goodyear blimps. Goodyear operates three blimps in the United States, and The Lightship Group operates up to 19 advertising blimps around the world. Airship Management Services owns and operates three Skyship 600 blimps. Two operate as advertising and security ships in North America and the Caribbean.

Skycruise Switzerland AG owns and operates two Skyship 600 blimps. One operates regularly over Switzerland used on sightseeing tours.



The Spirit of Dubai approaches its motorised mooring mast

The Switzerland-based Skyship 600 has also played other roles over the years. For example, it was flown over Athens during the 2004 Summer Olympics as a security measure. In November 2006, it carried advertising calling it "The Spirit of Dubai" as it began a publicity tour from London to Dubai, UAE on behalf of The Palm Islands, the world's largest man-made islands created as a residential complex.

Los Angeles-based Worldwide Aeros Corp. produces FAA Type Certified Aeros 40D Sky Dragon airships.

In May 2006, the US Navy began to fly airships again after a hiatus of nearly 44 years. The program uses a single American Blimp Company A-170 non-rigid airship, with designation MZ-3A. Operations focus on crew training and research, and the platform integrator is Northrop Grumman. The program is directed by the Naval Air Systems Command and is being carried out at NAES Lakehurst, the original center of US Navy lighter-than-air operations in previous decades.

In November 2006, the US Army bought an A380+ airship from American Blimp Corporation through a Systems level contract with Northrop Grumman and Booz Allen Hamilton. The airship started flight tests in late 2007 with a primary goal of carrying 2,500 lb (1,100 kg) of payload to an altitude of 15,000 ft (4,600 m) under remote control and autonomous waypoint navigation. The program will also demonstrate carrying 1,000 lb (450 kg) of payload to 20,000 ft (6,100 m) The platform could be used for Multi-Intelligence collections. Northrop Grumman (formerly Westinghouse) has responsibility for the overall program.

In 2008 the *CA-150* airship was launched by Vantage Airship. This is an improved modification of model *CA-120* and completed manufacturing in 2008. With larger volume and increased passenger capacity, it is the largest manned non-rigid airship in China at present.

In 2010, the U.S. Army awarded a \$517 million (£350.6 million) contract to Northrop Grumman, to develop Long Endurance Multi-Intelligence Vehicle (LEMV) systems.

An airship starred in the *James Bond* 1985 film "*A view to a kill*" The airship had the livery of Zorin Industries.

Recent developments

In the 1930s, Zeppelins successfully competed with other means of transatlantic transport. Their advantages included the ability to carry significantly more passengers than other contemporary aircraft in greater comfort with less engine noise, vibration and turbulence, while providing amenities similar to those on ocean liners, such as private cabins, observation decks, dining rooms, and even a smoking lounge on the *Hindenburg*. Less importantly, the technology was potentially more energy-efficient than heavier-than-air designs. Zeppelins were also faster than ocean liners. On the other hand, operating the giants was quite involved, especially in terms of personnel. Often the crew would outnumber passengers on board, and on the ground large teams were necessary to assist starting and landing. Also, to accommodate Zeppelins like *Hindenburg* (which was more than five times as long as the height of the Statue of Liberty without the pedestal), very large hangars were required at airports.

Today, with large, fast, and more cost-efficient fixed-wing aircraft, it is unknown whether huge airships can operate profitably in regular passenger transport though, as energy costs rise, attention is once again returning to these lighter than air vessels as a viable alternative. At the very least, the idea of comparatively slow, "majestic" cruising at relatively low altitudes and in comfortable atmosphere certainly has retained some appeal. There have been some niches for airships in and after World War II, such as long-duration observations, antisubmarine patrol, platforms for TV camera crews, and advertising; these, however, generally require only small and flexible craft, and have thus generally been better fitted for cheaper blimps.

Heavy lifting

It has periodically been suggested that airships could be employed for cargo transport, especially delivering extremely heavy loads to areas with poor infrastructure over great distances. This has also been called roadless trucking. Also, airships could be used for heavy lifting over short distances (e.g. on construction sites); this is described as heavy-lift, short-haul. In both cases, the airships are heavy haulers. One recent enterprise of this sort was the *Cargolifter* project, in which a hybrid (thus not entirely Zeppelin-type) airship even larger than *Hindenburg* was projected. Around 2000, this idea was realized, when the CargoLifter AG constructed the world's largest cantilever shop hall measuring 360 m (1,180 ft) long, 210 m (690 ft) wide and 107 m (351 ft) high about 60 km (37 mi) south of Berlin. In May 2002, the project was stopped for financial reasons; the company had to file bankruptcy. Although no rigid airships are currently used for heavy lifting, hybrid airships are being developed for such purposes. John McPhee's *The Deltoid Pumpkin Seed* is the story of one company attempting this.

Passenger transport



A Zeppelin NT airship

In the 1990s, the successor of the original Zeppelin company in Friedrichshafen, the *Zeppelin Luftschifftechnik GmbH*, reengaged in airship construction. The first experimental craft (later christened *Friedrichshafen*) of the type *Zeppelin NT* flew in September 1997. Though larger than common blimps, the *Neue Technologie* (new technology) Zeppelins are much smaller than their giant ancestors and not actually Zeppelin-types in the classical sense; they are sophisticated semi-rigids. Apart from the greater payload, their main advantages compared to blimps are higher speed and excellent maneuverability. Meanwhile, several *Zeppelin NT* have been produced and operated profitably in joyrides, research flights and similar applications.

In June 2004, a Zeppelin NT was sold for the first time to a Japanese company, Nippon Airship Corporation, for tourism and advertising mainly around Tokyo. It was also given a role at the 2005 Expo in Aichi. The aircraft began a flight from Friedrichshafen to Japan, stopping at Geneva, Paris, Rotterdam, Munich, Berlin, Stockholm and other European cities to carry passengers on short legs of the flight. However, Russian

authorities denied overflight permission so the airship had to be dismantled and shipped to Japan rather than following the historic *Graf Zeppelin* flight from Germany to Japan.

In 2008, Airship Ventures Inc. began operations from Moffett Federal Airfield near Mountain View, California and currently offers tours of the San Francisco Bay Area for up to 12 passengers.

Use in exploration

In November 2005, De Beers, the diamond mining company, launched an airship exploration program over the remote Kalahari desert. A Zeppelin, loaded with high-tech equipment, is used to find potential diamond mines by scanning the local geography for low-density rock formations - so-called kimberlite pipes. On 21 September 2007, the airship was severely damaged by a whirlwind while in Botswana. One crew member, who was on watch aboard the moored craft, was slightly injured but released after overnight observation in hospital.

Thermal Airships and Remotes



Thermal airship (manufacturer GEFA-FLUG/Germany)

Several companies, such as Cameron Balloons in Bristol, United Kingdom, build hot-air airships. These combine the structures of both hot-air balloons and small airships. The envelope is the normal 'cigar' shape, complete with tail fins, but is inflated with hot air (as in a balloon) to provide the lifting force, instead of helium. A small gondola, carrying the pilot and passengers, a small engine, and the burners to provide the hot air are suspended below the envelope, below an opening through which the burners protrude.

Hot-air airships typically cost less to buy and maintain than modern helium-based blimps, and can be quickly deflated after flights. This makes them easy to carry in trailers or trucks and inexpensive to store. They are usually very slow moving, with a typical top speed of 25–30 km/h (15–20 mph, 6.7–8.9 m/s). They are mainly used for advertising, but at least one has been used in rainforests for wildlife observation, as they can be easily transported to remote areas.

Remote controlled (RC) airships, a type of Unmanned Aerial System (UAS), are sometimes used for commercial purposes such as advertising and aerial video and photography as well as recreational purposes. They are particularly common as an advertising mechanism at indoor stadiums. While RC airships are sometimes flown outdoors, doing so for commercial purposes is illegal in the US. In particular, Docket FAA-2006-25714 states that: "The FAA recognizes that people and companies other than modelers might be flying UAS with the mistaken understanding that they are legally operating under the authority of AC 91-57. AC 91-57 only applies to modelers, and thus specifically excludes its use by persons or companies for business purposes." The same docket item identifies 14CFR121 as the appropriate certification basis for experimental unmanned aircraft, which would include unmanned airships operating for commercial purposes, so commercial use of a unmanned airship is not prohibited - instead it must be certified under part 121 not 91.

A total of 4,700 total airships and blimps exist across the world.

Present-day research

Prototypes and experimental models

Hybrid designs such as the Heli-Stat airship/helicopter, the Aereon aerostatic/aerodynamic craft, and the CycloCrane (a hybrid aerostatic/rotorcraft), have struggled to take flight. The CycloCrane was also interesting in that the airship's envelope rotated along its longitudinal axis.

CL 160 was a very large semi-rigid airship to be built by the start-up Cargolifter, but funding ran out in 2002 after a massive hangar was built. The hangar, built just outside Berlin, has since been converted into a resort called Tropical Islands.

In 2005, a short-lived project of the US Defense Advanced Research Projects Agency (DARPA) was WALRUS HULA which explored the potential for using airships as long-distance, heavy lift craft. The primary goal of the research program was to determine the

feasibility of building an airship capable of carrying 500 short tons (450 t) of payload a distance of 12,000 mi (19,000 km) and land on an unimproved location without the use of external ballast or ground equipment (such as masts). In 2005, two contractors, Lockheed Martin and US Aeros Airships were each awarded approximately \$3 million to do feasibility studies of designs for WALRUS. In late March 2006, DARPA announced the termination of work on WALRUS after completion of the current Phase I contracts.

The US government is funding two major projects in the high altitude arena. The Composite Hull High Altitude Powered Platform (CHHAPP) is sponsored by US Army Space and Missile Defense Command. This aircraft is also sometimes called *HiSentinel High-Altitude Airship*. This prototype ship made a five-hour test flight in September 2005. The second project, the high-altitude airship (HAA), is sponsored by DARPA. In 2005, DARPA awarded a contract for nearly \$150 million to Lockheed Martin for prototype development. First flight of the HAA is planned for 2008.

Many companies are working on high-altitude airships.

In 1999 Lindstrand Technologies, in partnership with Daimler Chrysler Aerospace of Germany, was awarded a design contract by the European Space Agency (ESA) to develop a High Altitude Long Endurance airship for possible use in the telecommunications market. As a result of this, Per Lindstrand was awarded the German-based Körber Prize for engineering excellence. These stratospheric long endurance platforms inhabit the calm upper atmosphere at usually 21 km (69,000 ft) where airspace is uncontrolled, in a geo-synchronous position and remain in the same place by motoring into the prevailing wind. About 60 and 90 m (295 ft) long, they are intended to stay up for a period of three to five years without maintenance. Applications include cellular phone (S-UMTS) base station, passenger information system, digital broadcast, remote monitoring, metropolitan area network and emergency response network.

E-Green Technologies, Inc., is developing a high-altitude version of their spherically and bullet shaped airships. JP Aerospace has discussed its long-range plans that include not only high altitude communications and sensor applications but also an "orbital airship" capable of lifting cargo into low Earth orbit with a marginal transportation cost of \$1 per short ton per mile of altitude (0.70 US\$/t-km).

On 31 January 2006 LockheedMartin made the first flight of their secretly built hybrid airship designated the P-791. The design is very similar to the SkyCat, unsuccessfully promoted for many years by the now financially troubled British company Advanced Technology Group. Although Lockheed Martin is developing a design for the DARPA WALRUS HULA project, it claimed that the P-791 is unrelated to WALRUS. Nonetheless, the design represents an approach that may well be applicable to WALRUS. Some believe that Lockheed Martin had used the secret P-791 program as a way to get a "head start" on the other WALRUS competitor, US Aeros Airships.

A privately funded effort to build a heavy-lift aerostatic/aerodynamic hybrid craft, called the Dynalifter, is being carried out by Ohio Airships. Test flights are to begin in Spring 2006.

The research and development company for airship technologies, 21st century Airships Inc., has developed a spherical-shaped airship, and airships for high altitude, environmental research, surveillance and military applications, heavy lift and sightseeing. Its airships have set numerous world records.

In Russia, AUGUR-RosAerosystems Group is manufacturing non-rigid multi-functional airships for up to ten passengers, as well as patrol airships including the Au-12 and Au-30. They are also working on developmental programs for heavy-lift cargo models and high-altitude stratospheric ships.

Airships in Planetary Exploration

Several proposals have been made for the use of airships in the robotic exploration of those planets (and one moon, Titan) which have atmosphere thick enough to provide buoyancy. Some of these applications are discussed under Aerobots.

Hybrid Airship

A Hybrid airship is a general term for an aircraft that combines characteristics of heavier-than-air (airplane or helicopter) and lighter-than-air technology. Examples include helicopter/airship hybrids intended for heavy lift applications and dynamic lift airships intended for long-range cruising. It should be noted that most airships, when fully loaded with cargo and fuel, are usually ballasted to be heavier than air, and thus must use their propulsion system and shape to create aerodynamic lift, necessary to stay aloft. All airships can be operated to be slightly heavier than air at periods during flight (descent). However, the term 'hybrid airship' refers to craft that obtain a significant portion of their lift from aerodynamic lift or other kinetic means.

For example, the Aeroscraft is a buoyancy assisted air vehicle that generates lift through a combination of aerodynamics, thrust vectoring and gas buoyancy generation and management, and for much of the time will fly heavier than air. Aeroscraft is Worldwide Aeros Corporation's continuation of DARPA's now canceled Walrus HULA(Hybrid Ultra Large Aircraft) project.

Practical comparison with heavier-than-air aircraft

The advantage of airships over airplanes is that static lift sufficient for flight is generated by the lifting gas and requires no engine power. This was an immense advantage before the middle of World War I and remained an advantage for long distance, or long duration operations until World War II. Modern concepts for high altitude airships include photovoltaic cells to reduce the need to land to refuel, thus they can remain in the air until consumables expire.

The disadvantages are that an airship has a very large reference area and comparatively large drag coefficient, thus a larger drag force compared to that of airplanes and even helicopters. Given the large flat plate area and wetted surface of an airship, a practical limit is reached around 80–100 miles per hour (130–160 km/h). Thus airships are used where speed is not critical.

The gross lift capability of an airship is equal to the buoyant force minus the weight of the airship. This assumes standard air temperature and pressure conditions. Corrections are usually made for water vapor and impurity of lifting gas, as well as percentage of inflation of the gas cells at liftoff. Based on specific lift (pounds of lift per thousand cubic feet of lifting gas), the greatest static lift is provided by hydrogen (71 lbs. lift/1000 cubic feet of gas) with helium (66 lbs. lift/1000 cubic feet of gas) a close second. At 39 lbs./1000 cubic feet, steam is a distant third. Other gases, such as methane, carbon monoxide, ammonia and natural gas have even less lifting capacity and are flammable, toxic, corrosive, or all three. Operational considerations such as whether the lift gas can be economically vented and produced in flight for control of buoyancy (as with hydrogen) or even produced as a byproduct of propulsion (as with steam) affect the practical choice of lift gas in airship designs.

Considering the *Hindenburg* disaster, one may question why such a flammable gas as hydrogen was used in the first place, when it is only marginally better than helium as a lifting gas. The answer to this lies in the availability of the gas. Hydrogen can be produced easily and economically through the electrolysis of water, or by chemical reactions, whereas helium exists only in trace amounts and can only be extracted from a few natural gas wells.

In addition to static lift, an airship can obtain a certain amount of dynamic lift from its engines. Dynamic lift in past airships has been about 10% of the static lift. Dynamic lift allows an airship to "take off heavy" from a runway similar to fixed-wing and rotary-wing aircraft. However, this requires additional weight in engines and fuel, negating some of the static lift capacity.

The altitude at which an airship can fly largely depends on how much lifting gas it can lose due to expansion before stasis is reached. The ultimate altitude record for a rigid airship was set in 1917 by the L-55 under the command of Hans-Kurt Flemming when he forced the airship to 24,000 ft (7,300 m) attempting to cross France after the "Silent Raid" on London. The L-55 lost lift as the descent to lower altitudes over Germany compressed the gas left in the cells, and thus the weight of air displaced. L-55 crashed due to loss of lift. While such waste of gas was necessary for the survival of airships in the later years of WW I, it was impractical for commercial operations, or operations of helium-filled military airships. The highest flight made by a hydrogen filled passenger airship was 5,500 ft (1,700 m) on the *Graf Zeppelin's* around the world flight. The practical limit for rigid airships was about 3,000 feet (900 m), and for pressure airships around 8,000 ft (2,400 m).

Modern airships use dynamic helium volume. At sea level altitude, helium only takes up a small part of the hull, while the rest is filled with air. As the airship ascends, the helium inflates with reduced outer pressure, and air is pushed out and released from the downward valve. This allows an airship to reach any altitude with balanced inner and outer pressure if the buoyancy is enough. Some civil aerostats could reach 100,000 ft (30,000 m) without explosion due to overloaded inner pressure.

The greatest disadvantage of the airship is size, which is essential to increasing performance. As size increases, the problems of ground handling increase geometrically. As the German Navy transitioned from the "p" class Zeppelins of 1915 with a volume of over 1,100,000 cu ft (31,000 m³) to the larger "q" class of 1916, the "r" class of 1917, and finally the "w" class of 1918, at almost 2,200,000 cu ft (62,000 m³) ground handling problems reduced the number of days the Zeppelins were able to make patrol flights. This availability declined from 34% in 1915, to 24.3% in 1916 and finally 17.5% in 1918.

So long as the power-to-weight ratios of aircraft engines remained low and specific fuel consumption high, the airship had an edge for long range or duration operations. As those figures changed, the balance shifted rapidly in the airplane's favor. By mid-1917 the airship could no longer survive in a combat situation where the threat was airplanes. By the late 1930s, the airship barely had an advantage over the airplane on intercontinental over-water flights, and that advantage had vanished by the end of WW II.

This is in face-to-face tactical situation, current High Altitude Airship project is planned to survey hundreds of kilometers as their operation radius, often much farther than normal engage range of a military airplane. This provides better early warning, even farther than the Aegis system. The current Aegis system is often based on a sea vessel like Ticonderoga Class and Burke Class, which have restricted radio horizon and line of sight. For example, a radar mounted on a vessel platform 30 m (100 ft) high has radio horizon at 20 km (12 mi) range, while a radar at 18,000 m (59,000 ft) altitude has radio horizon at 480 km (300 mi) range. This is significantly important for detecting low-flying cruise missiles or fighter-bombers.

The blimp remained a viable military system only until the conventional submarine was replaced by the nuclear submarine. Today, airships are used primarily for command, control and as a communication platform; to establish and maintain reliable and secure connectivity among all forces, provide transparent data across the echelons; precisely locate friendly and enemy forces; detect targets on an extended battlefield at a minimal exposure to enemy forces; real time targeting; navigation assistance; battle management; monitor radio conversations, etc.

Safety

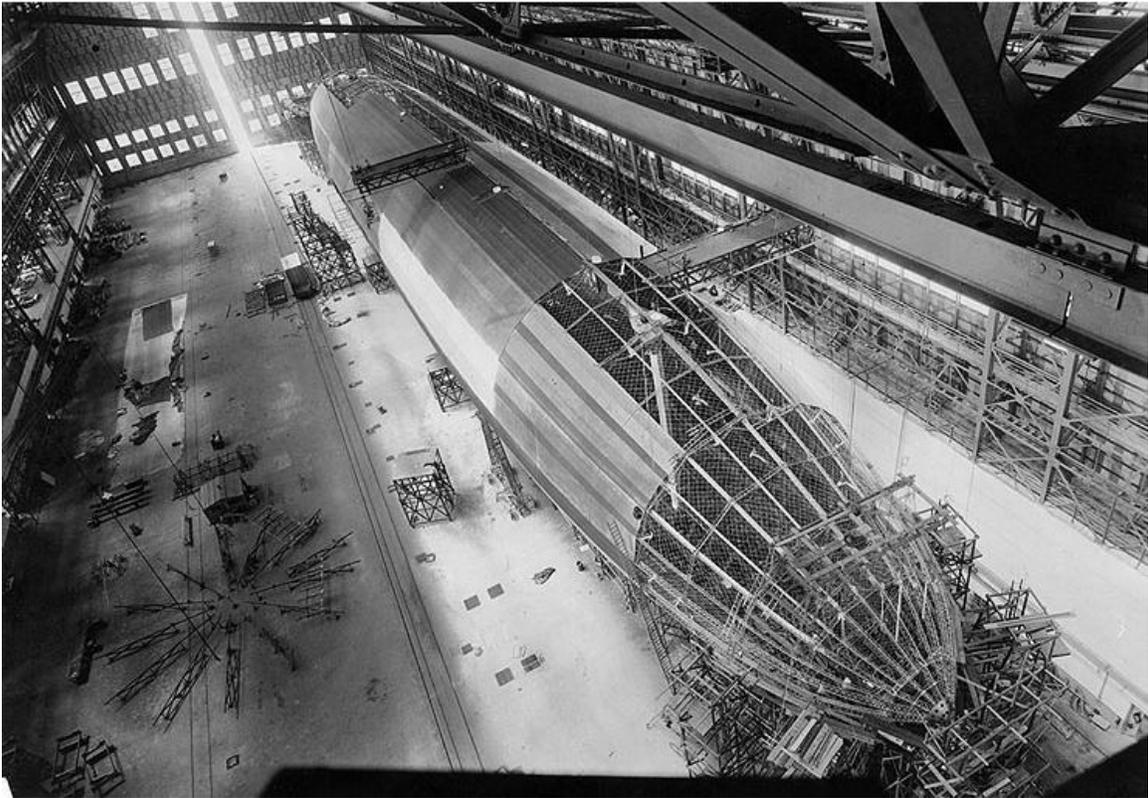
The most commonly used lift gas, helium, is not merely inert but acts as a fire extinguisher, since it is non-flammable. Modern airships have a natural buoyancy and special design that offers a virtually zero catastrophic failure mode. While on long-haul flights weather patterns would be flown to avoid bad weather, the hull's mass largely

dampens the effect of turbulence, just as a large tanker rides through rough seas. An airship is usually a poor lightning target, as it is constructed mainly from composite materials. If it is struck, built-in protection devices minimise the risk to the vehicle and its cargo.

A series of structural vulnerability tests were done by the UK Defence Evaluation and Research Agency DERA on a Skyship 600, an earlier airship built by the Munk team to a similar pressure-stabilised design. Several hundred high-velocity bullets were fired through the hull, and even two hours later the vehicle would have been able to return to base. The airship is virtually impervious to automatic rifle and mortar fire: ordnance passes through the envelope without causing critical helium loss. In all instances of light armament fire evaluated under both test and live conditions, the vehicle was able to complete its mission and return to base. The internal hull pressure is maintained at only 1–2% above surrounding air pressure, the vehicle is highly tolerant to physical damage or to attack by small-arms fire or missiles.

Chapter 2

Rigid Airship



Construction of USS *Shenandoah* (ZR-1), 1923, showing the framework of a rigid airship

A **rigid airship** was a type of airship in which the envelope retained its shape by the use of an internal structural framework rather than by being forced into shape by the pressure of the lifting gas within the envelope as used in blimps (also termed pressurized airships) and semi-rigid airships.

Rigid airships were produced and relatively successfully employed from the beginning of the 1900s to the end of the 1930s; their heyday ended when the Hindenburg ignited on May 6, 1937.

Terminology

Although "rigid airship" is the proper formal term, these aircraft are often casually referred to by several other names such as *dirigibles*, *zeppelins* (after the most successful ships of this type built by the Zeppelin Company) or the *big rigids*.

Early days

By 1874 several people had conceived of a rigid dirigible (in contrast to non-rigid powered airships which had been flying since 1852). Frenchman Joseph Spiess had published a rigid airship proposal in 1873 but failed to get funding. Count Zeppelin had outlined his thoughts of a rigid airship in diary entries from 25 March 1874 through to 1890 when he resigned from the military. David Schwarz had thought about building an airship in the 1880s and had likely started design work in 1891, definitely by 1892 he was starting construction. It was not until after Schwarz's death in 1897 that his all-aluminium airship, built with help from with Carl Berg and the Prussian Airship Battalion, was test flown. Schwarz and Berg had an exclusive contract and Count Zeppelin was obliged to come to a legal agreement with Schwarz's heirs to obtain aluminium from Carl Berg, although the two men's designs were different and independent from each other. With Berg's aluminum, Zeppelin was able in 1899 to start building and, in 1900 July, to fly the Zeppelin LZ1.

Great Britain

Great Britain and the USA lagged behind Germany in rigid airship technology. According to a 2001 PBS documentary, much of Britain's knowledge was based on reverse engineered technology from World War I German zeppelin crashes. After several crashes of experimental airships, the British ceded this field to the Germans.

France

France's only rigid airship was built by Alsatian Joseph Spiess using a wooden framework and it flew on April 13, 1913. It was 146 metres (479 ft) long, with a diameter of 13.5 metres (44.3 ft) and a gas volume of 16,400 cubic metres (579,161 cubic feet). Joseph Spiess is buried in the famous Cimetiere du Pere-Lachaise in Paris. His gravestone celebrates his achievements with a bronze frieze of his rigid airship.

Germany

In 1900, Count Ferdinand von Zeppelin began trials with a rigid airship based on the theories of Austrian engineer David Schwartz. Germany had over twenty very large lighter-than-air rigid airships by the beginning of World War I, seven owned by the company Luftschiffbau Zeppelin. In the five years prior to the outbreak of war, his airline carried 32,722 passengers on over 1,588 flights totalling 172,530 kilometres (107,205 miles). The German war ministry took over two of them in 1909 and one crashed.

Commercial airlines ended in Germany at the outbreak of the War, during which Zeppelin's company built 95 giant military airships. German military airship stations had been established before the War and on September 2–3, 1914, the Zeppelin LZ 17 dropped three 200 lb bombs on Antwerp in Belgium. On January 19, 1915, two further airships dropped bombs on Norfolk, England, killing numerous people; the third ship in the air raid returned to Germany with engine trouble before reaching England. On May 31, 1915, the first bombs fell on London. The night of September 2–3, 1916 was when the first German airship was shot down over English soil; it was done using a small heavier-than-air aircraft. Further bombs were dropped on London during the night of November 27–28, 1916, this time by a winged aircraft. However, the build-up of England's defences against such aircraft led to the discontinuation of airship raids by Germany. The last casualties occurred on April 12, 1918.

United States

The United States rigid airship program was mostly stationed in Lakehurst Naval Air station, New Jersey. The ZR-1 Shenandoah was one of the first, serving from 1923 to 1925. The ZR-2 was a British airship intended to join the naval fleet, but it crashed in 1921. The ZR-3 was a German airship, sold to the United States in 1924 and named Los Angeles. The ship was grounded in 1931, due to the Depression, but was not dismantled for over 5 years. The sister ships Akron and Macon both crashed after technical failure. These crashes ended the rigid airship program.

Production

As well as the Zeppelin Company, Schütte-Lanz also manufactured them. Both America and Britain have manufactured rigid airships at some point.

Demise

Following the Hindenburg disaster in 1937, Germany grounded its airship fleet with the intention of replacing their hydrogen gas with non-flammable helium. By this time, however, Europe was well on the path to World War II, and the United States, the only country with substantial helium reserves, refused to sell the necessary gas. International travel was crippled during the war, and commercial aircraft - able to fly much faster than rigid airships - soon became the favored method of international air travel.

Some famous rigid airships

- *R34*, British airship and the first aircraft to traverse the Atlantic Ocean from east to west, in 1919.
- USS *Shenandoah*, American naval airship which served the U.S. Navy from 1923 until its crash in Ohio in 1925.
- *R38 (ZR-2)*, British airship intended to join the American naval fleet, but crashed during testing in 1921.

- USS *Los Angeles*, German airship sold to the United States in 1924 as part of German reparations from World War I. The ship served with distinction from 1924 to 1931.
- LZ 127 *Graf Zeppelin*, German passenger airship designed and piloted by Hugo Eckener. It circumnavigated the globe in 1929 and had a spotless safety record. It was ultimately dismantled by the Nazis at the outset of World War II.
- R-100, British airship built by the Airship Guarantee Company, a private company created solely for the construction of this airship, as a subsidiary of the armaments firm, Vickers.
- R-101, British airship designed and built by the British government in a kind of competition with the R-100. The R-101 crashed on its maiden flight in 1930 in France, with considerable loss of life. Its crash effectively ended British participation in rigid airship construction.
- USS *Akron*, American naval airship designed and built by the Goodyear Tire and Rubber Company in Ohio in 1931. Deployed as an airborne aircraft carrier, it was lost at sea in a storm off New Jersey in 1933 with considerable loss of life.
- USS *Macon*, sister ship to the *Akron*, it was a near carbon-copy of her. Though it suffered only 2 deaths, its crash in 1935 off the coast of California ended American participation in rigid airship development.
- LZ 129 *Hindenburg*, German passenger airship also designed and built by Hugo Eckener. The airship was lost in a famous fire in New Jersey in 1937. With its end came the end of the age of the Great Rigid Airships.

Modern rigids

There are no rigid airships flying today. The Zeppelin company refers to their NT ship as a rigid but this is a misnomer. The envelope shape is retained in part by super-pressure of the lifting gas, and so the NT is more correctly classified as a semi-rigid.

Chapter 3

Blimp



An American Blimp Corporation A-60+, the MetLife Snoopy Two



Steerable ducted fans on a Skyship 600 provide thrust, limited direction control, and also serve to inflate the ballonets to maintain the necessary overpressure

A **blimp**, or **non-rigid airship**, is an airship without an internal supporting framework or keel. A non-rigid airship differs from a semi-rigid airship and a rigid airship (e.g., a Zeppelin) in that it does not have any rigid structure, neither a complete framework nor a partial keel, to help the airbag maintain its shape. Rather, these aircraft rely on both a higher pressure of the lifting gas (usually helium) inside the envelope and the strength of the envelope itself.

The term "blimp" refers only to free-flying aircraft. The term is sometimes erroneously used to refer to the tethered craft known as moored balloons. While often very similar in shape, moored balloons have no propulsion and are tethered to the ground.

Principle

Since blimps keep their shape with internal overpressure, typically the only solid parts are the passenger car (gondola) and the tail fins. A non-rigid airship that uses heated air instead of a light gas (such as helium) as a lifting medium is called a hot-air airship.



A modern blimp from Airship Management Services showing a strengthened nose, ducted fans attached to the gondola under the hull, and cable-braced fins at the tail

Volume changes of the lifting gas, due to temperature changes, is balanced using ballonets (air bags), in order to maintain the overpressure. Without sufficient overpressure, the blimp loses its ability to be steered and top speed is degraded. The propeller air stream can be used to inflate the hull. In some models, such as the Skyship 600, differential ballonet inflation can provide a measure of pitch trim control.

The engines driving the propellers are usually directly attached to the gondola, and in some models are partly steerable.

Blimps are the most commonly built airships, because they are relatively easy to build and easy to transport once deflated. However, because of their unstable hull, their size is limited. A blimp with too long a hull may kink in the middle when the overpressure is insufficient or when maneuvered too fast (this has also happened with semi-rigid airships with weak keels). This led to the development of semi-rigids and rigid airships.

Modern blimps launch somewhat heavier than air (overweight), in contrast to historic blimps. The missing lift is provided by lifting the nose and using engine power. Some types also use steerable propellers or ducted fans. Operating in a state heavier than air avoids the need to dump ballast at lift-off and also avoids the need to lose costly lifting gas on landing.

Etymology



The Spirit of Goodyear, one of the iconic Goodyear Blimps

The term "blimp" is reportedly onomatopoeic, the sound the airship makes when one taps the envelope (balloon) with a finger. Although there is some disagreement among historians, credit for coining the term is usually given to Lt. A.D. Cunningham of the British Royal Navy in 1915.

A 1943 etymology published in the *New York Times* confirms the British origin during the first World War when the British were experimenting with lighter-than-air craft. The initial non-rigid aircraft was called the A-limp; and a second version called the B-limp was deemed more satisfactory.

A different derivation is given by Barnes & James in *Shorts Aircraft since 1900*:

"In February 1915 the need for anti-submarine patrol airships became urgent, and the Submarine Scout type was quickly improvised by hanging an obsolete B.E.2c fuselage from a spare Willows envelope; this was done by the R.N.A.S. at Kingsnorth, and on seeing the result for the first time, Horace Short, already noted for his very apt and original vocabulary, named it 'Blimp', adding, 'What else would you call it?'"

An oft-repeated, but false, alternative explanation for the term says that at some time in the early 20th century, the United States military had two classes for airships: Type A-rigid and Type B-limp (hence "blimp"). In fact,

"there was no American 'A-class' of airships as such—all military aircraft, heavier or lighter-than-air were designated with 'A' until the appearance of B-class airships in May 1917. There was an American B airship—but there seems to be no record of any official designation of non-rigids as 'limp'. Further, according to the Oxford Dictionary, the first appearance of the word in print was in 1916, in England, a year before the first B-class airship." ("Etymology of 'Blimp'" by Dr. A. D. Topping, AAHS Journal, Winter 1963.)

The perpetuation of this erroneous explanation is an example of false etymology.

Examples of non-rigid airships

There are several blimps worldwide. Some examples include:

- TC-3 and Tc-7, two US Army Corps non-rigid blimps used for parasite fighter trials during 1923–24.
- SS, SSP, SST, SSZ and NS class blimps, convoy escort blimps used by the UK in World War I.
- G class blimp and L class blimp, US training blimps built by Goodyear during World War II.
- K class blimp and M class blimp, US anti-submarine blimps operated during World War II.
- N class blimp (the "Nan ship"), used for anti-submarine and as a radar early-warning platform during the 1950s.
- Goodyear Blimps, a fleet of blimps operated for advertising purposes and as a television camera platform.
- Skyship 600, a private blimp used by advertising companies
- P-791, an experimental aerostatic/aerodynamic hybrid airship developed by Lockheed-Martin corporation.
- SVAM CA-80, an airship manufactured by the Shanghai Vantage Airship Manufacture Co in China

Chapter 4

Semi-rigid Airship



Explorer Roald Amundsen crossed the North Pole in the semi-rigid airship *Norge* in 1926

Semi-rigid airships are airships with a partial framework. These often consist of a rigid, or occasionally, flexible, keel frame along the long axis under the aerodynamic hull envelope. The partial framework can also be located inside the hull. Semi-rigids were built in quantity from the late 19th century but since the 1930s they fell out of favour until the development of the Zeppelin NT

Principle

More or less integrally attached to the hull are the gondola, engines and sometimes the empennage (tail). The framework has the task of distributing the suspension loads of these attachments and the lifting gas loads evenly throughout the whole hull's surface and may also partially relieve stresses on the hull during manoeuvres. In early airships which relied on nets, fabric bands, or complicated systems of rope rigging to unite the lifting envelope with the other parts of the ship, semi-rigid construction was able to achieve improvements in weight, aerodynamic, and structural performance. The boundary

between semi-rigid and non-rigid airships is vague. Especially with small types, it is unclear whether the structure is merely an extended gondola or a proper structural keel.

As in non-rigid airships, the hull's aerodynamic shape is maintained by an overpressure of the gas inside and light framework at the nose and tail. Changes in volume of the lifting gas is balanced using ballonets (air filled bags). Ballonets also may serve to provide pitch control. For small types the lifting gas is sometimes held in the hull itself, while larger types tend to use separate gas cells which mitigates the consequences of a single gas cell failure and helps reduce the amount of overpressure needed.

History

In the first decade of the twentieth century, semi-rigid airships were considered more suitable for military use because, unlike rigid airships, they could be deflated, stored and transported by land or by sea. Non-rigid airships had a limited lifting capacity due to the strength limitations of the envelope and rigging materials then in use.

An early successful example is the Groß-Basenach design made by Major Hans Groß from the *Luftschiffer-Bataillon Nr. 1* in Berlin, the experimental first ship flying in 1907. It had a rigid keel under the envelope. Four more military airships of this design were built, and often rebuilt, designated M I to M IV, up to 1914.

The most advanced construction of semi-rigid airships between the two World Wars took place in Italy. There, the state-factory *Stabilimento di Costruzioni Aeronautiche* (SCA) constructed several. Umberto Nobile, later General and director, was its most well-known member, and he designed and flew several semi-rigid airships, including the *Norge* and *Italia*, for his overflights of the North Pole, and the *W6 OSOAVIAKhIM*, for the Soviet Union's airship program.

List of other semi-rigid airships

Pre-War and WWI

- "*Bartholomeu de Gusmão*" from Augusto Severo de Albuquerque Maranhão in Brazil in 1894, destroyed in March 1894 by a gust of wind
- "*Pax*" from Augusto Severo de Albuquerque Maranhão in France in 1902, caught fire at its first ascent, killing the pilot
- *Le Jaune* - Built by Lebaudy Frères in France, first flight: 1902-11-13. Lebaudy built many other semi-rigid airships, among them the *Patrie* and the *République*.
- Forlanini F.1 *Leonardo da Vinci*, Italy, 3265 m³, 40 PS, first ascent: 1909; 1910-02-01 damaged beyond repair
- The Groß-Basenach-type airship (5 built for the Prussian army)
- The *Luftschiff von Veeh*, (also *Veeh I* or *Stahlluftschiff*) built by Albert Paul Veeh from Apolda in Düsseldorf in the 1910s
- Siemens-Schuckert I (1911)

- M.1, Italian, first flight 1912, 83 metre long, 17 metre diameter, 2x 250 PS Fiat SA.76-4 engines each with one airscrew, payload: 3800 kg, first with the Army then the Navy, 164 flights, decommissioned 1924
- M.2, *Città di Ferrara*, Italian, first flight 1913, hull identical to the M.1, 83 metre long, 17 metre diameter, 4x125 PS driving two airscrews, payload 3000 kg, speed: 85 km/h, a Navy airship, stationed in Jesi, on 1915-06-08 shot down by an Austrian flying boat
- Forlanini F.2 *Città di Milano*, Italy, 11,500 m³, 2x85 PS, first flight: 1913-04-09, destroyed 1914-04-09 at Como
- SR.1 (M-class) built by Italy for England 1918, 12,500 m³, 83 m long, 17 m Diameter, 9 man crew, internal keel of triangular steel components

1920's and 1930s

- among the Parseval airships designed by August von Parseval in the 1900s-1930s:
 - PL 26 and PL 27
 - Parseval-Naatz designs
- Zodiac V10 was built 1930 for the French Navy
- O-1 (airship) built by SCDA, Italy, and the only true semi-rigid airship to serve with United States Navy.
- RS-1 was the only semi-rigid American military airship (used by the United States Army) built in the USA. Manufacturer: Goodyear, maiden flight: 1926.
- Raab-Katzenstein 27 - maiden flight: 1929-05-04

Nobile's company designed or built the following airships:

- T 34 *Roma*, 33,810 m³, sold to the US, successfully crossed Atlantic and later destroyed after collision with high tension wires
- N 1 *Norge*, 19,000 m³, reached the North Pole in 1926
- N 2 a 7000 m³-airship built in hangars at Augusta (Italy)
- N 3 Sold to Japan as naval Airship No. 6, first flight on 1927-04-06. It was lost in 1927 after encountering a typhoon in the Pacific.
- N 4 *Italia* Flew to Svalbard for Arctic expedition 1928, crashed after third polar flight on return from North Pole
- N 5 was a project for a 55,000 cubic metre keel airship, many times interrupted, eventually abandoned 1928
- Nobile-designed airships of the Russian airship program, such as the Soviet SSSR-V6 OSOAVIAKhIM (1934–1938)

Current developments

As of 2008 the only flying manned semi-rigid airship is the Zeppelin NT. It comprises a single gas cell kept at a slight over-pressure, ballonets to maintain constant volume, and a triangular keel structure internal to the cell.

CL160 "Cargolifter" was an unrealised design of the now liquidated German Cargolifter AG (1996–2003). **Cargolifter Joey** was a small semi-rigid experimental airship produced to test the design

Chapter 5

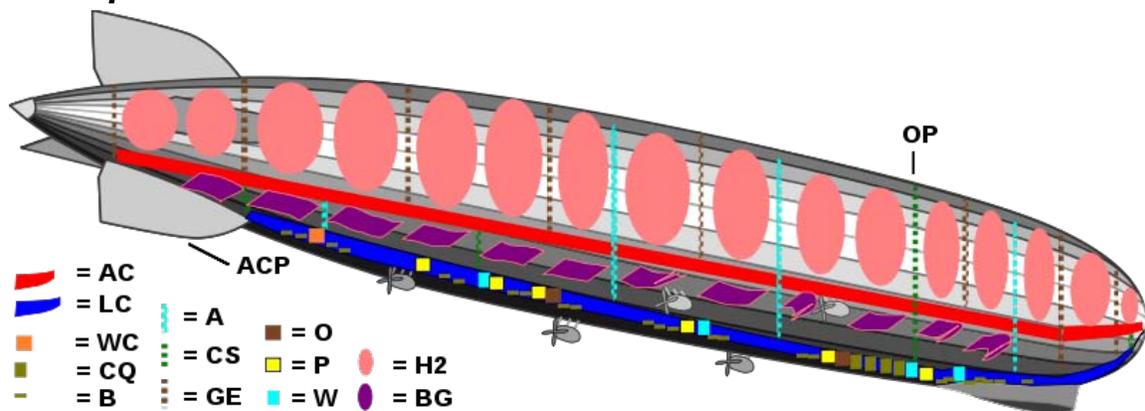
Zeppelin

A **Zeppelin** is a type of rigid airship pioneered by the German Count Ferdinand von Zeppelin in the early 20th century. It was based on designs he had outlined in 1874 and detailed in 1893. His plans were reviewed by committee in 1894 and patented in the United States on 14 March 1899. Given the outstanding success of the Zeppelin design, the term *zeppelin* in casual use came to refer to all rigid airships.

Zeppelins were operated by the Deutsche Luftschiffahrts-AG (DELAG). DELAG, the first commercial airline, served scheduled flights before World War I. After the outbreak of war, the German military made extensive use of Zeppelins as bombers and scouts.

The World War I defeat of Germany in 1918 halted the airship business temporarily. But under the guidance of Hugo Eckener, the deceased Count's successor, civilian zeppelins became popular in the 1920s. Their heyday was during the 1930s when the airships LZ 127 *Graf Zeppelin* and LZ 129 *Hindenburg* operated regular transatlantic flights from Germany to North America and Brazil. The Art Deco spire of the Empire State Building was originally if impractically designed to serve as a dirigible terminal for Zeppelins and other airships to dock. The Hindenburg disaster in 1937, along with political and economic issues, hastened the demise of the Zeppelin.

Principal characteristics



The LZ 127 Graf Zeppelin's main elements labelled. Each of the five engines was housed in its own gondola, the passenger and command gondola was at the front, lower

right. :ACP = Auxiliary control post in the lower vertical stabiliser :red = AC = axial corridor running to the front mooring hub :blue = LC = lower corridor leading to a ladder at the front joining the axial corridor :orange = WC = crew's toilet :beige = CQ = crew's quarters with tables, chairs and berths :beige = B = berths or cargo space :blue stripes = A = air ventilation shaft :green stripes = CS = climbing shaft :brown stripes GE = exhaust gas shaft :brown box = O = oil tanks :yellow box = P = petrol tanks :light blue box = W = water tank :pink cell = H2 = hydrogen lifting gas cell :magenta cell = BG = propulsion Blaugas cell :OP = Observation post on top of hull

The most important feature of Zeppelin's design was a rigid metal alloy skeleton, made of rings and longitudinal girders. The advantage of this design was that the aircraft could be much larger than non-rigid airships (which relied on a slight overpressure within the single gasbag to maintain their shape). This enabled Zeppelins to lift heavier loads and be fitted with more and more powerful engines.

The basic form of the first Zeppelins was a long cylinder with tapered ends and complex multi-plane fins. During World War I, as a result of improvements by the rival firm Schütte-Lanz Luftschiffbau, the design was changed to the more familiar streamlined shape and cruciform fins used by almost all airships ever since. Within this outer envelope, several separate balloons, also known as "cells" or "gasbags", contained the lighter-than-air gas hydrogen or helium. For most rigid airships the gasbags were made of many sheets of goldbeater's skin from the intestines of cows. About 200,000 were needed for a typical World War I Zeppelin. The sheets were joined together and folded into impermeable layers. Non-rigid airships do not have multiple gas cells.

Forward thrust was provided by several internal combustion engines, mounted in nacelles (cowlings) connected to the skeleton. The R101 airship used diesel engines, which were then an untried technology for powering aircraft; they were unsuccessful. The Graf Zeppelin used spark-ignition engines, but fuelled with a natural gas called Blaugas, which was stored uncompressed. It was similar to propane and was named after its inventor rather than its colour (*Blau* is German for "blue"). The advantage of Blaugas for airships was that it weighed more or less the same as air and so as the fuel was used up, it did not affect the trim of the airship.

A Zeppelin was steered by adjusting and selectively reversing engine thrust and by using rudder and elevator fins. The word for these combined control surfaces is empennage.

A comparatively small compartment for passengers and crew was built into the bottom of the frame, but in large Zeppelins this was not the entire habitable space; they often carried crew or cargo internally for aerodynamic reasons.

History

The first generations

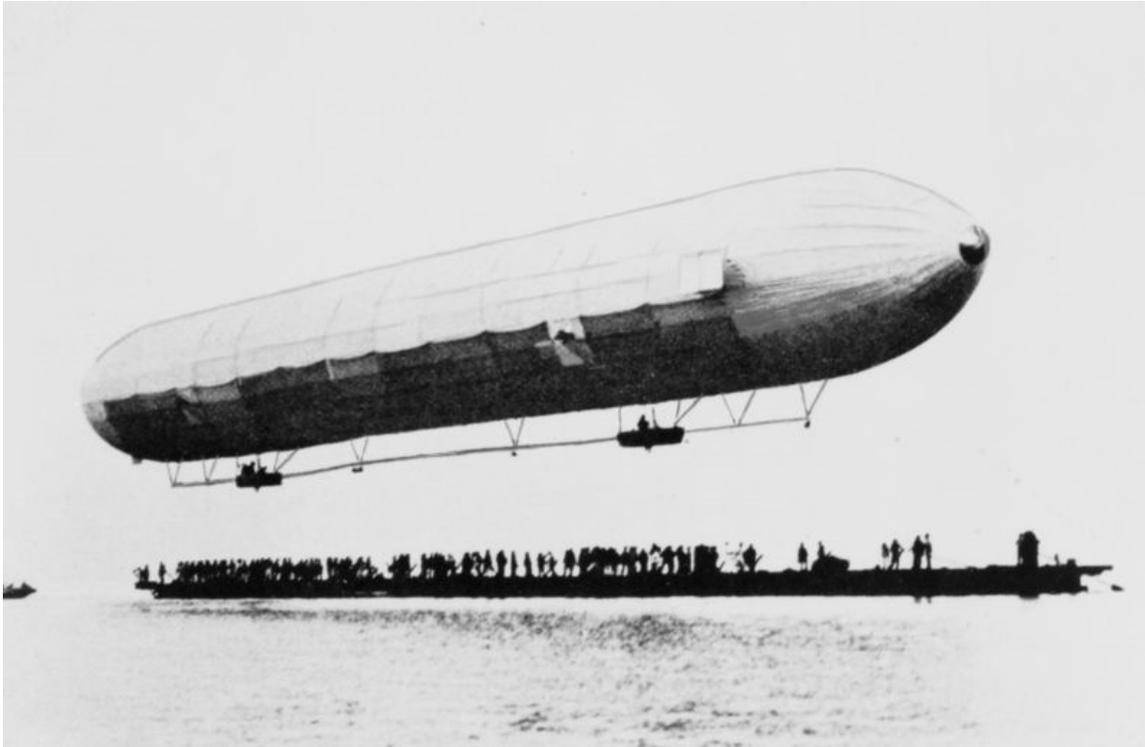
Count Ferdinand von Zeppelin became interested in constructing a "Zeppelin balloon" after the Franco-Prussian War of 1870–1871, where he witnessed the French use balloons to transport mail during the early part of the war. He had also encountered Union Army balloons in 1863, during the American Civil War, where he was a military observer. He first wrote of his dirigible interest in 1874 and began to seriously pursue his project after his early retirement from the military in 1890 at the age of 52.

Convinced of the potential importance of aircraft designs, he started working on various designs shortly after leaving the military in 1891. He had already outlined an overall system in 1874, and detailed designs in 1893 that were reviewed by committee in 1894, and that he patented on 31 August 1895, with Theodor Kober producing the technical plans. After hearing about the rigid airship constructed by David Schwarz and witnessing its trial flight at the Tempelhof Airfield near Berlin on November 3, 1897, he proceeded to buy the patent rights from the widow of the prematurely deceased Schwarz, in order to allow Carl Berg to supply aluminium. However, Schwarz's design was "radically different from Zeppelin's" and in December 1897 Zeppelin admitted the Schwarz design could not be developed. Sean Dooley speculates on the indirect benefits Zeppelin gained from Carl Berg and Schwarz's work. In 1899, Zeppelin started constructing his first airship from his own designs.

One unusual idea, which never saw service, was the ability to connect several independent airship elements like train wagons; indeed, the patent title called the design *Lenkbarer Luftfahrzeug* (steerable air train).

An expert committee to whom he had presented his plans in 1894 showed little interest, so the count was on his own in realizing his idea. In 1898 he founded the *Gesellschaft zur Förderung der Luftschiffahrt* (Society for the promotion of airship flight), contributing more than half of its 800,000 Mark share capital himself. He assigned the technical implementation to the engineer Theodor Kober and later to Ludwig Dürr.

Construction of the first Zeppelin began in 1899 in a floating assembly hall on Lake Constance in the Bay of Manzell, Friedrichshafen. This location was intended to facilitate the difficult launching procedure, as the hall could easily be aligned with the wind. The prototype airship LZ 1 (LZ for *Luftschiff Zeppelin*, or "Airship Zeppelin") had a length of 128 metres (420 ft), was driven by two 14.2 horsepower (10.6 kW) Daimler engines and was controlled in pitch by moving a weight between its two nacelles.



The first ascent of LZ1 over Lake Constance (the Bodensee) in 1900

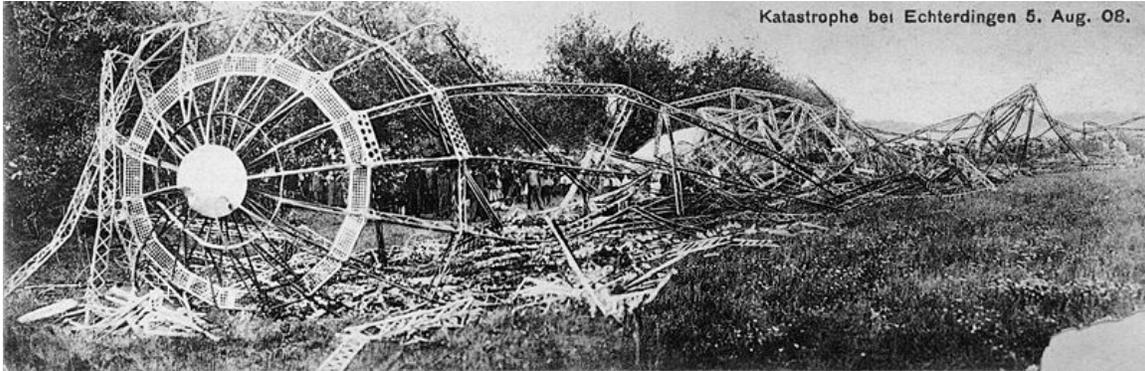
The first Zeppelin flight occurred on 2 July 1900 over Lake Constance (the Bodensee). It lasted only 18 minutes before *LZ 1* was forced to land on the lake after the winding mechanism for the balancing weight failed. After it was placed back in the hangar an apparatus used to suspend it broke. Upon repair, rigid airship technology proved its potential in subsequent flights (the second and third flights were on 17 October 1900 and 24 October 1900) beating the 6 m/s velocity record of the French airship *La France* by 3 m/s. Despite this performance, the shareholders declined to invest more money, and so the company was liquidated, with Count von Zeppelin purchasing the ship and equipment. The Count wished to continue experimenting, but he eventually dismantled the ship in 1901.

It was largely due to support by aviation enthusiasts that von Zeppelin's idea got a second (and third) chance and would be developed into a reasonably reliable technology. Only then could the airships be profitably used for civilian aviation and sold to the military.

Donations, the profits of a special lottery, some public funding, a mortgage of Count von Zeppelin's wife's estate and a 100,000 Mark contribution by Count von Zeppelin himself allowed the construction of *LZ 2*, which took off for the only time on 17 January 1906. After both engines failed, it made a forced landing in the Allgäu mountains, where the anchored ship was subsequently damaged beyond repair by a storm.

Incorporating all usable parts of *LZ 2*, the successor *LZ 3* became the first truly successful Zeppelin, which by 1908 had travelled a total of 4,398 kilometres (2,733 mi)

in the course of 45 flights. The technology then interested the German military, who bought *LZ 3* and redesignated it *Z 1*. She served as a school ship until 1913, when she was decommissioned as obsolescent.



Wreckage of LZ 4. It was destroyed when a storm broke the zeppelin from its mooring, causing it to crash into a tree and catch fire.

The army was also willing to buy *LZ 4*, but requested a demonstration of her ability to make a 24-hour trip. While attempting to fulfill this requirement, the crew of *LZ 4* had to make an intermediate landing in Echterdingen near Stuttgart. During the stop, a storm tore the airship away from its anchorage in the afternoon of 5 August 1908. She crashed into a tree, caught fire, and quickly burnt out. No one was seriously injured, although two technicians repairing the engines escaped only by making a hazardous jump. This accident would have certainly knocked out the Zeppelin project economically had not one of the spectators in the crowd spontaneously initiated a collection of donations, yielding an impressive total of 6,096,555 Mark. This enabled the Count to found the *Luftschiffbau Zeppelin GmbH* (Airship Construction Zeppelin Ltd.) and a Zeppelin Foundation.

Before World War I



A monument near Bad Iburg commemorating the 1910 LZ 7 crash

Before World War I, a total of 21 Zeppelin airships (*LZ 5* to *LZ 25*) were manufactured. In 1909 *LZ 6* became the first Zeppelin used for commercial passenger transport. The world's first airline, the newly founded *DELAG*, bought seven Zeppelins by 1914. The airships were given names in addition to their production numbers, four of which were *LZ 8 Deutschland II* (1911), *LZ 11 Viktoria Luise* (1912), *LZ 13 Hansa* (1912) and *LZ 17 Sachsen* (1913). Seven of the twenty-seven were destroyed in accidents, mostly while being moved into their halls. There were no casualties. One of them was *LZ 7 Deutschland* which made its maiden voyage on 19 June 1910. On 28 June it began a pleasure trip to make Zeppelins more popular. Among those aboard were 19 journalists, two of whom were reporters of well known British newspapers. *LZ 7* crashed in bad weather at Mount Limberg near Bad Iburg in Lower Saxony, its hull getting stuck in trees. The crew then let down a ladder to allow all the passengers to leave the ship. One crew member was slightly injured on leaving the craft.

All together, the several airships traveled approximately 200,000 kilometres (120,000 mi) and transported about 40,000 passengers.

The German Army and Navy purchased 14 Zeppelins, who labeled their aircraft Z 1/2/... and L 1/2/..., respectively. During the war, the Army changed their scheme twice: following *Z XII*, they switched to using LZ numbers, later adding 30 to obscure the total

production. When World War I broke out, the military also took over the three remaining DELAG ships. By this time, it had already decommissioned three other Zeppelins (*LZ 3* "Z 1" included). Five more had been lost in accidents, in which two people had died; a storm forced Navy Zeppelin *LZ 14* or "L 1" down into the North Sea, drowning 14; *LZ 18* or "L 2" burst into flames following an engine explosion, killing the entire crew.

By 1914, state-of-the-art Zeppelins had lengths of 150 to 160 metres (490 to 520 ft) and volumes of 22,000–25,000 m³, enabling them to carry loads of around 9,000 kilograms (20,000 lb). They were typically powered by three Maybach engines of around 400 to 550 horsepower (300 to 410 kW) each, reaching speeds of up to 80 kilometres per hour (50 mph).

During World War I

Bombers and scouts

Zeppelins were used as bombers during World War I. At the beginning of the conflict the German command had high hopes for the craft, as they appeared to have compelling advantages over contemporary aircraft – they were almost as fast, carried many more guns, and had a greater bomb-load and enormously greater range and endurance. However, their great weakness was their vulnerability to incendiary ammunition.

The German airships were operated by both the Army and Navy as two entirely separate divisions. At the beginning of the war the German Army had nine machines (including three DELAG craft requisitioned from civilian ownership), the Navy had four. All the craft were identified with the pre-war prefix *LZ* and a number, to avoid confusion between craft with the same number it is customary to use the prefix *LZ* for Naval craft and just *L* for Army craft (the Schütte-Lanz and Parseval types are sometimes identified with the respective prefixes *SL* and *PL*). Before the war the Army had lost three zeppelins to accidents and the Navy two, both Naval losses occurred in 1913 and accounted for the majority of experienced personnel. There were major differences in doctrine. The Army emphasised bombing from a low level and close support to ground forces, while the Navy had trained for reconnaissance.



The observation car preserved at the Imperial War Museum

At the beginning of the war, Captain Ernst A. Lehmann and Baron Gemmingen, Count Zeppelin's nephew, developed an observation car for use by Zeppelin dirigibles. The car was equipped with a wicker chair, chart table, electric lamp, compass, telephone, and a lightning conductor. With the Zeppelin sometimes within, sometimes above the clouds and unable to see the ground, the observer in the hanging basket would relay orders on navigation and when and which bombs to drop. Defenders could hear the engines but their searchlights and artillery fire could not reach the airship. The LZ26's basket was lowered from the airship on a specially constructed tether 1000 metres long; other airships may have used one approximately 750 metres long. The tether was high-grade steel with a brass core insulated with rubber to act as the telephone cable.

Patrols

The main use of the craft was in reconnaissance over the North Sea and the Baltic, where the endurance of the craft led German warships to a number of Allied vessels. Zeppelin patrolling had priority over any other airship activity. During the war around 1,200 scouting flights were made. The German Navy had some 15 Zeppelins in commission in 1915 and was able to have two or more patrolling continuously at any one time, almost regardless of weather. They prevented British ships from approaching Germany, spotted when and where the British were laying mines and later aided in the destruction of those

mines. Zeppelins would sometimes land on the sea next to a minesweeper, bring aboard an officer and show him the lay of the mines. Before the widespread availability of incendiary ammunition made commerce raiding too risky, they would also land or hover close to a merchant ship suspected of carrying contraband, order all ship's hands to leave in boats, then inspect the ship, and either destroy it or take it back to Germany as a prize.

1915 raids



1917 watercolour by Felix Schwormstädt - translated title: "In the rear engine gondola of a Zeppelin airship during the flight through enemy airspace after a successful attack on England"

The Naval and Army Air Services also directed a number of strategic raids against Britain, leading the way in bombing techniques and also forcing the British to bolster their anti-aircraft defences. The possibility of airship raids was approved by the Kaiser on 19 January 1915, although he excluded London as a target and further demanded that no attacks be made on historic or government buildings or museums. The nighttime raids were intended to target only military sites on the east coast and around the Thames estuary, but after blackouts became widespread, many bombs fell at random on East Anglia.

The first attack was planned for 13 January 1915. Four Zeppelins were launched but bad weather forced all the craft to abandon the raid. The first successful raid was on the night of January 19–20, 1915, in which two Zeppelins, *L.3* and *L.4*, were directed towards the Humber but, diverted by strong winds, dropped twenty-four 50 kg high explosive bombs and ineffective 3 kg incendiaries on Great Yarmouth, Sheringham, King's Lynn and the surrounding villages. In all 4 people were killed and 16 were injured. Monetary damage was estimated at £7,740.

The Kaiser allowed the bombing of London docks from February 1915, but no raids took place on London until May. The first two London raids failed owing to poor weather – *L.8* crashed near Ghent on 26 February and a four airship raid by the Army ran into fog on 17 March and was abandoned. One Army airship was damaged on landing and three more were lost in the next few weeks. With two Navy raids failing due to bad weather on 14 April and 15, it was decided to hold off further action until the more capable P-class Zeppelins were in service. The Army received its P-class Zeppelins first and undertook the first raids. Erich Linnarz commanded *LZ.38* on a raid over Ipswich on April 29–30 and again on May 9–10, attacking Southend; it also attacked Dover and Ramsgate on May 16–17, before returning to bomb Southend on May 26–27. These four raids killed 6 people and injured 6, causing property damage estimated at £17,000. Twice Royal Naval Air Service (RNAS) aircraft tried to intercept *LZ.38* but on both occasions the zeppelin was either able to outclimb the aircraft or was already at too great an altitude for the aircraft to intercept – the BE2 took some fifty minutes to climb to 10,000 feet (3,000 m).



Crater of a Zeppelin bomb in Paris

The Kaiser extended the, so far theoretical, ambit of the London raids in May 1915, allowing attacks anywhere east of the Tower of London. On 31 May Captain Linnarz again commanded *LZ.38* on the first London raid; *LZ.37* was also to be part of the raid but suffered structural damage early on and returned to Namur. Flying from Evere *LZ.38*

crossed the English coast near Margate at 21:42 before turning west once over Southend. London police were warned of an incoming raid around 23:00; a few minutes later small incendiaries began to fall. The devices were a simple metal canister filled with a mix of thermite, tar, and benzol; the exterior was wrapped in tarred rope and a simple fuse was fitted. The first device fell on a house at 16 Alkham Road, others were scattered around residential streets as the Zeppelin flew south over Stoke Newington and then Hoxton. Two incendiaries fell on Shoreditch Empire Music Hall and as *LZ.38* turned southeast explosive bombs were dropped on Spitalfields and a whiskey distillery in Commercial Road. Turning northeast the remaining load was dropped on Stepney, Stratford and finally, around 23:30, five bombs fell on Leytonstone. *LZ.38* then headed back towards Southend, crossing the coast near Foulness. In total some 120 devices were dropped, totalling 3,000 pounds (1,400 kg), including 91 incendiaries, 28 bombs and two 'grenades'. 7 people were killed, 35 were injured; forty-one fires were started, burning out seven properties, damage was priced at £18,596. The RNAS had fifteen aircraft in the air, but only one even sighted the Zeppelin; no ground-based guns fired and no searchlights found the airship. This marked failure by the capital's defences led to the British government implementing strong press restrictions on the reporting of air-raids.

The Naval airships also tried to raid London. *L.10* attempted to reach the city on 4 June, strong winds led the commander to misjudge his position and the bombs were dropped on Gravesend. *L.9* was also diverted by the weather on June 6–7, attacking Hull instead of London and causing considerable damage. On the same night an Army raid of three Zeppelins also failed because of the weather; in an added blow, as the craft returned to Evere they coincided with a pre-planned raid by RNAS aircraft flying from Furnes, France. *LZ.38* was destroyed on the ground while *LZ.37* was intercepted in the air by R. A. J. Warneford in his Morane Parasol, he dropped six 20 pounds (9.1 kg) Hales bombs on the zeppelin which caught fire and crashed into the convent school of St. Amansdsberg. 2 nuns were killed and the entire crew of the Zeppelin also died except for one man. Flight S/L Warneford was awarded the Victoria Cross for his achievement. As a further consequence of the raid both the Army and Navy withdrew from all bases in Belgium; the vulnerability of such sites was now clear.

The short summer nights discouraged further raids for some months, after an ineffective attack by *L.10* on Tyneside on June 15–16. In the same period the remaining Army Zeppelins were re-assigned to the Russian Front. The Navy returned to raids on Britain in August. On August 9–10 four Zeppelins were directed against London; none reached their target and one, *L.12*, was damaged by ground fire while near Dover and ditched into the sea off Zeebrugge. Despite eight attacks by RNAS aircraft the craft was towed into Ostend where it was abandoned and later dismantled. The four-Zeppelin raid was repeated on August 12–13; again only one craft made landfall, *L.10* dropped its bombs on Harwich. A third four-Zeppelin raid again tried to reach London on August 17–18, two turned back with mechanical problems, one bombed Ashford, Kent on 10 August in the belief it was Woolwich, but *L.10* became the first Navy airship to reach London. *L.10* was also misnavigated, mistaking the reservoirs of the Lea Valley for the Thames, and consequently dropping the bombs on Walthamstow and Leytonstone. 10 people were killed, 48 injured, property damage was estimated at £30,750 by the London Fire

Brigade. A number of guns fired at *L.10* and a few aircraft were launched (two Caudron G.3s crashed on landing after their search), but the Zeppelin suffered no damage in the raid (*L.10* was destroyed a little over two weeks later in a thunderstorm over the North Sea; it crashed off Cuxhaven and the whole crew was killed).

Two Army Zeppelins successfully bombed London on September 7–8, *SL.2* dropped bombs on the Isle of Dogs, Deptford, Greenwich and Woolwich. *LZ.74* was forced to drop weight on its approach and scattered 39 bombs over Cheshunt, before heading on to London and dropping devices on Bermondsey, Rotherhithe and New Cross. 18 people were killed and 28 injured, property damage totalled £9,616. Fog and mist prevented any aircraft being launched but a number of anti-aircraft guns fired at *LZ.74* with no effect.

The Navy attempted to follow up the Army's success the following night. Three Zeppelins were directed against London and one against an ironworks at Skinningrove. *L.11* turned back early with engine trouble; *L.14* suffered the same problem while over Norfolk, its bombs were dropped on East Dereham and the Zeppelin returned home. *L.13* reached London, approaching over Golders Green, *Kapitänleutnant* Heinrich Mathy began bombing around 22:40. Amongst the bomb-load was a 300 kilograms (660 lb) device, the largest yet carried by a significant margin. It exploded on Bartholomew Close, did much property damage, gouged a crater eight feet deep and killed two men. The Zeppelin was repeatedly caught by searchlights and all twelve anti-aircraft emplacements in London were active – but every shell exploded too low and the falling shrapnel caused both damage and alarm on the ground. Three aircraft were in the air. None even saw the Zeppelin; one crashed on landing killing the pilot. The raid took 22 lives and injured 87. The wavering line of destruction through central London caused damage estimated at £530,787.

After three more raids were scattered by the weather a five-Zeppelin raid was launched by the Navy on 13 October, the "Theatreland Raid." Arriving over the Norfolk coast around 18:30 the Zeppelins encountered new ground defences installed since the September raid under the guidance of Sir Percy Scott. These new gun sites proved ineffectual. Indeed a 13-pounder near Broxbourne was actually put out of action by three bombs dropped from *L.15*. *L.15* continued on to London and began bombing over Charing Cross, the first bombs striking the Lyceum Theatre and the corner of Exeter and Wellington Streets, killing 17 and injuring 20. Further bombs were dropped on Holborn, as the airship neared Moorgate it was engaged by a new 75 mm gun sited at the Honourable Artillery Company. *L.15* quickly recognised this new threat and dumped ballast, dropped only three more bombs (one landing on Aldgate High Street causing much damage) before departing, having suffered some engine damage from the shells. *L.13* dropped its bombs around Guildford and later near Woolwich. *L.14* dropped bombs on Otterpool Army Camp, killing 14 soldiers and injuring 12, and later bombed Tonbridge and East Croydon, on its return path it almost collided with *L.13* over Bromley. Both the other Zeppelins, *L.16* and *L.11*, were even further off course, *L.16* dropped up to fifty bombs on Hertford and *L.11* scattered a few bombs over Norfolk before heading home. In total 71 people were killed and 128 injured. This was the last

raid of 1915, as bad weather coincided with the new moon in both November and December 1915, and continued into January 1916.

There were twenty raids in 1915, in which 37 tons of bombs were dropped, killing 181 people and injuring 455.

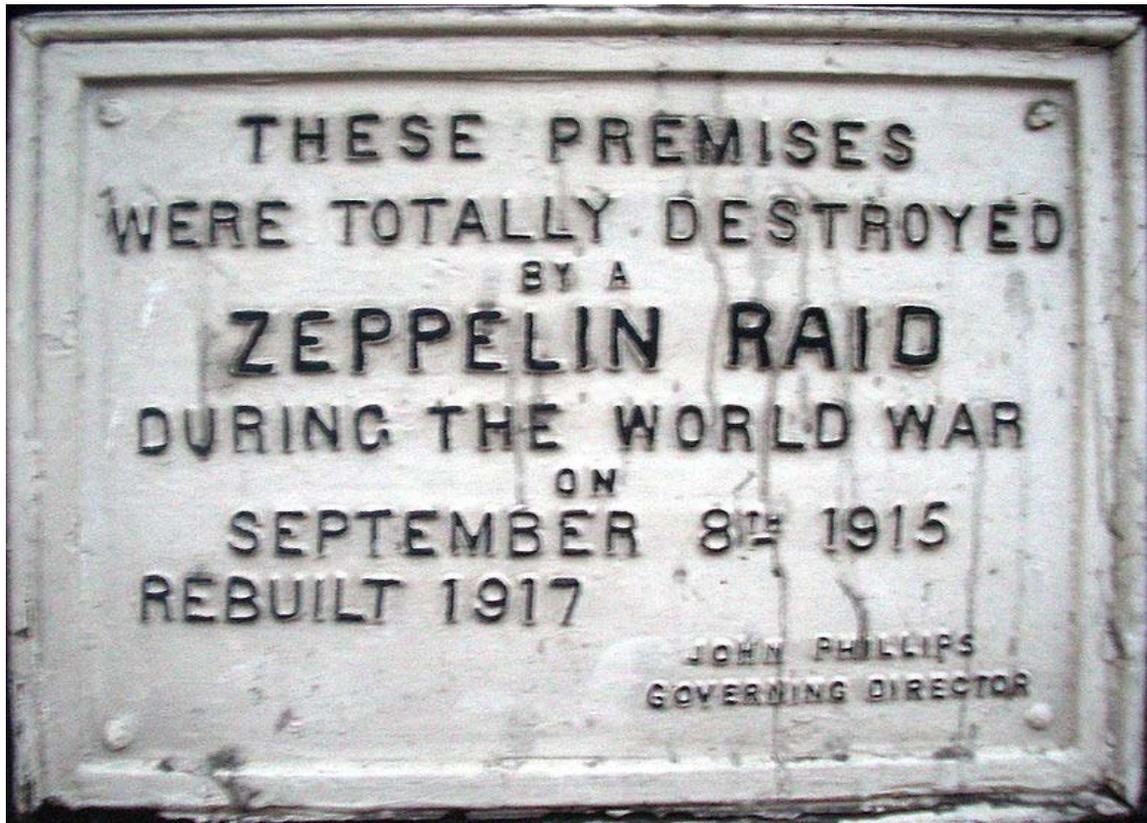
Italy was the only country other than Germany to use lighter-than-air craft for bombing purposes. Italian airships were "semi-rigid dirigibles," they were different to the "rigid" Zeppelins in that they had a keel only, as opposed to the entire frame favoured by the Germans. Their first bombing raid was on 26 May 1915, three days after entering the war, when they crossed the Adriatic to attack Sebenico, which was attacked by a dirigible again the following day. On 8 June 1915, the *Città di Ferrara* took off from an airfield in Pordenone to bomb the Whitehead Torpedo factory and the oil refinery at Fiume, killing one woman in Fiume and injuring several other people, but only causing slight damage. It then turned for home, but a L-48 flying boat from the Austro-Hungarian Naval Air Service shot it down over the Kvarner Gulf near the island of Lussino. This seems to have been the first airship ever shot down in a combat action.

1916 raids

British ground defences were divided between the Royal Navy and the British Army at first, before the Army took full control in February 1916, and a variety of sub 4-inch (less than 102 mm) calibre guns were converted to anti-aircraft use. Searchlights were introduced, initially manned by police, their inexperience led to a number of illuminated clouds being mistaken for attacking airships. In January 1916 a set of two defensive rings was proposed for London with 490 guns and 490 searchlights divided between them, this grand scheme was soon reduced and by mid-1916 there were *nationally* 271 anti-aircraft guns and 258 searchlights.

Aerial defences against Zeppelins were haphazard and divided between the RNAS and the Royal Flying Corps (RFC), with the Navy engaging enemy craft approaching the coast while the RFC took responsibility once the enemy had crossed the coastline. The lack of an interrupter gear in early fighters meant the basic technique of downing them was to drop bombs on them (a technique which was to resurface in World War II). Initially the War Office also believed that the Zeppelins used a layer of inert gas to protect themselves from incendiary bullets and discouraged the use of such ammunition in favour of bombs. The initial trials of incendiary bullets in mid-1915 were unimpressive. Incendiary ammunition also underwent several separate development tracks, the first bullet was designed by John Pomery, but by mid-1916 the RFC also had Brock, Buckingham and 'Sparklet' incendiary cartridges. Ten 'home defence' squadrons were organised from February 1916, with London's defences assigned to No. 19 RAS at Sutton's Farm and Hainault Farm (renamed No. 39 (Home Defence) Squadron in April 1916 who were also allocated North Weald Bassett airfield in August 1916). The actual number of aircraft varied, in February there were only eight squadrons and less than half the number of aircraft expected, by June the number of squadrons were cut to six and

only No. 39 Squadron was at full strength and equipped with newer aircraft – BE12s with interrupter gear and Lewis guns firing a mix of explosive, incendiary and tracer rounds.



A plaque, (located on 61 Farringdon Road, London), commemorating a World War I Zeppelin raid on London.

Raids continued in 1916. In December 1915 new Q-class airships were delivered to both the German Army and Navy as well as additional P-class Zeppelins. The Q-class simply added two more gas cells to the P-class, lengthening the craft to 585 feet (178 m), adding 100,000 cubic feet (2,800 m³) of gas, and improving both ceiling and bomb-load.

The first raid of 1916 was organised by the Navy. Nine Zeppelins were sent to Liverpool over the night of 31 January – 1 February. A combination of poor weather, difficult navigation and mechanical problems scattered the aircraft across the English Midlands and several towns were bombed. A total of 61 people were reported killed and 101 injured by the raid. Despite ground-fog, twenty-two aircraft were launched to find the Zeppelins but none succeeded. In attempting to land in the poor conditions, sixteen aircraft suffered various degrees of damage and two pilots were killed. One airship, the L.19, crashed in the North Sea because of engine failure and damage from Dutch ground-fire; all 16 crew were lost. Further raids were curtailed by an extended period of poor weather and also by the withdrawal of the majority of Naval Zeppelins in an attempt to identify and remove the recurrent mechanical failures. Three P-class Zeppelins did attack Hull on March 5–6, causing significant property damage.

On July 28–29 the first 'Super Zeppelin', the 650 ft M-class *L.31*, appeared in English skies. Powered by six engines and capable of operating at 13,000 ft (4,000 m), (with another 5,000 ft (1,500 m) to its maximum ceiling), while carrying up to four tonnes of bombs. Part of a ten-Zeppelin raid that achieved very little, four returned home early and the rest wandered over a fog-shrouded landscape before giving up. Adverse weather dispersed the next raid on July 30–31 and again on August 2–3. On August 8–9 two M-class Zeppelins were part of a nine craft raid that did much damage to Hull. The sixth successful London raid was on August 24–25, thirteen Navy Zeppelins were launched and Heinrich Mathy's *L.31* reached London, flying above low cloud, thirty-six bombs were dropped in ten minutes on West Ferry Road, Deptford Dry Dock, the station at Norway Street and homes in Greenwich, Eltham and Plumstead. 9 people were killed, 40 injured and £130,000 of damage was caused. *L.31* suffered no damage in the attack but several weeks of repair-work was needed following a rough landing.

The biggest raid so far was launched on September 2–3, twelve Navy craft and four Zeppelins from the Army took part. A combination of rain and snowstorms scattered the craft while they were still over the North Sea. None of the Naval craft reached London. Only the Army's *LZ.98* and the newly commissioned *SL.11* achieved their objective. *SL.11* came in over Foulness with the intention of looping around and attacking the capital from the north-west. The craft dropped a few bombs over London Colney and South Mimms. At about 01:50 it was picked up by a searchlight over Hornsey and subjected to an intense but ineffective barrage. *SL.11* was lost in cloud over Wood Green but rediscovered by the searchlights at Waltham Abbey as it bombed Ponders End. At around 02:15 one of the three aircraft in the sky that night finally came into range – a BE2c piloted by Lt. William Leefe Robinson flying from Suttons Farm. Robinson fired three drums of ammunition from his Lewis gun, one on each of three passes. After emptying the third drum the airship began burning from the stern and was quickly enveloped in flames, it fell to the ground near Cuffley. There were no survivors. Four Naval Zeppelins which had regrouped over Hertfordshire saw the fate of *SL.11* and quietly slipped away. For the first Zeppelin downed on British soil and the first 'night fighter' victory Leefe Robinson received the Victoria Cross. The pieces of *SL.11* were gathered up and sold by the Red Cross to raise money for wounded soldiers.

The loss of *SL.11* ended the Army's interest in raids on Britain. The Navy remained aggressive and a twelve Zeppelin raid was launched on September 23–24, eight older craft bombing targets in the Midlands and four M-class Zeppelins (*L.30*, *L.31*, *L.32*, and *L.33*) attacking London. *L.30* did not even cross the coast, dropping its bombs at sea.

L.31 approached London from the south, dropped a few bombs on Kenley and Mitcham and was picked up by a number of searchlights. Forty-one devices were then dropped in rapid succession over Streatham, killing 7 and wounding 27. More bombs were dropped on Brixton before crossing the river and dropping ten bombs on Leyton, killing another 8 people and injuring 30. *L.31* then headed home. Also coming in from the south was *L.32*, running late due to engine problems, it dropped a few bombs on Sevenoaks and Swanley before crossing Purfleet at about 01:00. The Zeppelin then came under anti-aircraft fire as it dropped bombs on Aveley and South Ockendon. Shortly thereafter, at 01:10, a BE2c

piloted by 2nd Lieutenant Frederick Sowrey engaged *L.32*. He fired three drums of incendiaries and succeeded in starting a blaze which quickly covered the entire craft. The Zeppelin crashed to earth at Snail's Hall Farm, Great Burstead, the entire crew was killed although some, including the commander *Oberleutenant-zur-See* Werner Peterson, chose to jump rather than burn.

L.33 dropped a few incendiaries over Upminster before losing its way and making a number of turns, heading over London and dropping bombs on Bromley at around midnight. As the bombs began to explode, the Zeppelin was hit by an anti-aircraft shell fired from the guns at either Beckton, Wanstead, or Victoria Park despite being at 13,000 feet (4,000 m). Dropping bombs now to shed weight, a large number fell on homes in Botolph Road and Bow Road. As the craft headed towards Chelmsford it continued to lose height, coming under fire at Kelvedon Hatch and briefly exchanging fire with a BE2c. Despite the efforts of the crew, *L.33* was forced to the ground at around 01:15 in a field close to New Hall Cottages, Little Wigborough. The Zeppelin was set alight and the crew headed south before being arrested at Peldon by the police. A close inspection of the wreckage enabled the British to understand where their own rigid airship designs had been deficient. Furthermore, one 250 hp (190 kW) engine recovered from the wreck subsequently substituted for two (of four) 180 hp (130 kW) engines on a Vickers-built machine, the hitherto underpowered *R.9*.

The next raid came on 1 October 1916. Eleven Zeppelins were launched at targets in the Midlands and at London. As usual weather played a major role and only *L.31* under the experienced Heinrich Mathy, on his fifteenth raid, reached London. Approaching from Suffolk, *L.31* was picked up by the searchlights at Kelvedon Hatch around 21:45; turning away, the craft detoured over Harlow, Stevenage and Hatfield before cutting its engines and drifting with the wind over Hertford. As the airship neared Cheshunt at about 23:20 the engines were restarted and the craft was quickly picked up by six searchlights. Three aircraft of No. 39 Squadron were in the air and closed on *L.31*. Mathy ordered the dumping of bombs, (fifty fell on Cheshunt), in order to gain altitude. A BE2c piloted by 2nd lieutenant Wulstan Tempest engaged the Zeppelin around 23:50; three bursts were sufficient to set *L.31* ablaze and it crashed near Potters Bar with all nineteen crew dying – although again many decided to jump rather than burn (including Mathy, whose body was found near the wreckage, embedded some four inches in the softened earth). Tempest had had to dive out of the way of the stricken craft and, over-wrought, had crashed on landing, suffering minor injuries.

With the next raid on November 27–28, the Zeppelins avoided London for targets in the Midlands. But again the aircraft and the incendiary bullet proved lethal – *L.34* was shot down over the mouth of the Tees and *L.21* was attacked by two aircraft and crashed into the sea off Lowestoft. There were no further raids in 1916 although the Navy lost three more craft, all on 28 December – *SL.12* was destroyed at Ahlhorn by strong winds after sustaining damage on a poor landing, and at Tondern *L.24* crashed into the shed while landing and the resulting fire destroyed both *L.24* and the adjacent *L.17*.

There were 23 airship raids in 1916 in which 125 tons of ordnance were dropped, killing 293 people and injuring 691.

1917 raids

Anti-aircraft defences were becoming tougher and new Zeppelins were introduced with an increased operating altitude of 16,500 feet (5,000 m) and a maximum ceiling of 21,000 feet (6,400 m). The first S-class Zeppelins entered service in February 1917. They were largely a modification of the M-class, sacrificing weight for improved altitude. The surviving M-class Zeppelins were converted to S-class, notably by reducing the number of engines from six to five. To avoid searchlights, they flew above the clouds whenever possible, lowering an observer through them in a *Spähkorb* (observation gondola) to direct the bombing. The improved safety was counteracted by the extra strain on the airship crews who became more prone to altitude sickness and exposure to extreme cold and high altitude winds.

The first raid of 1917 did not occur until March 16–17 and the five high flying Zeppelins encountered very strong winds and none reached their targets. This experience was repeated on May 23–24. Two days later twenty-one Gotha bombers attempted a daylight raid on London. They were halted by heavy cloud but the effort led the Kaiser to announce that airship raids on London were past; under pressure he later relented to allow Zeppelin attacks to continue under "favourable circumstances".

On June 16–17 another Zeppelin raid was attempted, only two out of six Zeppelins reached England in the face of strong winds. *L.42* bombed Ramsgate, hitting a munitions store. The month-old *L.48*, commanded by *Korvettenkapitän* Franz Eichler, but with *Korvettenkapitän* Viktor Schutze also on board, suffered from both engine problems and compass malfunction. It was forced to drop to 13,000 feet (4,000 m) where it was caught by four aircraft and destroyed, crashing near Theberton, Suffolk. This was the last Zeppelin raid to explicitly target London.

After ineffectual raids on the Midlands and other targets in the north of England on August 21–22 and September 24–25 the last major Zeppelin raid was launched on October 19–20 with thirteen airships headed for Sheffield, Manchester and Liverpool. Two Zeppelins did not launch and the remainder quickly found themselves badly affected by powerful headwinds which made navigation extremely difficult. *L.45* was trying to reach Sheffield, instead it dropped bombs on Northampton and London. Undetected and with no warning its bombs did great damage – the first few fell on Hendon Aerodrome but the rest, dropped at random from 16,000 feet (4,900 m), struck in Piccadilly, Camberwell and Hither Green. *L.45* then reduced altitude to try and escape the winds but was forced back into the higher air currents by a BE2e. The craft then had mechanical failure in three engines and was pushed by the wind out over France, eventually coming down near Sisteron; it was set ablaze and the crew surrendered. *L.44*, *L.49*, and *L.50* were also lost to anti-aircraft fire or the weather over France. *L.55* was badly damaged on landing and later scrapped.

There were no more raids in 1917, although the airships were not abandoned but refitted with new, more powerful engines.

1918 raids

There were only four raids in 1918, all against targets in the Midlands and northern England. The final raid on 5 August 1918 resulted in the loss of *L.70* and the death of its entire crew under the command of *Frigattenkapitän* Peter Strasser, head of the Imperial German Naval Airship Service and the *Führer der Luftschiffe*. Crossing the North Sea during daylight, the airship was intercepted by a Royal Air Force DH.4 biplane piloted by Major Egbert Cadbury, and shot down in flames.

On 5 January 1918 a fire at Ahlhorn destroyed four of the specialised double sheds along with four Zeppelins and one Schütte-Lanz. The British had begun bombing the Zeppelin production lines and their sheds in Cologne and Düsseldorf as early as September/October 1914. This was followed by the Cuxhaven Raid, which included Zeppelins as its targets, on Christmas Day 1914. In July 1918, the Tondern Raid conducted by the RNAS, destroyed two Zeppelins in their sheds.

Supply

In 1917, the German High Command made an attempt to deliver much needed supplies using a dirigible to Lettow-Vorbeck's East African Campaign in German East Africa. *L.59* Zeppelin travelled over 6,400 km (4,000 miles) in 95 hours, but in the end failed to deliver the supplies. The craft had been purpose-built and was intended to be broken up and used on arrival. It never attempted the mission again, and was converted into a bomber.

Technological progress

Strategic issues aside, Zeppelin technology improved considerably as a result of the increasing demands of warfare.

The pre-war M-class designs were quickly enlarged, first to the 530 feet (160 m) long duralumin P-class, which increased gas capacity from 880,000 cubic feet (25,000 m³) to 1,130,000 cubic feet (32,000 m³), introduced a fully enclosed gondola, and extra engines. these modifications added 2,000 feet (610 m) to the maximum ceiling, over 10 mph to the top speed, and greatly increased crew comfort and hence endurance. Twenty-two P-class craft were ordered and the first, *LZ.38*, was delivered to the Army on 3 April 1915.

In 1916 the Zeppelin Company, having spawned several dependencies around Germany with shipyards closer to the fronts than Friedrichshafen, delivered airships of around 200 m (660 ft) in length (some even more) and with volumes of 56,000–69,000 m³. These M-class dirigibles could carry loads of 3–4 tons of bombs and reach speeds of up to 100 to 130 kilometres per hour (62 to 81 mph) using six Maybach engines of 260 hp (190 kW) each.

To avoid enemy defences such as British aircraft, guns and searchlights, Zeppelins became capable of much higher altitudes (up to 7,600 metres (24,900 ft)) and they also proved capable of long-range flights. For example, *LZ.104 L.59*, based in Yambol, Bulgaria, was sent to reinforce troops in German East Africa (today Tanzania) in November 1917. The ship did not arrive in time and had to return following reports of a German defeat by British troops, but it had traveled 6,757 kilometres (4,199 mi) in 95 hours and thus had broken a long-distance flight record.

A considerable, frequently overlooked, contribution to these technological advancements originated from Zeppelin's only serious competitor, the Mannheim-based Schütte-Lanz airship construction company. While their dirigibles never became comparably successful, Professor Schütte's more scientific approach to airship design led to a number of important innovations copied, over time, by the Zeppelin company. These included the streamlined hull shape, the simple yet functional cruciform fins (replacing the more complicated box-like arrangements of older Zeppelins), individual direct-drive engine cars, anti-aircraft machine-gun positions, and gas ventilation shafts which removed excess hydrogen.

End of the war

The German defeat in the war also marked the end of German military dirigibles, as the victorious Allies demanded a complete disarmament of German air forces and delivery of the remaining airships as reparations. Specifically, the Treaty of Versailles contained the following articles dealing explicitly with dirigibles:

Article 198

The armed forces of Germany must not include any military or naval air forces. [...] No dirigible shall be kept.

Article 202

On the coming into force of the present Treaty, all military and naval aeronautical material [...] must be delivered to the Governments of the Principal Allied and Associated Powers. [...] In particular, this material will include all items under the following heads which are or have been in use or were designed for warlike purposes:

[...]

- *Dirigibles able to take to the air, being manufactured, repaired or assembled.*
- *Plant for the manufacture of hydrogen.*
- *Dirigible sheds and shelters of every kind for aircraft.*

Pending their delivery, dirigibles will, at the expense of Germany, be maintained inflated with hydrogen; the plant for the manufacture of hydrogen, as well as the sheds for dirigibles may at the discretion of the said Powers, be left to Germany until the time when the dirigibles are handed over. [...]

On 23 June 1919, a week before the treaty was signed, many war Zeppelin crews destroyed their airships in their halls in order to avoid delivery. In doing so, they followed the example of the German fleet which had been scuttled two days before in Scapa Flow. The remaining dirigibles were transferred to France, Italy, Britain, and Belgium in 1920.

A total of 84 Zeppelins were built during the war. Over 60 were lost, roughly evenly divided between accident and enemy action. 51 raids had been undertaken, in which 5,806 bombs were dropped, killing 557 people and injuring 1,358 while causing damaged estimated at £1.5 million. It has been argued the raids were effective far beyond material damage in diverting and hampering wartime production, one estimate was that the due to the 1915-16 raids "one sixth of the total normal output of munitions was entirely lost," and diverting 12 fighter squadrons and over 10,000 personnel to air defences.

After World War I

Renaissance

Count von Zeppelin had died in 1917, before the end of the war. Dr. Hugo Eckener, a man who had long envisioned dirigibles as vessels of peace rather than of war, took command of the Zeppelin business. With the Treaty of Versailles having knocked out their competitor Schütte-Lanz, the Zeppelin company and DELAG hoped to resume civilian flights quickly. In fact, despite considerable difficulties, they completed two small Zeppelins: *LZ 120 Bodensee*, which first flew in August 1919 and in the following two years actually transported some 4,000 passengers; and *LZ 121 Nordstern*, which was envisaged being used on a regular route to Stockholm.

However, in 1921, the Allied Powers demanded these two Zeppelins be delivered as war reparations, as compensation for the dirigibles destroyed by their crews in 1919. Further Zeppelin projects could not be realized, partly because of Allied interdiction. This temporarily halted German Zeppelin aviation.

Eckener and his co-workers refused to give up and kept looking for investors and a way to circumvent Allied restrictions. Their opportunity came in 1924. The United States had started to experiment with rigid airships, constructing one of their own, the ZR-1 USS *Shenandoah* (see below), and ordering another from the UK when the British *R38 (ZR-2)* was cancelled. However, the *R38* (based on the Zeppelin L70, ordered as *ZR-2*) broke apart and exploded during a test flight above the Humber on 23 August 1921, killing 44 crewmen.

Under these circumstances, Eckener managed to acquire an order for the next American dirigible. Of course, Germany had to pay the costs for this airship itself, as they were calculated against the war reparation accounts, but for the Zeppelin company, this was secondary. So engineer Dr. Dürr designed *LZ 126*, and using all the expertise accumulated over the years, the company finally achieved its best Zeppelin so far, which took off for a first test flight on 27 August 1924.



ZR-3 USS *Los Angeles* over southern Manhattan



The USS *Los Angeles*, a US Navy zeppelin built by the Zeppelin Company



Zeppelin docking tower in Recife, Brazil – the only one preserved in its original form

No insurance company was willing to issue a policy for the delivery to Lakehurst, which, of course, involved a transatlantic flight. Eckener, however, was so confident of the new ship that he was ready to risk the entire business capital, and on 12 October 07:30 local time, the Zeppelin took off for the US under his command. His faith was not disappointed, and the ship completed her 8,050 kilometres (5,000 mi) voyage without any difficulties in 81 hours and two minutes. American crowds enthusiastically celebrated the arrival, and President Calvin Coolidge invited Dr. Eckener and his crew to the White House, calling the new Zeppelin an "angel of peace".

Under its new designation the ZR-3 USS *Los Angeles* (the former *LZ 126*), became the most successful American airship. She operated reliably for eight years until she was retired in 1932 for economic reasons. She was dismantled in August 1940.

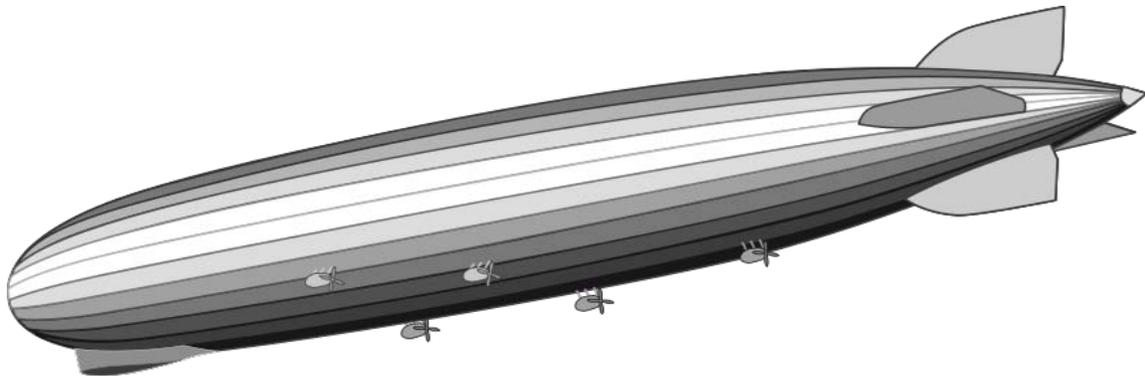
Golden age

With the delivery of *LZ 126*, the Zeppelin company had reasserted its lead in rigid airship construction, but it was not yet quite back in business. Acquiring the necessary funds for the next project proved a problem in the difficult economic situation of post-World-War-I Germany, and it took Eckener two years of lobbying and publicity work to secure the realization of *LZ 127*.

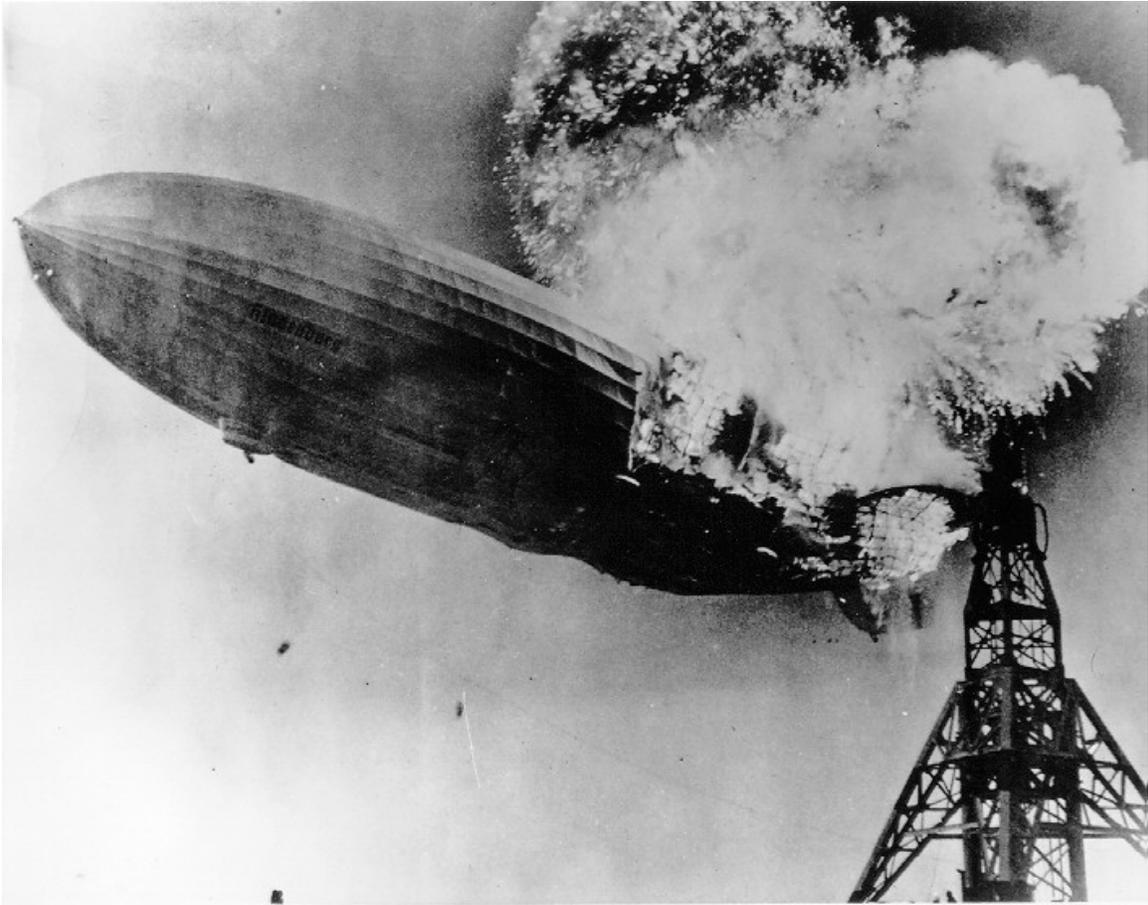
Another two years passed before 18 September 1928, when the new dirigible, christened *Graf Zeppelin* in honor of the Count, flew for the first time. With a total length of 236.6 metres (776 ft) and a volume of 105,000 m³, she was the largest dirigible yet.

Eckener's initial concept was to use *Graf Zeppelin* for experimental and demonstration purposes to prepare the way for regular airship traveling, by carrying passengers and mail to cover the costs. In October 1928 the first long-range voyage brought her to Lakehurst, where Eckener and his crew were once more welcomed enthusiastically with confetti parades in New York and another invitation to the White House. *Graf Zeppelin* toured Germany and visited Italy, Palestine, and Spain. A second trip to the United States was aborted in France due to engine failure in May 1929.

In August 1929 *LZ 127* departed for another daring enterprise: a circumnavigation of the globe. The growing popularity of the "giant of the air" made it easy for Eckener to find sponsors. One of these was the American press tycoon William Randolph Hearst, who requested the tour officially start in Lakehurst. As with the October 1928 flight to New York, Hearst had placed a reporter, Grace Marguerite Hay Drummond-Hay, on board who therefore became the first woman to circumnavigate the globe by air. From there, *Graf Zeppelin* flew to Friedrichshafen, then Tokyo, Los Angeles, and back to Lakehurst, in 21 days 5 hours and 31 minutes. Including the initial and final trips Friedrichshafen–Lakehurst and back, the dirigible traveled 49,618 kilometres (30,831 mi).



Airship LZ 127 "Graf Zeppelin"



The Hindenburg on fire in 1937

In the following year, *Graf Zeppelin* undertook a number of trips around Europe, and following a successful tour to Recife, Brazil in May 1930, it was decided to open the first regular transatlantic airship line. This line operated between Frankfurt and Recife in 68 hours, and later, between Frankfurt and Rio de Janeiro, with a stop in Recife. Despite the beginning of the Great Depression and growing competition from fixed-wing aircraft, *LZ 127* would transport an increasing volume of passengers and mail across the ocean every year until 1936. The ship pursued another spectacular venue in July 1931 with a research trip to the Arctic. This had already been a dream of Count von Zeppelin twenty years earlier, which could, however, not be realized at the time due to the outbreak of war.

Eckener intended to supplement the successful craft by another, similar Zeppelin, projected as *LZ 128*. However the disastrous accident of the British passenger airship *R101* on 5 October 1930 led the Zeppelin company to reconsider the safety of hydrogen-filled vessels, and the design was abandoned in favour of a new project. *LZ 129* would advance Zeppelin technology considerably, and was intended to be filled with inert helium.

Hindenburg, end of an era

Following 1933, the establishment of the Third Reich in Germany began to overshadow the Zeppelin business. The Nazis were not interested in Eckener's ideals of peacefully connecting people; they also knew very well dirigibles would be useless in combat and thus chose to focus on heavier-than-air technology.

On the other hand, they were eager to exploit the popularity of the airships for propaganda. As Eckener refused to cooperate, Hermann Göring, the German Air minister, formed a new airline in 1935, the *Deutsche Zeppelin-Reederei* (DZR), which took over operation of airship flights. Zeppelins would now display the Nazi swastika on their fins and occasionally tour Germany to play march music and propaganda speeches for the people from the air.

On 4 March 1936, LZ 129 *Hindenburg* (named after former President of Germany Paul von Hindenburg by Eckener) made her first flight. The *Hindenburg* was the largest airship ever built. However, in the new political situation, Eckener had not obtained the helium to inflate it due to a military embargo; only the United States possessed the rare gas in usable quantities. So, in what ultimately proved a fatal decision, the *Hindenburg* was filled with flammable hydrogen. Apart from the propaganda missions, LZ 129 began to serve the transatlantic lines together with *Graf Zeppelin*.

On 6 May 1937, while landing in Lakehurst after a transatlantic flight, in front of thousands of spectators, the tail of the ship caught fire, and within seconds, the *Hindenburg* burst into flames, killing 35 of the 97 people on board and one member of the ground crew. The actual cause of the fire has not been definitively determined; it is likely that a combination of leaking hydrogen from a torn gas bag, the vibrations caused by a swift rotation for a quicker landing to have started static electricity in the duralumin alloy skeleton and a flammable outer coating similar to rocket fuel accounted for the fact that the fire spread from its starting point in the tail to engulf the entire airship so rapidly (34 seconds).

Whatever caused the disaster, the end of the dirigible era was due to politics and the upcoming war, not the wreck itself, though it surely led to some public misgivings. Despite everything, there remained a list of 400 people who still wanted to fly as Zeppelin passengers and had paid for the trip. Their money was refunded in 1940.

Graf Zeppelin completed more flights, though not for overseas commercial flights to the U.S., and was retired one month after the *Hindenburg* wreck and turned into a museum. Dr. Eckener kept trying to obtain helium gas for *Hindenburg*'s sister ship, *Graf Zeppelin II*, but due to political bias against the airship's commercial use by the Nazi leadership, coupled with the inability to obtain helium gas in sufficient quantities due to an embargo by the United States, his efforts were in vain. The intended new flagship Zeppelin was completed in 1938 and, inflated with hydrogen, made some test flights (the first on 14 September), but never carried passengers. Another project, LZ 131, designed to be even

larger than *Hindenburg* and *Graf Zeppelin II*, never progressed beyond the production of some single skeleton rings.

The career of *Graf Zeppelin II* was not over. She was assigned to the *Luftwaffe* and performed about 30 test flights prior to the beginning of World War II. Most of those test flights were carried out near the Polish border, first in the Sudeten mountains region of Silesia, then in the Baltic Sea region. During one such flight *LZ 130* crossed the Polish border near the Hel Peninsula, where she was intercepted by a Polish Lublin R-XIII aircraft from Puck naval airbase and forced to leave Polish airspace. During this time, *LZ 130* was used as an electronic scouting airframe and was equipped with various telemetric equipment. From May to August 1939, she performed flights near the coastline of Great Britain in an attempt to determine whether the 100-metre towers erected from Portsmouth to Scapa Flow were used for aircraft radio localization. Photography, radio wave interception, magnetic and radio frequency analysis were unable to detect operational British Chain Home radar due to searching in the wrong frequency range. The frequencies searched were too high, an assumption based on the Germans' own radar systems. The mistaken conclusion was the British towers were not connected with radar operations, but formed a network of naval radio communications and rescue.

After the German invasion of Poland started the Second World War on 1 September, the *Luftwaffe* ordered *LZ 127* and *LZ 130* moved to a large Zeppelin hangar in Frankfurt, where the skeleton of *LZ 131* was also located. In March 1940 Göring ordered the destruction of the remaining airships and the Duralumin fed into the Nazi war industry. In May a fire broke out in the Zeppelin facility, which destroyed most of the remaining parts. The rest of the parts and materials were soon scrapped, with almost no trace of the German "giants of the air" remaining by the end of the year.

Non-German Zeppelin-type airships



U.S. Navy Zeppelin ZRS-5 "*USS Macon*" over Moffett Field in 1933

Airships using the Zeppelin construction method are sometimes referred to as zeppelins even if they had no connection with the Zeppelin business. Several airships of this kind were built in the USA and Britain in the 1920s and 1930s, mostly imitating original Zeppelin designs derived from crashed or captured German World War I airships.

The British *R33* and *R34*, for example, were near identical copies of the German *L-33*, which crashed virtually intact in Essex on 24 September 1916. Despite being almost three years out of date by the time they were launched in 1919, these sister ships were two of the most successful in British service. On 2 July 1919, *R34* began the first return crossing of the Atlantic by aircraft. She landed at Mineola, Long Island on 6 July 1919 after 108 hours in the air. The return crossing commenced on 8 July because of concerns about mooring the ship in the open, and took 75 hours. Their success led to proposals for a fleet of airships to link far-flung British colonies, but unfortunately post-war economic conditions resulted in most airships being scrapped and trained personnel dispersed, until design and construction of the *R-100* and *R-101* commenced in 1925.

Another example was the first American-built rigid dirigible *ZR-1 USS Shenandoah*, launched in September, 1923, while the *USS Los Angeles (ZR-3)* was still under construction. The ship was christened on 20 August in Lakehurst, New Jersey and was the first to be inflated with helium, which was still so rare at the time that *Shenandoah* contained most of the world's reserves. When *Los Angeles* was delivered, she was at first

filled with helium borrowed from ZR-1. Other airships were the USS Akron (ZRS-4) and the USS Macon (ZRS-5).

Chapter 6

Rotorcraft



An AS332 helicopter from the Hong Kong Government Flying Service conducts a water bomb demonstration at the Hong Kong International Airport

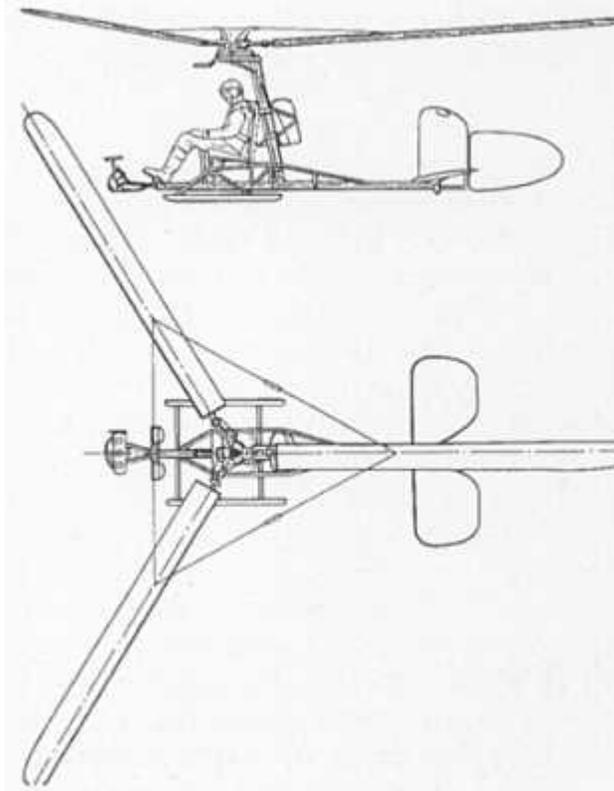
A **rotorcraft** or **rotary wing aircraft** is a heavier-than-air flying machine that uses lift generated by wings, called rotor blades, that revolve around a mast. Several rotor blades mounted to a single mast are referred to as a rotor. The International Civil Aviation Organization (ICAO) defines a rotorcraft as "supported in flight by the reactions of the air on one or more rotors". Rotorcraft generally include those aircraft where one or more rotors are required to provide lift throughout the entire flight, such as helicopters, autogyros, and gyrodynes. Compound rotorcraft may also include additional thrust engines or propellers and static lifting surfaces.



Mil Mi-26, the world's largest production helicopter

Rotorcraft, or rotary-wing aircraft, use a spinning rotor with aerofoil section blades (a *rotary wing*) to provide lift. Types include helicopters, autogyros and various hybrids such as gyrodynes and compound rotorcraft.

Helicopters have powered rotors. The rotor is driven (directly or indirectly) by an engine and pushes air downwards to create lift. By tilting the rotor forwards, the downwards flow is tilted backwards, producing thrust for forward flight.



US-Recognition Manual (very likely copy of German drawing)

Autogyros or *gyroplanes* have unpowered rotors, with a separate power plant to provide thrust. The rotor is tilted backwards. As the autogyro moves forward, air blows upwards across the rotor, making it spin.(cf. Autorotation) This spinning dramatically increases the speed of airflow over the rotor, to provide lift. Juan de la Cierva (a Spanish civil engineer) used the product name *autogiro*, and Bensen used *gyrocopter*. *Rotor kites*, such as the Focke Achgelis Fa 330 are unpowered autogyros, which must be towed by a tether to give them forward ground speed or else be tether-anchored to a static anchor in a high-wind situation for kited flight.

Gyrodynes are a form of helicopter, where forward thrust is obtained from a separate propulsion device rather than from tilting the rotor. The definition of a 'gyrodyne' has changed over the years, sometimes including equivalent autogyro designs. The *Heliplane* is a similar idea.

Compound rotorcraft have wings which provide some or all of the lift in forward flight. Compound helicopters and compound autogyros have been built, and some forms of gyroplane may be referred to as compound gyroplanes. They are nowadays classified as *powered lift* types and not as rotorcraft. *Tiltrotor* aircraft (such as the V-22 Osprey) have their rotors horizontal for vertical flight, and pivot the rotors vertically like a propeller for forward flight. The *Coleopter* had a cylindrical wing forming a duct around the rotor. On the ground it sat on its tail, and took off and landed vertically like a helicopter. The whole

aircraft would then have tilted forward to fly as a propeller-driven fixed-wing aircraft using the duct as a wing (though this transition was never achieved in practice.)

Some rotorcraft have reaction-powered rotors with gas jets at the tips, but most have one or more lift rotors powered from engine-driven shafts.

Classes of rotorcraft

Helicopter

A helicopter is a rotorcraft whose rotors are driven by the engine(s) throughout the flight, to allow the helicopter to take off vertically, hover, fly forwards, backwards and laterally, as well as to land vertically. Helicopters have several different configurations of one or more main rotors.

Helicopters with one driven main rotor require some sort of antitorque device such as a tail rotor, fantail, or NOTAR, except some rare examples of helicopters using tip jet propulsion which generates almost no torque.

Autogyro



A German-registered autogyro

An autogyro (sometimes called gyrocopter, gyroplane, or rotaplane) utilizes an unpowered rotor driven by aerodynamic forces in a state of autorotation to develop lift, and an engine-powered propeller, similar to that of a fixed-wing aircraft, to provide thrust. While similar to a helicopter rotor in appearance, the autogyro's rotor must have air flowing up and through the rotor disk in order to generate rotation. Early autogyros resembled the fixed-wing aircraft of the day, with wings and a front-mounted engine and propeller in a tractor configuration to pull the aircraft through the air. Late-model autogyros feature a rear-mounted engine and propeller in a pusher configuration.

Gyrodyne



Fairey Rotodyne prototype

The rotor of a gyrodyne is normally driven by its engine for takeoff and landing—hovering like a helicopter—with anti-torque and propulsion for forward flight provided by one or more propellers mounted on short or stub wings. As power is increased to the propeller, less power is required by the rotor to provide forward thrust resulting in reduced pitch angles and rotor blade flapping. At cruise speeds with most or all of the thrust being provided by the propellers, the rotor receives power only sufficient to the amount needed to overcome the profile drag and maintain lift. The effect is a rotorcraft operating in a more efficient manner than the freewheeling rotor of an autogyro in autorotation, and minimizing the adverse effects of retreating blade stall of helicopters at higher airspeeds.

Rotor configuration

Number of blades

A rotary wing is characterised by the number of blades. Typically this is between two and six.

Number of rotors

A rotorcraft may have one or more rotors. Various rotor configurations have been used:

- Single rotor - One rotor disc.
- Twin rotor - Two rotor discs. These usually rotate in opposite directions, so that no tail rotor or other yaw stabiliser is needed:
 - Tandem - One in front of the other.
 - Transverse - Side by side.
 - Coaxial - One rotor disc above the other, with concentric drive shafts.
- More than two rotor discs: in the case of one at each corner giving a quadrotor.

Intermeshing

Where a rotorcraft has two or more rotors, the rotor discs may be arranged to pass through each other. The blades of the two rotors must be synchronised so that they **intermesh** without touching each other.

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. The arrangement allows the helicopter to function without the need for a tail rotor. This configuration is sometimes referred to as a **synchropter**.



Flettner Fl 282 "Kolibri" was an early ancestor of helicopters with intermeshing rotors



HH-43 Huskie with intermeshing rotors

The arrangement was developed in Germany by Anton Flettner for a small anti-submarine warfare helicopter, the Flettner Fl 265 and later the Flettner Fl 282 Kolibri. During the Cold War the American Kaman Aircraft company produced the HH-43 Huskie, for USAF firefighting purposes. One example of the Kaman K-225 experimental synchropter was fitted with a small turboshaft engine in late 1951, becoming the world's first gas turbine powered helicopter of any type. Intermeshing rotored helicopters have high stability and powerful lifting capability. The latest Kaman K-MAX model is a dedicated sky crane design used for construction work.

Chapter 7

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'Amécourt in 1861, which originates from the Greek *helix/helik-* (ἕλιξ) = "twisted, curved" 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*.



70PH WPB

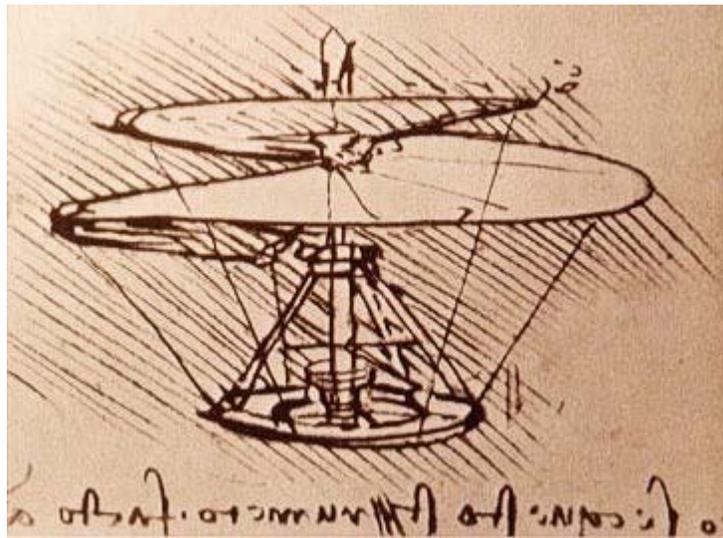




History

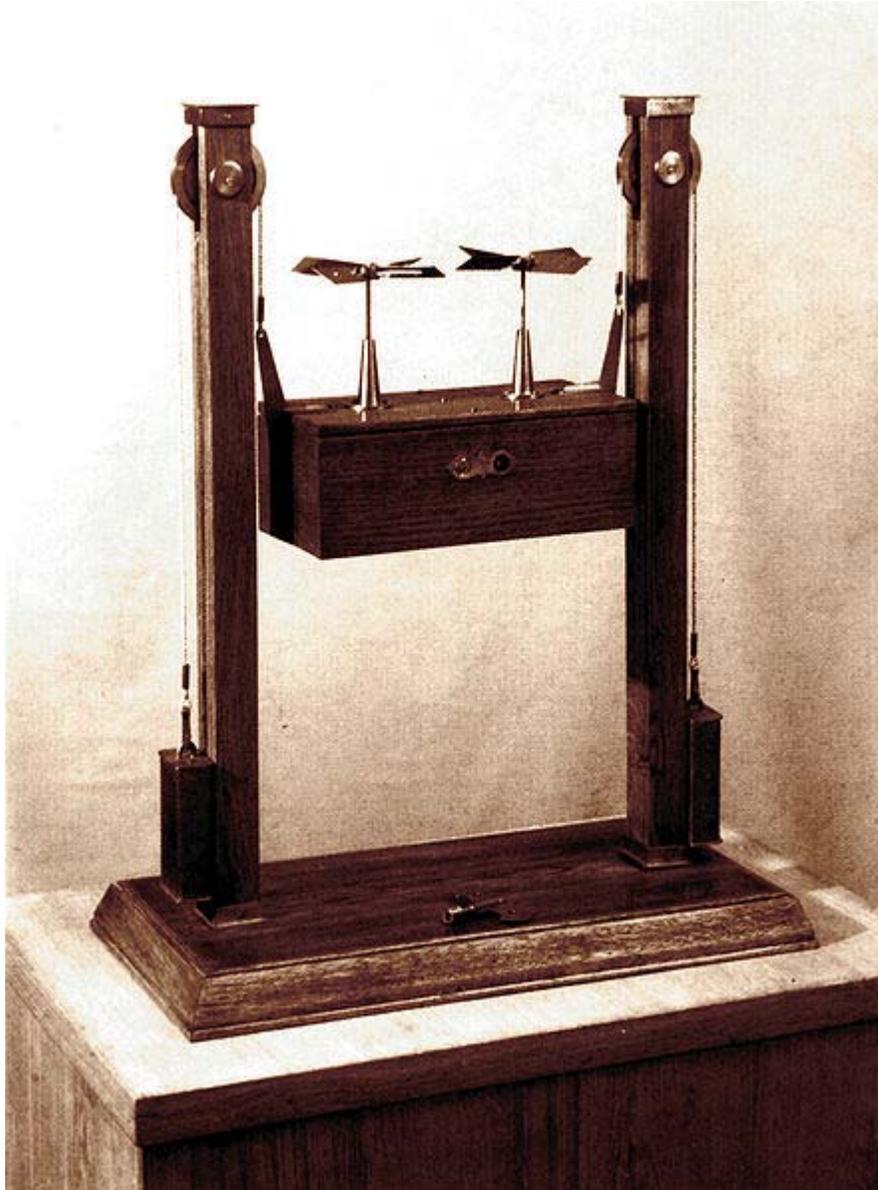
The earliest references for vertical flight have come from China. Since around 400 BC, Chinese children have played with bamboo flying toys, and the 4th-century AD Daoist book *Baopuzi* (抱朴子 "Master who Embraces Simplicity") reportedly describes some of the ideas inherent to rotary wing aircraft:

“ 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 gun cotton, 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

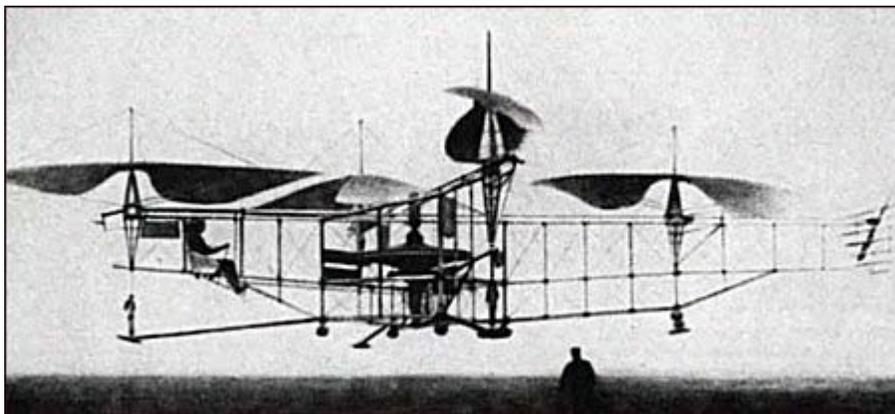
In 1906, two French brothers, Jacques and Louis Breguet, began experimenting with airfoils for helicopters and in 1907, those experiments resulted in the *Gyroplane No. 1*. Although there is some uncertainty about the dates, sometime between 14 August and 29 September 1907, the Gyroplane No. 1 lifted 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 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).



AH-1 on display





Apache

In the Soviet Union, Boris N. Yuriev and Alexei M. Cheremukhin, two aeronautical engineers working at the *Tsentralniy Aerogidrodinamicheskii Institut* (TsAGI, Russian: Центральный аэрогидродинамический институт (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 Monosoupe 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 showed the design's simplicity and ease of use. 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 stand as 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 British Westland WAH-64 Apache attack helicopter



HH-65 Dolphin demonstrating hoist rescue capability



A Sikorsky S-76C+ air ambulance being loaded by firefighters



RAF Westland Sea King for rescue of people in distress around the United Kingdom

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.

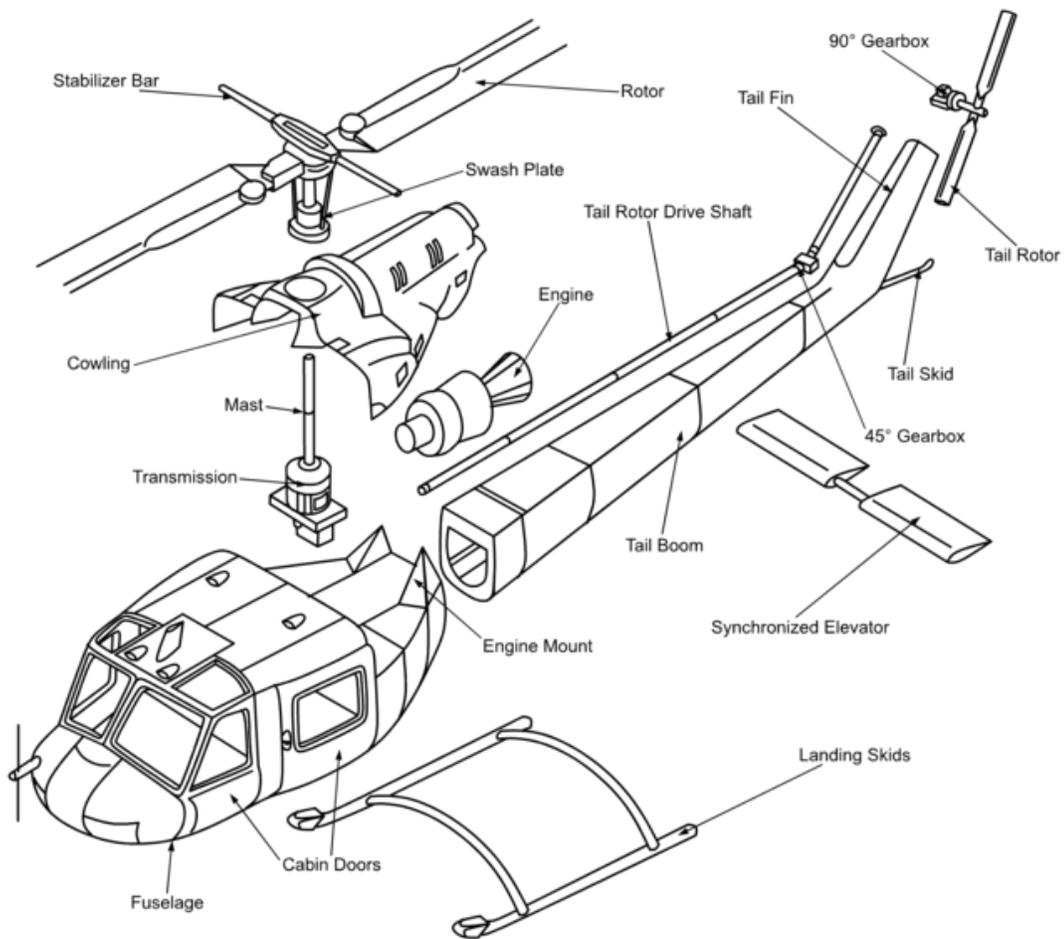
Military forces use attack helicopters to conduct aerial attacks on ground targets. Such helicopters are mounted with missile launchers and miniguns. Transport helicopters are used to ferry troops and supplies where the lack of an airstrip would make transport via fixed-wing aircraft impossible. The 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

Rotor system

The rotor system, or more simply *rotor*, is the rotating part of a helicopter which generates lift. A rotor system may be mounted horizontally as main rotors are, providing lift vertically, or it may be mounted vertically, such as a tail rotor, to provide lift horizontally as thrust to counteract torque effect. The rotor consists of a mast, hub and rotor blades.



A semirigid rotor system

The *mast* is a cylindrical metal shaft which extends upwards 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 by a number of different methods. 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 types.

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.



Aramco Helicopter



ArmyMi-17s



As355 811hs



As355cockpit krj

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, 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 in a narrow range of RPM. The throttle controls the power produced by the engine, which is connected to the rotor by a fixed ratio 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.



Helicopter hovering over boat in rescue exercise

- **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. 1986: 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.

World records

Record type	Record	Helicopter	Pilot(s)	Date	Location	Note
Speed	400.87 km/h	Westland Lynx	John Trevor Egginton	11 August 1986	England	
Distance without landing	3,561.55 km	Hughes YOHO-6A	Robert G. Ferry (USA)	6 April 1966	USA	
Around-the-world speed	136.7 km/h	Agusta A109S Grand	Scott Kasprovicz (USA)	August 2008	From and to New York via Europe, Russia, Alaska, Canada	No in-flight refueling

Highest level flight altitude	11,010 m	Sikorsky CH-54 Tarhe	James K. Church	4 Nov 1971	USA
Altitude with 40-tonne payload	2,255 m	Mil V-12	Vasily Kolochenko et al	6 Aug 1969	Soviet Union

Chapter 8

Helicopter Rotor



The rotor head of a Sikorsky S-92

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



Bundesarchiv, Bild 102-12440
Foto: o.Ang. | Oktober 1931

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

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. An example of this type of rotor system is the Agusta AW109 series of aircraft; later models have switched from a traditional bearing system to an Elastomeric bearing based system.

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 semirigid rotor can also be referred to as a teetering or seesaw rotor. This system is normally composed of two blades which meet just under a common flapping, or teetering hinge at the rotor shaft. This allows the blades to flap together in opposite motions like a seesaw. This underslinging of the blades below the teetering hinge, combined with an adequate dihedral or coning angle on the blades, minimizes variations in the radius of each blade's center of mass from the axis of rotation as the rotor turns, which in turn reduces the stress on the blades from lead and lag forces caused by coriolis effect. Secondary flapping hinges may also be provided to provide sufficient flexibility to minimize bouncing. Feathering is accomplished by the feathering hinge at the blade root, which allows changes to the pitch angle of the blade. The most widespread implementations of this system are the Bell 206/OH-58 series of aircraft and the Robinson R22 series.

Stabilizer bar

A number of engineers, among them Arthur M. Young in the U.S., and Dieter Schlüter in Germany, found that flight stability for helicopters could be achieved with a stabilizer bar or flybar. The stabilizer bar has weighted ends which cause the bar to stay relatively

stable in the plane of rotation. Through mechanical linkages, the stable rotation of the bar is mixed with the swashplate movement so that internal (steering) as well as external (wind) forces on the rotor are dampened. This eases the workload of the pilot to maintain control of the aircraft. Stanley Hiller arrived at a similar method to improve stability by adding short stubby airfoils, or paddles, at each end; However, Hiller's "Rotomatic" system was also used to deliver cyclic control inputs to the main rotor as a sort of control rotor, the paddles provided the added stability by dampening the effects of external forces on the rotor.

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

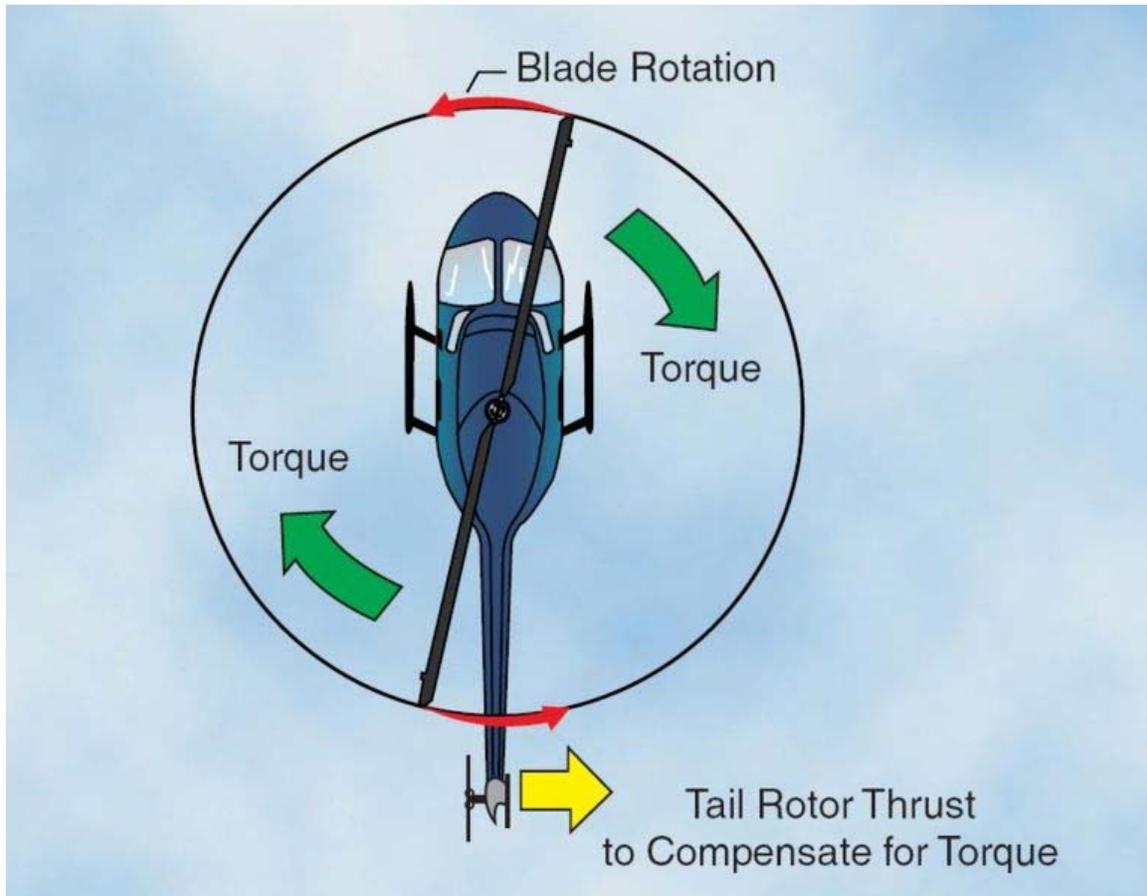
Combination

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. Examples include Bell 407, Bell 430, Eurocopter A-Star(AS350)/Twin-Star(AS355) and arguably MD Helicopters (Formerly Hughes 500), this model has externally mounted lead-lag dampeners {which makes it more of a hingeless fully articulated hub}.

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



Tail rotor of an SA 330 Puma

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

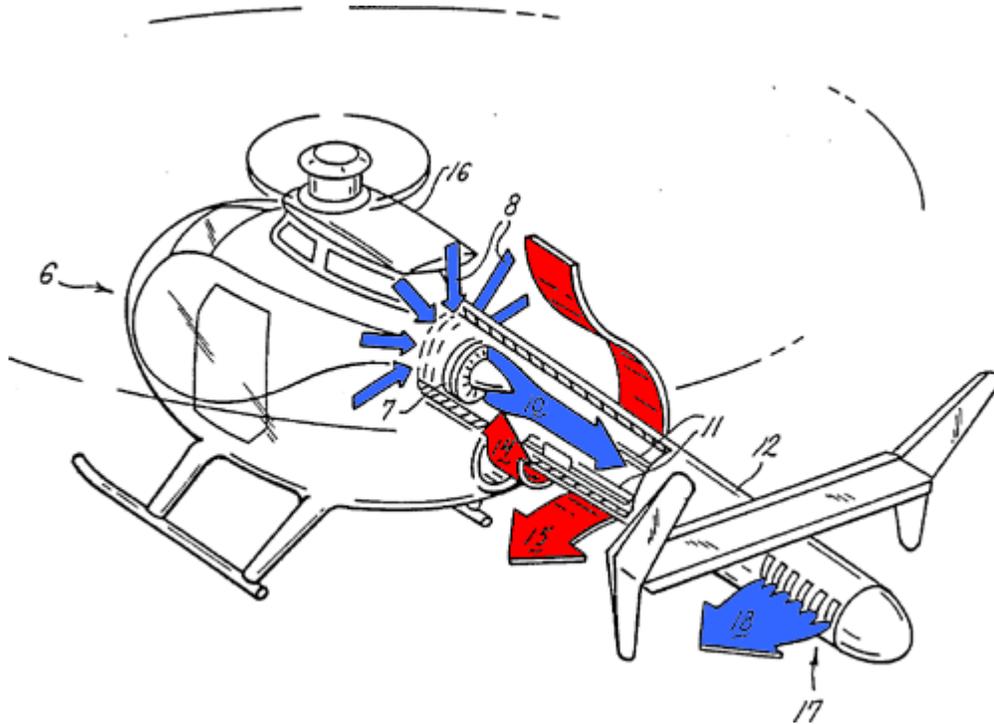


Diagram showing the movement of air through the NOTAR system

NOTAR, an acronym for *NO Tail Rotor*, 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)

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 of the Russian Air Force, with coaxial rotors

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.

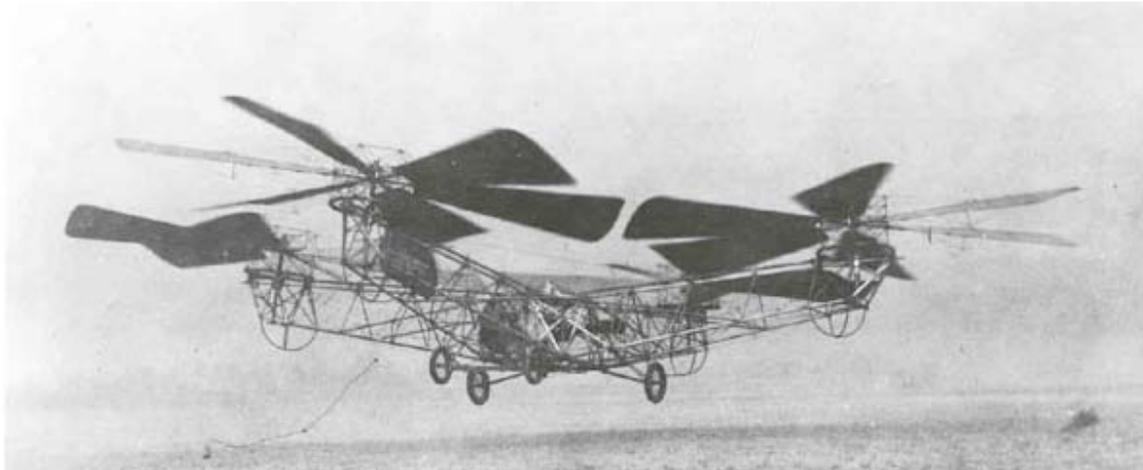
Transverse



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 the Bell XV-15 and the newer Bell-Boeing V-22 Osprey.

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 9

Specific Types of Helicopters

Agusta A.101

A.101



A.101 helicopter in 1964. Third from right is Count Domenico Agusta and fourth is Filippo Zappata

Role	Transport helicopter
Manufacturer	Agusta
Designed by	Filippo Zappata
First flight	19 October 1964
Number built	1

The **Agusta A.101** (originally designated **AZ.101**) was a large prototype transport helicopter developed in Italy during the course of the 1960s. Despite prospective orders from the Italian armed forces, no buyers emerged and the project was abandoned in 1971.

The A.101 was of conventional, single-rotor configuration with tricycle undercarriage and powered by triple turboshaft engines. The fuselage was provided with a rear loading ramp and two large sliding troop doors.

The final stage in the A.101's development was to stretch the fuselage by 3 m (10 ft) and upgrade the engines to the more powerful General Electric T58. This resulted in a marked improvement in performance, but in the end, the Italian government opted for variants of the SH-3 Sea King, licence-built by Agusta instead of their own design.

The single prototype is preserved at the Museo Agusta at Cascina Costa.

Specifications (AZ.101G configuration)

General characteristics

- **Crew:** two pilots
- **Capacity:** 35 passengers *or* 5,000 kg (11,000 lb) cargo *or* 18 stretchers and 5 attendants
- **Length:** 20.2 m (66 ft 3 in)
- **Main rotor diameter:** 19.8 m (64 ft 11 in)
- **Height:** 6.6 m (12 ft 8 in)
- **Main rotor area:** 308 m² (3,314 ft²)
- **Empty weight:** 6,400 kg (14,000 lb)
- **Gross weight:** 11,500 kg (25,000 lb)
- **Powerplant:** 3 × Rolls-Royce Gnome H1400 turboshafts, 1,030 kW (1,380 hp) each

Performance

- **Maximum speed:** 225 km/h (140 mph)
- **Range:** 383 km (239 miles)
- **Service ceiling:** 3,950 m (13,000 ft)
- **Rate of climb:** 12.3 m/s (2,420 ft/min)

Agusta A.103

A.103



Role	Light helicopter
Manufacturer	Agusta
First flight	1959

The **Agusta A.103** was an Italian prototype single-seat light helicopter flown in October 1959. The pilot was enclosed by a perspex bubble with the engine at the rear and the tail rotor carried on an enclosed boom.

Specifications

General characteristics

- **Crew:** one, pilot
- **Length:** 6.13 m (20 ft 1 in)
- **Main rotor diameter:** 7.4 m (24 ft 3 in)
- **Height:** 2.3 m (7 ft 7 in)
- **Main rotor area:** 43 m² (463 ft²)
- **Gross weight:** 460 kg (1,000 lb)
- **Powerplant:** 1 × Agusta GA.70, 64 kW (85 hp)

Performance

- **Maximum speed:** 150 km/h (90 mph)
- **Range:** 450 km (280 miles)
- **Service ceiling:** 2,000 m (6,600 ft)

Bell 427

Bell 427



Croatian Bell-427 landing

Role	Multipurpose utility helicopter
National origin	United States Canada
Manufacturer	Bell Helicopter Samsung Aerospace Industries (later part of Korea Aerospace Industries)
First flight	11 December 1997
Introduced	2000
Status	Active service
Developed from	Bell 407
Variants	Bell 429

The **Bell Model 427** is a twin engine, multirole, light utility helicopter designed and manufactured by Bell Helicopter and Samsung Aerospace Industries. Its design is based on Bell 407. It was replaced in production by the lengthened Bell 429.

Development

Bell has tried several incarnations of a twin version of its successful Bell 206 series, including the stillborn *Bell 400* and *440* of the mid 1980s, and the limited production *Bell 206LT TwinRanger* of the early 1990s. Bell's original concept for a replacement for the 206LT TwinRanger was the *Bell 407T*, a relatively straightforward twin engine development of the *Bell 407* with two Allison 250-C22B engines. However, Bell concluded that the payload/range performance of the 407T would not be sufficient.

The company began development of a new light twin, in partnership with South Korea's Samsung Aerospace Industries. In February 1996, Bell announced its **Model 427** at the Heli Expo in Dallas. The Bell 427 was the company's first aircraft designed entirely on computer. The Bell 427 first flew on December 11, 1997. Canadian certification was awarded on November 19, 1999, followed by US certification in January 2000, and US FAA dual pilot IFR certification in May 2000. Bell builds the 427's flight dynamics systems at Fort Worth, Texas, while final assembly is performed at Bell's Mirabel, Quebec facility. The 427's fuselage and tailboom are built by Samsung (later part of KAI) at its Sachon plant in South Korea. The first customer deliveries occurred in January 2000.

In 2004, Bell offered a redesigned 427 version, the **Bell 427i**, which was developed in partnership with South Korea's Korea Aerospace Industries and Japan's Mitsui Bussan Aerospace. The agreement gave KAI the development and production responsibility for the fuselage, cabin wiring, and fuel system. Mitsui Bussan became a financial backer. The 427i included a newer glass cockpit and navigation systems to allow single pilot flying under Instrument flight rules. The design had a fuselage lengthened 1 ft 2 in (0.36 m), a more powerful engine version and transmission, and increased takeoff weight. However, the program was canceled and focus shifted to the improved Bell 429. In February 2005, the existing 80 orders for the 427i were converted to the 429. On January 24, 2008, Bell announced plans to officially discontinue its 427 line after current order commitments are fulfilled in 2010.

Design



Bell-427 cockpit

The Bell 427 is powered by two Pratt & Whitney Canada PW207D turboshaft engines with FADEC. Like the Bell 407, the 427 uses a 4-blade main rotor system with a rigid, composite rotor hub and a 2-blade tail rotor.

The Bell 427's cabin is 13 in (33 cm) longer than the 407, and is largely of composite construction. The cabin lacks the roof beam which obstructs the cabin on the 206/206L/407, and has an optional sliding main cabin door.

The 427 offers 8-place seating including pilot in a 2+3+3 arrangement. Alternate layouts include four in the main cabin in a club configuration, or two stretchers and two medical attendants for medical evacuation duties.

Operators

-  Argentina
 - Entre Rios Police
-  Bahrain
 - Bahrain Public Security Force
-  Czech Republic
 - Czech HEMS - Alfa Helicopter

Specifications (Bell 427)

General characteristics

- **Crew:** 2 pilots
- **Capacity:** 7 passengers
- **Length:** 37 ft 6 in (11.42 m)
- **Rotor diameter:** 37 ft 0 in (11.28 m)
- **Height:** 10 ft 6 in (3.20 m)
- **Disc area:** 1,075 ft² (99.9 m²)
- **Empty weight:** 3,881 lb (1,760 kg)
- **Useful load:** 2,960 lb (1,340 kg; for internal load)
- **Max takeoff weight:** 6,550 lb (2,970 kg)
- **Powerplant:** 2× Pratt & Whitney Canada PW207D turboshaft, 710 hp (529 kW) each

Performance

- **Maximum speed:** 140 knots (161 mph, 259 km/h)
- **Cruise speed:** 138 knots (159 mph, 256 km/h)
- **Range:** 394 nmi (342 mi, 730 km)
- **Service ceiling:** 10,000 ft (3,048 m)
- **Rate of climb:** 2,000 ft/min (10.16 m/s)

Bell H-12

R-12 (Model 48)



YR-12B / YH-12B

Role	five/eight seat utility helicopter
Manufacturer	Bell Helicopter
First flight	1946
Status	pre-series
Primary user	United States Air Force
Number built	13
Developed from	Bell 47

The **Bell R-12 (Model 48)** was an American 1940s military utility helicopter built by Bell Helicopter company.

Development

During 1946 Bell Helicopter began development of a new helicopter, much larger, than Model 47. It was partly based upon its construction, first of all, a rotor system, and was basically a scaled-up version of Model 47. The basic variant was civilian Model 42, but the United States Air Force got interested in the design and ordered development of its military variant, **Model 48**. Two prototypes were ordered as the **XR-12**. It was powered by a 540 hp Pratt & Whitney R-1340-AN-1 radial engine and seated five. A production batch of 34 helicopters was ordered, under a designation **R-12A**, but it was cancelled afterwards. Another enlarged prototype (the **XR-12B**, Model 48A) with seats for eight and a more powerful 600 hp R-1340-55 engine was also ordered. It was followed by ten pre-series helicopters **YR-12B**, with a redesigned cabin, with a glazed nose, instead of car-like nose. With a change in designation system the helicopter was re-designated the

H-12. Test were not satisfactory, there were initially problems with a main rotor, and none were ordered.

Variants

XR-12

prototype, redesignated XH-12, two built.

R-12A

production version, 34 on order cancelled.

XR-12B

prototype with more powerful engine and increased seating, re-designated XH-12B, one built.

YR-12B

as XR-12B but with R-1340-55 engines, re-designated YH-12B, ten built.

XH-12

XR-12 re-designated in 1947.

XH-12B

XR-12B re-designated in 1947.

YH-12B

YR-12B re-designated in 1947.

Operators

 United States

- United States Air Force

Specifications (XR-12B)

General characteristics

- **Crew:** 2
- **Capacity:** 8
- **Length:** ft (12.06 m)(fuselage)
- **Rotor diameter:** 47 ft 6 in (14.48 m)
- **Height:** ft (3.43 m)
- **Disc area:** 1,772 ft² (164.62 m²)
- **Loaded weight:** lb (2854 kg)
- **Max takeoff weight:** 6,286 lb (2851 kg)
- **Powerplant:** 1× Pratt & Whitney R-1340-55 Wasp radial piston, 600 hp (447 kW)
- **Propellers:** 1 rotor, 1 per engine

Performance

- **Maximum speed:** 105 mph (169 km/h)
- **Cruise speed:** 90 mph (145 km/h)
- **Range:** 300 miles (483 km)
- **Service ceiling:** ft (3960 m)
- **Rate of climb:** ft/s (2.28 m/s)

Chapter 10

Autogyro



An **autogyro** (in Spanish **autogiro**), also known as **gyroplane**, **gyrocopter**, or **rotaplane**, is a type of rotorcraft which uses an unpowered rotor in autorotation to develop lift, and an engine-powered propeller, similar to that of a fixed-wing aircraft, to provide thrust. While similar to a helicopter rotor in appearance, the autogyro's rotor must have air flowing through the rotor disc in order to generate rotation. Invented by the Spanish engineer Juan de la Cierva to create an aircraft that could safely fly at slow speeds, the autogyro was first flown on 9 January 1923, at Cuatro Vientos Airfield in Madrid. De la Cierva's aircraft resembled the fixed-wing aircraft of the day, with a front-mounted engine and propeller in a tractor configuration to pull the aircraft through the air. Late-model autogyros patterned after Dr. Igor Bensen's designs feature a rear-mounted engine and propeller in a pusher configuration. The term *Autogiro* was a trademark of the Cierva Autogiro Company, and the term *Gyrocopter* was used by E. Burke Wilford who developed the Reiseler Kreiser feathering rotor equipped gyroplane in the first half of the twentieth century. The latter term was later adopted as a trademark by Bensen Aircraft.

Configuration

An autogyro is characterized by a free-spinning rotor that turns because of passage of air upward through the rotor. The vertical component of the total aerodynamic reaction of the rotor gives lift for the vehicle, and sustains the autogyro in the air. A separate propeller provides forward thrust, and can be placed in a tractor configuration with the engine and propeller at the front of the fuselage (e.g., Cierva), or pusher configuration with the engine and propeller at the rear of the fuselage (e.g., Bensen).

Whereas a helicopter works by forcing the rotor blades through the air, pushing air downwards, the autogyro rotor blade generates lift in the same way as a glider's wing by changing the angle of the air as it moves upwards and backwards relative to the rotor blade. The free-spinning blades turn by autorotation; the rotor blades are angled so that they not only give lift, but the angle of the blades causes the lift to accelerate the blades' rotation rate, until the rotor turns at a stable speed with the drag and thrust forces in balance.



The rotor head, pre-rotator shaft and Subaru engine configuration on a VPM M-16 autogyro

Pitch control of the autogyro is by tilting the rotor fore and aft; roll control is by tilting the rotor laterally (side to side). Three designs to affect the tilt of the rotor are a tilting hub (Cierva), swashplate (Air & Space 18A), or servo-flaps (Kaman SAVER). A rudder provides yaw control. On pusher configuration autogyros, the rudder is typically placed in the propeller slipstream to maximize yaw control at low airspeed (but not always, as seen in the McCulloch J-2, with twin rudders placed outboard of the propeller arc).

Flight controls

There are three primary flight controls: control stick, rudder pedals, and throttle. The control stick is termed *cyclic* and tilts the rotor in the desired direction to provide pitch and roll control. The rudder pedals provide yaw control, and the throttle controls engine power.

Secondary flight controls include the rotor transmission clutch, also known as a pre-rotator, which when engaged drives the rotor to start it spinning before takeoff, and collective pitch to reduce blade pitch before driving the rotor. Collective pitch controls are not usually fitted to autogyros, but can be found on the Air & Space 18A and McCulloch J-2 and the Westermayr Tragschrauber and are capable of near VTOL performance. Unlike a helicopter, autogyros without collective pitch need a runway to takeoff; however they are capable of landing with a very short, or zero ground roll.

Pusher vs tractor configuration



Montgomery Merlin single-seat autogyro

Modern autogyros typically follow one of two basic configurations. The most common design is the pusher configuration, where the engine and propeller are located behind the pilot and rotor mast, such as in the Bensen "Gyrocopter". It was developed by Igor

Bensen in the decades following World War II, and came into widespread use shortly afterward.

Less common today is the tractor configuration. In this version the engine and propeller are located at the front of the aircraft, ahead of the pilot and rotor mast. This was the primary configuration in early autogyros, but became less common after the advent of the helicopter. It has enjoyed a revival since the mid 1970s.

History

Juan de la Cierva was a Spanish engineer and aeronautical enthusiast. In 1921, he participated in a design competition to develop a bomber for the Spanish military. De la Cierva designed a three-engined aircraft, but during an early test flight, the bomber stalled and crashed. De la Cierva was troubled by the stall phenomenon and vowed to develop an aircraft that could fly safely at low airspeeds. The result was the first successful rotorcraft, which he named *Autogiro* in 1923. De la Cierva's autogyro used an airplane fuselage with a forward-mounted propeller and engine, a rotor mounted on a mast, and a horizontal and vertical stabilizer.

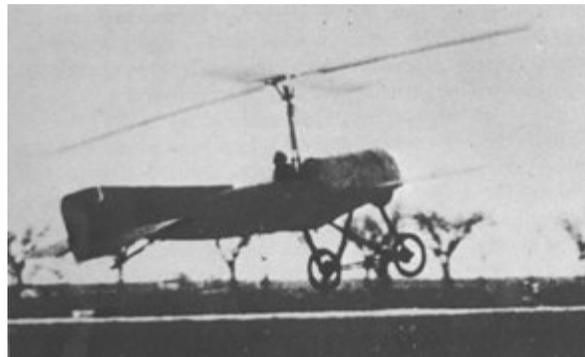
Early development



Cierva C.6 replica in Cuatro Vientos Air Museum, Madrid, Spain



Royal Air Force Avro Rota Mk 1 Cierva Autogiro C30 A, at the Imperial War Museum Duxford, UK.



The first autogyro to fly successfully (1923)

De la Cierva's first three designs (C.1, C.2, and C.3) were unstable because of aerodynamic and structural deficiencies in their rotors. His fourth design, the C.4, made the first successful flight of an autogyro on 9 January 1923, piloted by Alejandro Gomez Spencer at Cuatro Vientos airfield in Madrid, Spain. De la Cierva had fitted the rotor of the C.4 with flapping hinges to attach each rotor blade to the hub. The flapping hinges allowed each rotor blade to flap, or move up and down, to compensate for dissymmetry

of lift, the difference in lift produced between the right and left sides of the rotor as the autogyro moves forward. Three days later, the engine failed shortly after takeoff and the aircraft descended slowly and steeply to a safe landing, validating De la Cierva's efforts to produce an aircraft that could be flown safely at low airspeeds.

De la Cierva developed his C.6 model with the assistance of Spain's Military Aviation establishment, having expended all his funds on development and construction of the first five prototypes. The C.6 first flew in February 1925, including a flight of 10.5 km (7 miles) from Cuatro Vientos airfield to Getafe airfield in about 8 minutes, a significant accomplishment for any rotorcraft of the time. Shortly after De la Cierva's success with the C.6, Cierva accepted an offer from Scottish industrialist James G. Weir to establish the Cierva Autogyro Company in England, following a demonstration of the C.6 before the British Air Ministry at RAE Farnborough, on 20 October 1925. Britain had become the world centre of autogyro development.

A crash in February 1927, caused by blade root failure, led to an improvement in rotor hub design. A drag hinge was added in conjunction with the flapping hinge to allow each blade to move fore and aft and relieve in-plane stresses, generated as a byproduct of the flapping motion. This development led to the Cierva C.8, which, on 18 September 1928, made the first rotorcraft crossing of the English Channel followed by a tour of Europe.

The U.S. industrialist Harold Frederick Pitcairn, upon learning of the successful flights of the autogyro, had previously visited De la Cierva in Spain. In 1928 he visited him again, in England, after taking a C.8 L.IV test flight piloted by Arthur H.C.A. Rawson. Being particularly impressed with the autogyro's safe vertical descent capability, Pitcairn purchased a C.8 L.IV with a Wright Whirlwind engine. Arriving in the United States on 11 December 1928 accompanied by Rawson, this autogyro was redesignated C.8W. Subsequently, production of autogyros was licensed to a number of manufacturers, including the Pitcairn Autogyro Company in the U.S. and Focke-Wulf of Germany.



Avro-built Cierva C.19 Mk.IV Autogyro, built in 1932. Cuatro Vientos Airport Museum, Madrid, Spain.

In 1927 Engelbert Zaschka, a pioneering German engineer, invented a combined helicopter and autogyro. The principal advantage of the Zaschka machine is in its ability to remain motionless in the air for any length of time and to descend in a vertical line, so that a landing may be accomplished on the flat roof of a large house. In appearance, the machine does not differ much from the ordinary monoplane, but the carrying wings revolve around the body.

Development of the autogyro continued in search for a means to accelerate the rotor prior to takeoff (called prerotating). Rotor drives initially took the form of a rope wrapped around the rotor axle and then pulled by a team of men to accelerate the rotor - this was followed by a long taxi to bring the rotor up to speed sufficient for takeoff. The next innovation was flaps on the tail to redirect the propeller slipstream into the rotor while on the ground. This design was first tested on a C.19 in 1929. Efforts in 1930 had shown that development of a light and efficient mechanical transmission was not a trivial undertaking. But in 1932, the Pitcairn-Cierva Autogyro Company of Willow Grove, Pennsylvania, finally solved the problem with a transmission driven by the engine.

De la Cierva's early autogyros were fitted with fixed rotor hubs, small fixed wings, and control surfaces like those of a fixed wing aircraft. At low airspeeds, the control surfaces became ineffective and could readily lead to loss of control, particularly during landing.

In response, Cierva developed a direct control rotor hub, which could be tilted in any direction by the pilot. De la Cierva's direct control was first developed on the Cierva C.19 Mk. V and saw production on the Cierva C.30 series of 1934. In March 1934 this type of autogyro became the first rotorcraft to take off and land on the deck of a ship, when a C.30 performed trials onboard the Spanish navy seaplane tender *Dédalo* off Valencia.

Later that year, during the leftist Asturias' revolt in October, an autogyro made a reconnaissance flight for the loyal troops, marking the first military employment of a rotorcraft.

When improvements in helicopters made them practical, autogyros became largely neglected. They were, however, used in the 1930s by major newspapers, and by the US Postal Service for mail service between the Camden, NJ airport (USA) and the top of the post office building in downtown Philadelphia, Pennsylvania (USA).

World War II

In World War II, Germany pioneered a very small gyroglider rotor kite, the Focke-Achgelis Fa 330 "Bachstelze" (Water-wagtail), towed by U-boats to provide aerial surveillance.

The Imperial Japanese Army developed the Kayaba Ka-1 Autogyro for reconnaissance, artillery-spotting, and anti-submarine uses. The Ka-1 was based on an American design first imported to Japan in 1938. The craft was initially developed for use as an observation platform and for artillery spotting duties. The Army liked the craft's short take-off span, and especially its low maintenance requirements. In 1941 production began, with the machines assigned to artillery units for spotting the fall of shells. These carried two crewmen: a pilot and a spotter.

Later, the Japanese Army commissioned two small aircraft carriers intended for coastal antisubmarine (ASW) duties. The spotter's position on the Ka-1 was modified in order to carry one small depth charge. Ka-1 ASW autogyros operated from shore bases as well as the two small carriers. They appear to have been responsible for at least one submarine sinking.

The autogyro was used to calibrate the coastal radar stations during and after the Battle of Britain.

Postwar developments

The autogyro was resurrected after World War II when Dr. Igor Bensen, a Russian immigrant, saw a captured German U-Boat's Fa 330 gyroglider and was fascinated by its characteristics. At work he was tasked with the analysis of the British military "Rotachute" gyro glider designed by expatriate Austrian Raoul Hafner. This led him to adapt the design for his own purposes and eventually market the B-7. Bensen submitted an improved version, the Bensen B-8M, for testing to the United States Air Force, which

designated it the X-25. The B-8M was designed to use surplus McCulloch engines used on flying unmanned target drones.

Ken Wallis developed a miniature autogyro craft, the *Wallis* autogyro, in England in the 1960s, and autogyros built similar to Wallis' design appeared for a number of years. Ken Wallis' designs have been used in various scenarios including military training, police reconnaissance, and in another case a search for the Loch Ness Monster.

Three different autogyro designs have been certified by the Federal Aviation Administration for commercial production: the Umbaugh U-18/Air & Space 18A of 1965, the Avian 2-180 Gyroplane of 1967, and the McCulloch J-2 of 1972. All have been commercial failures, for various reasons.

Bensen Gyrocopter

The basic Bensen *Gyrocopter* design is a simple frame of square aluminium or galvanized steel tubing, reinforced with triangles of lighter tubing. It is arranged so that the stress falls on the tubes, or special fittings, not the bolts. A front-to-back keel mounts a steerable nosewheel, seat, engine, and a vertical stabilizer. Outlying mainwheels are mounted on an axle. Some versions may mount seaplane-style floats for water operations.



Bensen Aircraft B8MG Gyrocopter

Bensen-type autogyros use a pusher configuration for simplicity and to increase visibility for the pilot. Power can be supplied by a variety of engines. McCulloch drone engines,

Rotax marine engines, Subaru automobile engines, and other designs have been used in Bensen-type designs.

The rotor is mounted atop the vertical mast. The rotor system of all Bensen-type autogyros is of a two-blade teetering design. There are some disadvantages associated with this rotor design, but the simplicity of the rotor design lends itself to ease of assembly and maintenance and is one of the reasons for its popularity. Aircraft-quality birch was specified in early Bensen designs, and a wood/steel composite is used in the world speed record holding Wallis design. Gyroplane rotor blades are made from other materials such as aluminium and GRP-based composite blades.

Because of Bensen's pioneering of the concept and the popularity of his design, "Gyrocopter" has become a genericized trademark for pusher configuration autogyros.

Certification by national aviation authorities

US certification

A certificated autogyro must meet mandated stability and control criteria; in the United States these are set forth in *Federal Aviation Regulations Part 27: Airworthiness Standards: Normal Category Rotorcraft*. The U.S. Federal Aviation Administration issues a Standard Airworthiness Certificate to qualified autogyros. Amateur-built or kit-built aircraft are operated under a Special Airworthiness Certificate in the Experimental category. Per FAR 1.1, the FAA uses the term "gyroplane" for all autogyros, regardless of the type of Airworthiness Certificate.

UK certification



A VPM M-16 commences its take-off roll

Some autogyros, such as the Rotorsport MT03, have type approval by the United Kingdom Civil Aviation Authority (CAA) under British Civil Airworthiness Requirements CAP643 Section T. Others operate under a permit to fly issued by the Popular Flying Association— similar to the US experimental aircraft certification. However, the CAA's assertion that autogyros have a poor safety record means that permit to fly will only be granted to existing types of autogyro. All new types of autogyro must be submitted for full type approval under CAP643 Section T.

In 2005, the CAA issued a mandatory permit directive (MPD) which restricted operations for single seat autogyros, and were subsequently integrated into CAP643 Issue 3 published on 12 August 2005. The restrictions are concerned with the offset between the centre of gravity and thrust line, and apply to all aircraft unless evidence is presented to the CAA that the CG/Thrust Line offset less than 2 inches (5 cm) in either direction. The restrictions are summarised as follows:

- Aircraft with a cockpit/nacelle may only be operated by pilots with more than 50 hours solo flight experience following the issue of their licence.
- Open frame aircraft are restricted to a minimum speed of 30 mph (26 knots), except in the flare.
- All aircraft are restricted to a Vne of 70 mph (61 knots)
- Flight is not permitted when surface winds exceed 17 mph (15 knots) or if the gust spread exceeds 12 mph (10 knots)
- Flight is not permitted in moderate, severe or extreme turbulence and airspeed must be reduced to 63 mph (55 knots) if turbulence is encountered mid-flight.

World records

In 1931, Amelia Earhart flew a Pitcairn PCA-2 to a women's world altitude record of 18,415 ft (5,613 m).

Wing Commander Ken Wallis has held most of the autogyro world records during his autogyro flying career. These include the speed record of 186 km/h (111.7 mph), and the straight-line distance record of 869.23 km (543.27 miles). On 16 November 2002, at 89 years of age, Wallis increased the 3km speed record to 207.7 km/h (129.1 mph) - and simultaneously set another world record as the oldest pilot to set a world record.

The autogyro is one of the last remaining types of aircraft which has not yet been used to circumnavigate the globe. Expedition Global Eagle was the first attempt in history to circumnavigate the globe using an autogyro. The expedition set the record for the longest flight over water by an autogyro during the segment from Muscat, Oman to Karachi. The attempt was finally abandoned because of bad weather after a trip totalling 7,500 miles (12,100 km).

In February 2003, a year before the circumnavigation attempt, the *Global Eagle* piloted by Warrant Officer Barry Jones also broke the world range record by flying non-stop from Culdrose in Cornwall to Wick in Scotland, a total of 580 miles (928 km) breaking the old record held by Wing Commander Ken Wallis.

Andrew Keech made a transcontinental flight from Kitty Hawk, North Carolina to San Diego, California in October 2003 and set 3 world records for speed over a recognized course. The 3 records were verified by tower personnel or by official observers of the United States' National Aeronautic Association (NAA). On 9 February 2006, he broke two of his world records and set a record for distance, ratified by the Fédération Aéronautique Internationale (FAI); Speed over a closed circuit of 500 km (311 mi) without payload: 168.29 km/h (104.57 mph), speed over a closed circuit of 1,000 km (621 mi) without payload: 165.07 km/h (102.57 mph), and distance over a closed circuit without landing: 1,019.09 km (633.23 mi).

Chapter 11

Types of Autogyro

Cierva C.30

C.30



Avro 671 Rota Mk 1 at Imperial War Museum,
Duxford

Role	Autogyro
Designed by	Juan de la Cierva
First flight	1933
Introduced	1934
Number built	148
Variants	Cierva C.40

The **Cierva C.30** was an autogyro designed by Juan de la Cierva and built under licence from the Cierva Autogyro Company by A V Roe & Co Ltd (Avro), Lioré-et-Olivier and Focke-Wulf.

Design and development

Before the experimental Cierva C.19 Mk V, autogyros had been controlled in the same way as fixed wing aircraft, that is by deflecting the air flowing over moving surfaces such

as ailerons, elevators and rudder. At the very low speeds encountered in autogiro flight, particularly during landing, these controls became ineffective. The experimental machine showed that the way forward was to have a tilting rotor hub and a control rod coming down from the hub to the pilot's cockpit with which he could change the rotor plane. This was known as "direct control" and was fitted to the **C.30**. The production variant, called **C.30A** in England, was preceded by several development machines.

The first production design in the series was the **C.30**, a radial engine autogiro with a three blade, 37 ft (11.3 m) rotor mounted on an aft-leaning tripod, the control column extending into the rear of the two cockpits. The engine was the five-cylinder, 105 hp (78 kW) Armstrong Siddeley Genet Major I used in the **C.19** series. The fabric covered fuselage carried an unbraced tailplane, without elevators but with turned up tips. The port side plane had an inverted aerofoil section to offset the roll-axis torque produced in forward flight by the advancing port side blades. As with most autogiros, a high vertical tail was precluded by the sagging resting rotor, so the dorsal fin was long and low, extending well aft of the tailplane like a fixed rudder and augmented by a ventral fin. The wide track undercarriage had a pair of single, wire braced legs and a small tail wheel was fitted. This model flew in April 1933. It was followed by four improved machines designated **C.30P** (P here for pre-production) which differed in having a four-legged pyramidal rotor mounting and a reinforced undercarriage with three struts per side. The rotor could be folded rearwards for transport. The **C.30P** used the more powerful (140 hp, 104 kW) seven-cylinder Armstrong Siddeley Genet Major IA radial engine.



Avro 671 (Cierva C.30A) taxiing for take-off at Rearsby Aerodrome in June 1951

The production model, called the C.30A by Avro, was built under licence in Britain, France and Germany and was similar to the C.30P. The main alteration was a further increase in undercarriage track with revised strutting, the uppermost leg having a pronounced knee with wire bracing. There was additional bracing to the tailplane and both it and the fin carried small movable trimming surfaces. Each licensee used nationally built engines and used slightly different names. In all, 143 production C.30s were built, making it by far the most numerous pre-war autogyro.

Between 1933 and 1936, de la Cierva used one C.30A (*G-ACWF*) to perfect his last contribution to autogyro development before his death in a DC-2 (fixed wing) crash in late 1936. To enable the aircraft to take off without forward ground travel, he produced the "Autodynamic" rotor head, which allowed the rotor to be spun up by the engine in the usual way but to higher than take-off r.p.m at zero rotor incidence and then to reach operational positive pitch suddenly enough to jump some 20 ft (6 m) upwards.

At least one of the RAF C.30As was in January 1935 on floats as a Sea Rota.

Production

Avro

Avro obtained the licence in 1934 and subsequently built 78 examples, under their model designation, fitted with an Armstrong Siddeley Genet Major IA (known in the RAF as the Civet 1) 7-cylinder radial engine producing 140 hp (100 kW). The first production C.30A was delivered in July 1934.

Lioré-et-Olivier

Twenty-five aircraft were built in France by Lioré-et-Olivier as the LeO C.301 with a 175 hp (130 kW) Salmson 9NE 9-cylinder radial engine.

Focke-Wulf

Forty aircraft were built in Germany by Focke-Wulf as the C 30 Heuschrecke (Grasshopper) with a 140 hp (105 kW) Siemens Sh 14A 7-cylinder radial engine.

Operational history

Of the 66 non-RAF aircraft built in the UK by Avro, 37 appeared at least for a while on the UK register. Some (maybe a dozen) were sold on abroad, but others were flown by wealthy enthusiasts and by flying clubs who anticipated autogyro training needs. By the end of the decade private flyers were moving back to the comforts and economies of fixed wing aircraft and more C.30s moved abroad, leaving the Autogyro Flying Club at London Air Park, Hanworth as the major UK user. 26 aircraft were directly exported by Avro. These went both to private owners and to foreign air forces who wish to investigate the autogyro's potential.

In 1934, one Spanish navy C.30 piloted by Cierva landed on the Spanish Seaplane tender *Dedalo* anchored in Valencia harbor and later made a takeoff.

Twelve C.30A built by Avro for the Royal Air Force (RAF) entered service as the **Avro 671 Rota Mk 1** (Serials *K4230* to *K4239* and *K4296* & *K4775*). The twelve were delivered between 1934 to 1935. They equipped the Army School of Co-operation at Old Sarum near Salisbury.

Many of the surviving civil aircraft were also taken into RAF service between 1939 and 1940. In 1940 they equipped No. 1448 Flight at RAF Duxford. Later they equipped No. 529 Squadron RAF at Halton on radar calibration work. They disbanded in October 1945. At the end of the war the twelve survivors were sold.

Most of these did not last long, although two were used for pilot rotary wing experience by Fairey in their Fairey Gyrodyne helicopter programme. Rota Towels kept one ex-RAF Rota airworthy *G-AHTZ* until an accident in 1958. *G-ACUU*, the Imperial War Museum's C.30A exhibit at Duxford had one of the longest active lives. It joined Air Service Training Ltd in 1934, was impressed (as Rota *HM580*) in 1942, serving with 529 Squadron and returning to civil use by G.S. Baker based at Birmingham's Elmdon airport with its original registration plus the nickname *Billy Boy* and was not withdrawn from use until 1960.

Variants

C.30

Powered by a 78-kW (105-hp) Armstrong Siddeley Genet Major I radial piston engine.

C.30P

Improved model, powered by a 104-Kw (140-HP) Armstrong Siddeley Genet Major IA radial piston engine.

C.30A

Main production model, powered by a 104-kW (140-hp) Armstrong Siddeley Genet Major IA radial piston engine.

Rota Mk I

RAF designation of the Cierva C.30A.

Survivors

There are no flying survivors

Non flying

Avro Rota I (K4232)

On display at the Royal Air Force Museum, London, England.

Cierva C.30A (AP506)

On display at the Helicopter Museum, Weston-super-Mare, England.

Cierva C.30A (AP507)

On display at the Science Museum in London, England.

Avro Rota I (HM580 / G-ACUU)

On display at the Imperial War Museum Duxford, England.

Cierva C.30A (LN-BAD)

On display at the Aviodome, Netherlands.

Cierva C.30A (LV-FBL)

On display in Argentina.

Cierva C.30A (VH-USR)

On display at the Powerhouse Museum, Sydney, Australia.

Leo C.302 (F-BDAD)

On display at the Musée de l'Air et de l'Espace, Paris, France.

Cierva C.30A (H-KX)

On display at the Fantasy of Flight Museum, Florida, USA.

Cierva C.30 (I-CIER)

on display at the Museo della Scienza e della Tecnologia "Leonardo da Vinci", Milan, Italy.

In addition, a full-scale flying reproduction was built in Spain in the mid-1990s. After a brief flying career a crosswind accident led to the damage to the rare rotor blades. The aircraft is now on display at the Museo del Aire, Cuatro Vientos, Madrid, Spain.

Military operators



Argentina



Austria



Belgium



Denmark



Italy



Soviet Union



Spanish Republic



United Kingdom

- Royal Air Force
 - No. 80 Squadron RAF
 - No. 529 Squadron RAF



Kingdom of Yugoslavia

Specifications (C.30A)

General characteristics

- **Crew:** one, pilot
- **Length:** 19 ft 8 in (6 m)
- **Rotor diameter:** 37 ft (11.28 m)
- **Height:** 11 ft 1 in (3.38 m)
- **Empty weight:** 1,220 lb (554.5 kg)
- **Loaded weight:** 1,800 lb (818 kg)

- **Powerplant:** 1× Armstrong Siddeley Genet Major IA 7-cylinder air-cooled radial engine, 140 hp (104 kW)

Performance

- **Maximum speed:** 110 mph (177 km/h)
- **Cruise speed:** 95 mph (153 km/h)
- **Range:** 285 mi (458 km)
- **Rate of climb:** 700 ft/min (213.4 m/min)

Cierva C.6

C.6



Cierva C.6 replica in Cuatro Vientos Air Museum, Madrid, Spain

Role	Autogyro
Manufacturer	Cierva
Designed by	Juan de la Cierva
First flight	March 1924
Number built	1
Developed from	Cierva C.5



Cierva C.6 replica engine closeup

The **Cierva C.6** was the sixth autogyro designed by engineer Juan de la Cierva, and the first one to travel a "major" distance. Cierva, the engineer responsible for the invention of the autogyro, had spent all his funds in the research and creation of his first five prototypes. So, in 1923, he turned to the Cuatro Vientos Aerodynamics Laboratory chief, Commander Emilio Herrera, who succeeded in persuading General Francisco Echagüe, the director of the Military Aviation Aeronautics Department, to take over the second stage in the research and development of Cierva's Autogyros.

After several wind tunnel tests, Military Aviation built a Cierva C.6 autogyro in an Avro 504 frame. This machine, piloted by Captain Joaquín Loriga Taboada, performed three flights, all of them in March 1924. One of those flights, the eight minute trip from Cuatro Vientos airfield to Getafe airfield (10.5 km / 7 miles), was considered a giant's step and the "leap into glory" of Cierva's autogyros.

The Cierva C.6 prototype was fitted with ailerons mounted in two small wings, elevators and rudder. This complete three-axis control scheme was needed because the pilot had only limited control over the rotor. Only the front propeller was powered, so this aircraft could not hover, and could lose control at low speed. The vertical axis rotor spun freely; the faster the autogyro flew, the faster the rotor would spin and the greater lift it produced.

A replica of the Cierva C.6 was built to be shown in Murcia pavilion in Seville Expo '92 World's Fair. That replica can be now be seen in Museo del Aire, Cuatro Vientos, Madrid, Spain.

Variants

Cierva C.6

Prototype.

Cierva C.6A

Powered by a 82-kW (110-hp) Le Rhone 9Ja rotary piston engine.

Cierva C.6B

Cierva C.6C

Powered by a 97-kW (130-hp) Clerget rotary piston engine. Built in the United Kingdom as **Avro Type 574**.

Cierva C.6D

Powered by a 97-kW (130-hp) Clerget rotary piston engine. Built in the United Kingdom as the **Avro Type 575**.

Specifications (C.6)

General characteristics

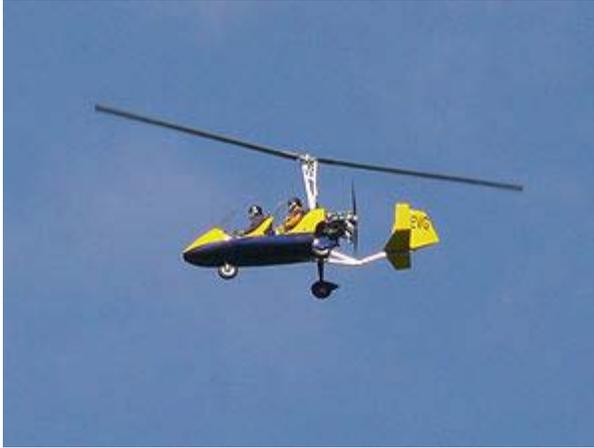
- **Crew:** One or two
- **Length:** 9 m (29 ft 6 in)
- **Rotor diameter:** 10 m (32 ft 9½ ft)
- **Height:** ()
- **Max takeoff weight:** 900 kg (1,984 lb)
- **Powerplant:** 1× Le Rhône 9J 9-cylinder rotary engine with a two-bladed propeller, 82 kW (110 hp)

Performance

- **Maximum speed:** 100 km/h (54 knots, 62 mph)

Rotorsport UK MT-03

Rotorsport UK MT-03



Role	Autogyro
National origin	United Kingdom
Manufacturer	Rotorsport UK
Developed from	AutoGyro MT-03
Variants	BAE Ampersand

The **Rotorsport UK MT-03** is a two-seater autogyro to British Civil Airworthiness Requirements CAP643 Section T. New build-aircraft based on the AutoGyro MT-03 design are imported from Germany and completed to British regulations by Rotorsport UK Limited in the United Kingdom.

The autogyro has two tandem seats and is powered by a 100 hp (75 kW) Rotax 912 ULS although optionally a 115 hp (86 kW) Rotax 914 UL Turbo can be fitted.

An unmanned reconnaissance technology demonstrator variant has been proposed as the BAE Ampersand.

Specifications (Rotax 912)

General characteristics

- **Crew:** 2
- **Length:** 4.95 m (16 ft 3 in)
- **Width:** 1.82 m (6 ft 0 in)
- **Height:** 2.7 m (8 ft 10 in)
- **Empty weight:** 250 kg (551 lb)
- **Max takeoff weight:** 450 kg (992 lb)
- **Powerplant:** 1 × Rotax 912 ULS four-stroke piston engine, 75 kW (100 hp)

- **Main rotor diameter:** 8.4 m (27 ft 7 in)
- **Propellers:** 3-bladed HTC 3 blade ground adjustable, composite, 1.72 m (5 ft 8 in) diameter

Performance

- **Never exceed speed:** 160 km/h; 87 kn (100 mph) Vne
- **Rate of climb:** 5.6 m/s (1,100 ft/min)