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Amphibious Aircraft

... a short overview

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PEDIAPRESS

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Overview

Amphibious aircraft

A Canadair CL-215T amphibian with retractable wheels

An **amphibious aircraft** or **amphibian** is an aircraft that can take off and land on both land and water. Fixed-wing amphibious aircraft are seaplanes (flying boats and floatplanes) that are equipped with retractable wheels, at the expense of extra weight and complexity, plus diminished range and fuel economy compared to planes designed for land or water only. Some amphibians are fitted with reinforced keels which act as skis, allowing them to land on snow or ice with their wheels up.

Design

Floatplanes often have floats that are interchangeable with wheeled landing gear (thereby producing a conventional land-based aircraft) however in cases where this is not practical amphibious floatplanes, such as the amphibious version of the DHC Otter, incorporate retractable wheels within their floats.

Many amphibian aircraft are of the flying boat type. These aircraft, and those designed as floatplanes with a single main float under the fuselage centerline (such as the Loening OL and Grumman J2F), require outrigger floats to provide lateral stability so as to avoid dipping a wingtip, which can destroy an aircraft if it happens at speed, or can cause the wingtip to fill with water and sink if stationary. While these impose weight and drag, amphibious aircraft also face the possibility of these getting hit when operating from a runway. A common solution is to make them retractable as those found on the Consolidated Catalina however these are even heavier than fixed floats. Some aircraft may have the tip floats removed for extended use from land. Other amphibians, such as the Dornier Seastar use stub wings called sponsons, mounted with their own lower surfaces nearly even with the ventral "boat-hull" shaped fuselage surface to provide the needed stability, while floatplane amphibians usually avoid the problem by dividing their buoyancy requirements between two floats, much like a catamaran.

Some non-amphibious seaplanes may be mistaken for amphibians (such as the Shin Meiwa PS-1) which carry their own beaching gear - usually this is a wheeled dolly or temporary set of wheels used to move a flying boat or floatplane from the water and allow it to be moved around on land but can also appear as a conventional undercarriage. These are not built to take the impact of the aircraft landing on them. An amphibian can leave the water without anyone getting in the water to attach beaching wheels (or even having to have any handy), yet a fully functional undercarriage is heavy and impacts the aircraft's performance, and isn't required in all cases, so an aircraft may be designed to carry its own.

Hazards

An occasional problem with amphibians is with ensuring the wheels are in the correct position for landing. In normal operation, the pilot uses a checklist, verifying each item. Since amphibians can land with them up or down though, the pilot must take extra care to ensure they are correct for the chosen landing place. Landing wheels up on land may damage the keel (unless done on wet grass, a technique occasionally used by pilots of pure flying boats), while landing wheels down on water will almost always flip the aircraft upside down, causing substantial damage.

Usage

Vickers Viking - an early amphibian.

Amphibious aircraft are heavier and slower, more complex and more expensive to purchase and operate than comparable landplanes but are also more versatile. Even if they cannot hover or land vertically, for some jobs they compete favorably with helicopters and do so at a significantly lower cost. Amphibious aircraft can be much faster and have longer range than comparable helicopters, and can achieve nearly the range of land based aircraft,[1] as an airplane's wing is more efficient than a helicopter's lifting rotor. This makes an amphibious aircraft, such as the Grumman Albatross and the Shin Meiwa US-2, useful for long-range air-sea rescue tasks. In addition, amphibious aircraft are particularly useful as "Bushplanes" engaging in light transport in remote areas, where they are required to operate not only from airstrips, but also from lakes and rivers.

History

In the United Kingdom, traditionally a maritime nation, a large number of amphibians were built between the wars, starting from 1918 with the Vickers Viking and the early 1920s Supermarine Seagull and were used for exploration and military duties including search and rescue, artillery spotting and anti-submarine patrol. The most notable being the Short Sunderland which carried out many anti-submarine patrols over the North

Atlantic on sorties of 8 – 12 hours duration. These evolved throughout the interwar period to ultimately culminate in the post World War 2 Supermarine Seagull, which was to have replaced the wartime Walrus and the Sea Otter but was overtaken by advances in helicopters.

replica of Osa's Ark - a Sikorsky S-38 used to explore Africa in the 1930s.

Starting in the mid-1920s and running into the late 1930s in the United States, Sikorsky produced an extensive family of amphibians (the S-34, S-36, S-38, S-39, S-41, S-43) that were widely used for exploration and as airliners around the globe, helping pioneer many overseas air routes where the larger flying boats could not go, and helping to popularize amphibians in the US. The Grumman Corporation, late-comers to the game, introduced a pair of light utility amphibious aircraft - the Goose and the Widgeon during the late 1930s for the civilian market. However, their military potential could not be ignored, and many were ordered by the US Armed forces and their allies during World War II. Not coincidentally, the Consolidated Catalina (named for Santa Catalina Island off the coast of southern California whose resort was partially popularized by the use of amphibians in the 1930s, including Sikorskys, and Douglas Dolphins) was redeveloped from being a pure flying boat into an amphibian during the war. After the war, the United States military ordered hundreds of the Grumman Albatross and its variants for a variety of roles, though, like the pure flying boat was made obsolete by helicopters which could operate in sea conditions far beyond what the best seaplane could manage.

Italian Air Force Piaggio P.136 during takeoff retracting the wheels that make it an amphibian.

Development of amphibians was not limited to the United Kingdom and the United States but few designs saw more than limited service - there being a widespread preference for pure flying boats and floatplanes due to the weight penalty the undercarriage imposed, yet Russia also developed a number of important flying boats, including the widely used pre-war Shavrov Sh-2 utility flying boat, and postwar the Beriev Be-12 anti-submarine and maritime patrol amphibian. Development of amphibians continues in Russia with the jet engined Beriev Be-200. Italy, bordering the Mediterranean and Adriatic has had a long history of waterborne aircraft going back to the first Italian aircraft to fly. While most were not amphibians, quite a few were, including the Savoia-Marchetti S.56A and the Piaggio P.136.

Amphibious aircraft were particularly useful in the unforgiving terrain of Alaska and northern Canada, where many remain in civilian service, providing remote communities with vital links to the outside world. The Canadian Vickers Vedette was developed for forestry patrol in remote areas, previously a job that was done by canoe and took weeks could be accomplished in hours, revolutionizing forestry conservation. Although successful, flying boat amphibians like it ultimately proved less versatile than floatplane amphibians and are no longer as common as they once were. Amphibious floats that could be attached to any aircraft were developed, turning any aircraft into an amphibian, and these continue to be essential for getting into the more remote locations during the summer months when the only open areas are the waterways.

Despite the gains of amphibious floats, small flying boat amphibians continued to be developed into the 1960s, with the Republic Seabee and Lake LA-4 series proving popular, though neither was a commercial success due to factors beyond their makers control. Many today are homebuilts, by necessity as the demand is too small to justify the costs of development, with the Volmer Sportsman being a popular choice amongst the many offerings.

ShinMaywa US-2, developed in the 2000s in Japan from the older Shin Meiwa US-1A

With the increased availability of airstrips in remote communities, fewer amphibious aircraft are manufactured today than in the past, although a handful of amphibious aircraft are still produced, such as the Bombardier 415, ICON A5, and the amphibious-float equipped version of the Cessna Caravan.

Development of amphibians has continued into the new millennium. The ShinMaywa US-2 was developed in the 2000s in Japan for the Japan Maritime Self-Defense Force.

See also

- Amphibious helicopter
- Amphibious vehicle
- List of seaplanes and amphibious aircraft
- Floatplane
- Flying boat
- Seaplane
- Tigerfish Aviation (retractable float)
- Unmanned aerial vehicle

References

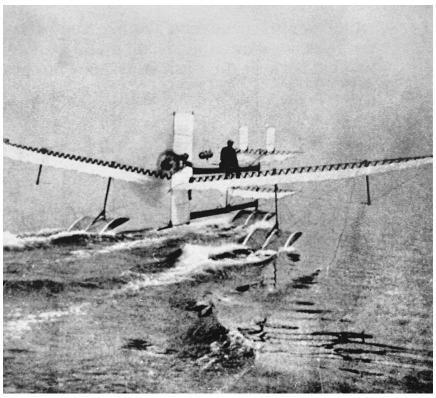
1. **^** *"Grumman Mallard"*.

Related types of aircraft

Floatplane

A **floatplane** (**float plane** or **pontoon plane**) is a type of seaplane, with one or more slender pontoons (known as "floats") mounted under the fuselage to provide buoyancy. By contrast, a flying boat uses its fuselage for buoyancy. Either type of seaplane may also have landing gear suitable for land, making the vehicle an amphibious aircraft.[1]

A De Havilland Canada DHC-3 Otter floatplane in Harbour Air livery



The 1910 French Fabre Hydravion was one of the first successful floatplanes

Use

Since World War II and the advent of helicopters, advanced aircraft carriers and land-based aircraft, military seaplanes have stopped being used. This, coupled with the increased availability of civilian airstrips, have greatly reduced the number of flying boats being built. However, numerous modern civilian aircraft have floatplane variants, most of these are offered as third-party modifications under a supplemental type certificate (STC), although there are several aircraft manufacturers that build floatplanes from scratch. These floatplanes have found their niche as one type of bush plane, for light duty transportation to lakes and other remote areas, as well as to small/hilly islands without proper airstrips. They may operate on a charter basis (including pleasure flights), provide scheduled service, or be operated by residents of the area for private, personal use.

Design

Float planes have often been derived from land-based aircraft, with fixed floats mounted under the fuselage instead of retractable undercarriage (featuring wheels).

Float planes offer several advantages since the fuselage is not in contact with water, which simplifies production by not having to incorporate the compromises necessary for water tightness, general impact strength and the hydroplaning characteristics needed for the aircraft to leave the water. Attaching floats to a landplane also allows for much larger production volumes to pay for the development and production of the small number of aircraft operated from the water. Additionally, on all but the largest seaplanes, floatplane wings usually offer more clearance over obstacles, such as docks, reducing the difficulty in loading while on the water. A typical single engine flying boat is unable to bring the hull alongside a dock for loading while most floatplanes are able to do so.

Floatplanes allow access to remote aquatic locations, such as Misty Fjords National Monument, Alaska, U.S.

Cessna 208 Caravan 1 floatplane at Gloucestershire Airport, England (2017)

Floats inevitably impose extra drag and weight, rendering floatplanes slower and less manoeuvrable during flight, with a slower rate of climb, relative to aircraft equipped with wheeled landing gear. Nevertheless, air races devoted to floatplanes attracted a lot of attention during the 1920s and 1930s, most notably in the form of the Schneider Trophy, not least because water takeoffs permitted longer takeoff runs which allowed greater optimization for high speed compared to contemporary airfields.

There are two basic configurations for the floats on floatplanes:

- "single float" designs, in which a single large float is mounted directly underneath the fuselage, with smaller stabilizing floats underneath the wingtips, on planes like the Nakajima A6M2-N and;
- "twin float" designs, with two main floats mounted side by side outboard of the fuselage. Some early twin float designs had additional wingtip stabilizing floats.

The main advantage of the single float design is its capability for landings in rough water: a long central float is directly attached to the fuselage, this being the strongest part of the aircraft structure, while the smaller floats under the outer wings provide the aircraft with lateral stability. By comparison, dual floats restrict handling, often to waves as little as one foot (0.3 metres) in height.[2] However, twin float designs facilitate mooring and boarding, and – in the case of torpedo bombers – leave the belly free to carry a torpedo.

See also

- Amphibious aircraft
- List of seaplanes and amphibious aircraft
- RAPT system

References

1. **^** *James M. Triggs (Winter 1971). "Floatplane Flying". Air Trails: 39.*
2. **^** NASM research Archived 2007-11-24 at the Wayback Machine.

External links

Wikimedia Commons has media related to ***Floatplanes***.

- "Why Seaplanes Fly With Bullet Speed", December 1931, Popular Science excellent article on the different design features of the floats on floatplanes
- "Will a Lake Be Your Postwar Landing Field?" *Popular Science*, February 1945, pp. 134–135.

Flying boat

A **flying boat** is a fixed-winged seaplane with a hull, allowing it to land on water, that usually has no type of landing gear to allow operation on land.[1] It differs from a floatplane as it uses a purpose-designed fuselage which can float, granting the aircraft buoyancy. Flying boats may be stabilized by under-wing floats or by wing-like projections (called sponsons) from the fuselage. Flying boats were some of the largest aircraft of the first half of the 20th century, exceeded in size only by bombers developed during World War II. Their advantage lay in using water instead of expensive land-based runways, making them the basis for international airlines in the interwar period. They were also commonly used for maritime patrol and air-sea rescue.

Short S23 "C" Class or "Empire" Flying Boat

Their use gradually trailed off after World War II, partially because of the investments in airports during the war. In the 21st century, flying boats maintain a few niche uses, such as dropping water on forest fires, air transport around archipelagos, and access to undeveloped areas. Many modern seaplane variants, whether float or flying boat types, are convertible amphibious aircraft where either landing gear or flotation modes may be used to land and take off.

History

Early pioneers

The Frenchman Alphonse Pénaud filed the first patent for a flying machine with a boat hull and retractable landing gear in 1876, but Austrian Wilhelm Kress is credited with building the first seaplane *Drachenflieger* in 1898, although its two 30 hp Daimler engines were inadequate for take-off and it later sank when one of its two floats collapsed.[2]


Gabriel Voisin, air pioneer, who made one of the earliest flights in a seaplane, with Henry Farman (left), in 1908.

On 6 June 1905 Gabriel Voisin took off and landed on the River Seine with a towed kite glider on floats. The first of his unpowered flights was 150 yards.[2] He later built a powered floatplane in partnership with Louis Blériot, but the machine was unsuccessful.

Other pioneers also attempted to attach floats to aircraft in Britain, Australia, France and the USA.

On 28 March 1910 Frenchman Henri Fabre successfully flew the first successful powered seaplane, the Gnome Omega-powered *hydravion*, a trimaran floatplane.[3] Fabre's first successful take off and landing by a powered seaplane inspired other aviators and he designed floats for several other flyers. The first hydro-aeroplane competition was held in Monaco in March 1912, featuring aircraft using floats from Fabre, Curtiss, Tellier and Farman. This led to the first scheduled seaplane passenger services at Aix-les-

Bains, using a five-seat Sanchez-Besa from 1 August 1912.[2] The French Navy ordered its first floatplane in 1912.

In 1911–12 François Denhaut constructed the first seaplane with a fuselage forming a hull, using various designs to give hydrodynamic lift at take-off. Its first successful flight was on 13 April 1912.[2] Throughout 1910 and 1911 American pioneering aviator Glenn Curtiss developed his floatplane into the successful Curtiss Model D land-plane, which used a larger central float and sponsons. Combining floats with wheels, he made the first amphibian flights in February 1911 and was awarded the first Collier Trophy for US flight achievement. From 1912 his experiments with a hulled seaplane resulted in the 1913 Model E and Model F, which he called "flying-boats".[2]

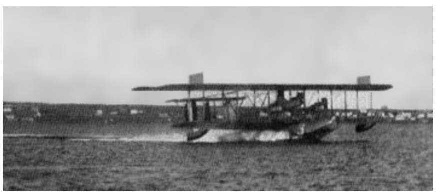
In February 1911 the United States Navy took delivery of the Curtiss Model E, and soon tested landings on and take-offs from ships using the Curtiss Model D.

In Britain, Captain Edward Wakefield and Oscar Gnosspelius began to explore the feasibility of flight from water in 1908. They decided to make use of Windermere in the Lake District, England's largest lake. The latter's first attempts to fly attracted large crowds, though the aircraft failed to take off and required a re-design of the floats incorporating features of Borwick's successful speed-boat hulls. Meanwhile, Wakefield ordered a floatplane similar to the design of the 1910 Fabre Hydravion. By November 1911, both Gnosspelius and Wakefield had aircraft capable of flight from water and awaited suitable weather conditions. Gnosspelius's flight was short-lived as the aircraft crashed into the lake. Wakefield's pilot however, taking advantage of a light northerly wind, successfully took off and flew at a height of 50 feet to Ferry Nab, where he made a wide turn and returned for a perfect landing on the lake's surface.

In Switzerland, Emile Taddéoli equipped the Dufaux 4 biplane with swimmers and successfully took off in 1912. A seaplane was used during the Balkan Wars in 1913, when a Greek "Astra Hydravion" did a reconnaissance of the Turkish fleet and dropped 4 bombs.[4][5]

Birth of an industry

In 1913, the *Daily Mail* newspaper put up a £10,000 prize for the first non-stop aerial crossing of the Atlantic which was soon "enhanced by a further sum" from the *Women's Aerial League of Great Britain*.



Curtiss NC Flying Boat "NC-3" skims across the water before takeoff, 1919

American businessman Rodman Wanamaker became determined that the prize should go to an American aircraft and commissioned the Curtiss Aeroplane and Motor Company to design and build an aircraft capable of making the flight. Curtiss' development of the *Flying Fish* flying boat in 1913 brought him into contact with John Cyril Porte, a retired Royal Navy Lieutenant, aircraft designer and test pilot who was to become an influential British aviation pioneer. Recognising that many of the early accidents were attributable to a poor understanding of handling while in contact with the water, the pair's efforts went into developing practical hull designs to make the transatlantic crossing possible.[6]

At the same time the British boat building firm J. Samuel White of Cowes on the Isle of Wight set up a new aircraft division and produced a flying boat in the United Kingdom. This was displayed at the London Air Show at Olympia in 1913.[7] In that same year, a collaboration between the S. E. Saunders boatyard of East Cowes and the Sopwith Aviation Company produced the "Bat Boat", an aircraft with a consuta laminated hull that could operate from land or on water, which today we call an amphibious aircraft.[7] The "Bat Boat" completed several landings on sea and on land and was duly awarded the Mortimer Singer Prize.[7] It was the first all-British aeroplane capable of making six return flights over five miles within five hours.

In the U.S. Wanamaker's commission built on Glen Curtiss' previous development and experience with the Model F[8] for the U.S. Navy which rapidly resulted in the *America*, designed under Porte's supervision following his study and rearrangement of the flight plan; the aircraft was a conventional biplane design with two-bay, unstaggered wings of unequal span with two pusher inline engines mounted side-by-side above the fuselage in the interplane gap. Wingtip pontoons were attached directly below the lower wings near their tips. The design (later developed into the Model H), resembled Curtiss' earlier flying boats, but was built considerably larger so it could carry enough fuel to cover 1,100 mi (1,800 km). The three crew members were accommodated in a fully enclosed cabin.

Trials of the *America* began 23 June 1914 with Porte also as Chief Test Pilot; testing soon revealed serious shortcomings in the design; it was under-powered, so the engines were replaced with more powerful engines mounted in a tractor configuration. There was also a tendency for the nose of the aircraft to try to submerge as engine power increased while taxiing on water. This phenomenon had not been encountered before, since Curtiss' earlier designs had not used such powerful engines nor large fuel/cargo loads and so were relatively more buoyant. In order to counteract this effect, Curtiss fitted fins to the sides of the bow to add hydrodynamic lift, but soon replaced these with sponsons, a type of underwater pontoon mounted in pairs on either side of a hull. These sponsons (or their engineering equivalents) and the flared, notched hull would remain a prominent feature of flying boat hull design in the decades to follow. With the problem resolved, preparations for the crossing resumed. While the craft was found to handle "heavily" on takeoff, and required rather longer take-off distances than expected, the full moon on 5 August 1914 was selected for the trans-Atlantic flight; Porte was to pilot the *America* with George Hallett as co-pilot and mechanic.

World War I

Curtiss and Porte's plans were interrupted by the outbreak of World War I. Porte sailed for England on 4 August 1914 and rejoined the Navy, as a member of the Royal Naval Air Service. Appointed Squadron Commander of Royal Navy Air Station Hendon, he soon convinced the Admiralty of the potential of flying boats and was put in charge of the naval air station at Felixstowe in 1915. Porte persuaded the Admiralty to commandeer (and later, purchase) the *America* and a sister craft from Curtiss. This was followed by an order for 12 more similar aircraft, one Model H-2 and the remaining as Model

H-4's. Four examples of the latter were assembled in the UK by Saunders. All of these were similar to the design of the *America* and, indeed, were all referred to as *America*s in Royal Navy service. The engines, however, were changed from the under-powered 160 hp Curtiss engines to 250 hp Rolls-Royce Falcon engines. The initial batch was followed by an order for 50 more (totalling 64 *Americas* overall during the war).[6] Porte also acquired permission to modify and experiment with the Curtiss aircraft.

The Curtiss H-4s were soon found to have a number of problems; they were underpowered, their hulls were too weak for sustained operations and they had poor handling characteristics when afloat or taking off.[9][10] One flying boat pilot, Major Theodore Douglas Hallam, wrote that they were "comic machines, weighing well under two tons; with two comic engines giving, when they functioned, 180 horsepower; and comic control, being nose heavy with engines on and tail heavy in a glide."[11]


The Felixstowe F.2A, the first production seaplane, and the basis for future development.

At Felixstowe, Porte made advances in flying boat design and developed a practical hull design with the distinctive "Felixstowe notch".[12] Porte's first design to be implemented in Felixstowe was the Felixstowe Porte Baby, a large, three-engined biplane flying-boat, powered by one central pusher and two outboard tractor Rolls-Royce Eagle engines.

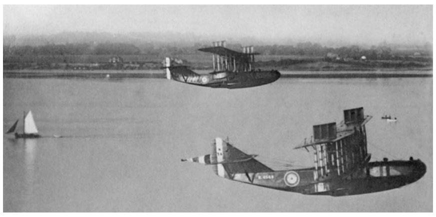
Porte modified an H-4 with a new hull whose improved hydrodynamic qualities made taxiing, take-off and landing much more practical, and called it the Felixstowe F.1.

Porte's innovation of the "Felixstowe notch" enabled the craft to overcome suction from the water more quickly and break free for flight much more easily. This made operating the craft far safer and more reliable. The "notch" breakthrough would soon after evolve into a "step", with the rear section of the lower hull sharply recessed above the forward lower hull section, and that characteristic became a feature of both flying boat hulls and seaplane floats. The resulting aircraft would be large enough to carry sufficient fuel to fly long distances and could berth alongside ships to take on more fuel.

Porte then designed a similar hull for the larger Curtiss H-12 flying boat which, while larger and more capable than the H-4s, shared failings of a weak hull and poor water handling. The combination of the new Porte-designed hull, this time fitted with two steps, with the wings of the H-12 and a new tail, and powered by two Rolls-Royce Eagle engines, was named the Felixstowe F.2 and first flew in July 1916,[13] proving greatly superior to the Curtiss on which it was based. It was used as the basis for all future designs.[14] It entered production as the Felixstowe F.2A, being used as a patrol aircraft, with about 100 being completed by the end of World War I. Another seventy were built, and these were followed by two F.2c, which were built at Felixstowe.

In February 1917, the first prototype of the Felixstowe F.3 was flown. It was larger and heavier than the F.2, giving it greater range and heavier bomb load, but poorer agility. Approximately 100 Felixstowe F.3s were produced before the end of the war.

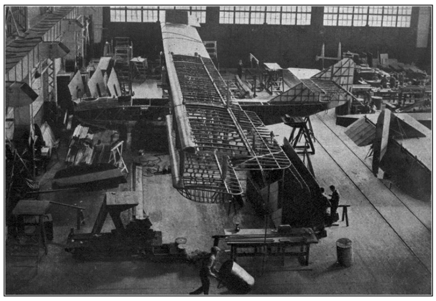
The Felixstowe F.5 was intended to combine the good qualities of the F.2 and F.3, with the prototype first flying in May 1918. The prototype showed superior qualities to its predecessors but, to ease production, the production version was modified to make extensive use of components from the F.3, which resulted in lower performance than the F.2A or F.3.



The Felixstowe F.5, designed by Lieutenant Commander John Cyril Porte at the Seaplane Experimental Station, Felixstowe

Porte's final design at the Seaplane Experimental Station was the 123 ft-span five-engined Felixstowe Fury triplane (also known as the "Porte Super-Baby" or "PSB").[15]

F.2, F.3, and F.5 flying boats were extensively employed by the Royal Navy for coastal patrols, and to search for German U-boats. In 1918 they were towed on lighters towards the northern German ports to extend their range; on 4 June 1918 this resulted in three F.2As engaging in a dogfight with ten German seaplanes, shooting down two confirmed and four probables at no loss.[6] As a result of this action, British flying boats were dazzle-painted to aid identification in combat.



Felixstowe F5L under construction at the Naval Aircraft Factory, Philadelphia, circa 1920.

The Curtiss Aeroplane and Motor Company independently developed its designs into the small Model "F", the larger Model "K" (several of which were sold to the Russian Naval Air Service), and the Model "C" for the U.S. Navy. Curtiss among others also built the Felixstowe F.5 as the Curtiss F5L, based on the final Porte hull designs and powered by American Liberty engines.

Meanwhile, the pioneering flying boat designs of François Denhaut had been steadily developed by the Franco-British Aviation Company into a range of practical craft. Smaller than the Felixstowes, several thousand FBAs served with almost all of the Allied forces as reconnaissance craft, patrolling the North Sea, Atlantic and Mediterranean oceans.

In Italy several seaplanes were developed, starting with the L series, and progressing with the M series. The Macchi M.5 in particular was extremely manoeuvrable and agile and matched the land-based aircraft it had to fight. 244 were built in total. Towards the end of World War I, the aircraft were flown by the Italian Navy Aviation, the United States Navy and United States Marine Corps airmen. Ensign Charles Hammann won the first Medal of Honor awarded to a United States naval aviator in an M.5

The Aeromarine Plane and Motor Company built some of the biggest sea planes of the time in Keyport, New Jersey. Mr.Uppercu built the factory on a 66-acre site in 1917 and Built the Aeromarine 75 and Aeromarine AMC flying Boats which with Aeromarine West Indies Airways flew Air Mail to Florida, Bahamas, and Cuba along with being passenger carriers.

The German aircraft manufacturing company Hansa-Brandenburg built flying boats starting with the model Hansa-Brandenburg GW in 1916. The Austro-Hungarian firm, Lohner-Werke began building flying boats, starting with the Lohner E in 1914 and the later (1915) influential Lohner L version.

Between the wars

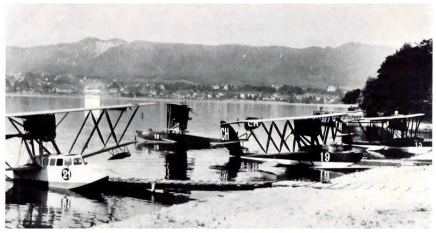
In September 1919 British company Supermarine started operating the first flying boat service in the world, from Woolston to Le Havre in France, but it was short-lived.

Two Supermarine Southamptons

A Curtiss NC-4 became the first aircraft to fly across the Atlantic Ocean in 1919, crossing via the Azores. Of the four that made the attempt, only one completed the flight. Before the development of highly reliable aircraft, the ability to land on water was a desirable safety feature for transoceanic travel.[16]

In 1923, the first successful commercial flying boat service was introduced with flights to and from the Channel Islands. The British aviation industry was experiencing rapid growth. The Government decided that nationalization was necessary and ordered five aviation companies to merge to form the state-owned Imperial Airways of London (IAL). IAL became the international flag-carrying British airline, providing flying boat passenger and mail transport links between Britain and South Africa using aircraft such as the Short S.8 Calcutta.

In 1928, four Supermarine Southampton flying boats of the RAF Far East flight arrived in Melbourne, Australia. The flight was considered proof that flying boats had evolved to become reliable means of long distance transport.



Flying boats of Ad Astra Aero S.A. at Zürichhorn water airport, Uetliberg in the background (~1920)

In the 1930s, flying boats made it possible to have regular air transport between the U.S. and Europe, opening up new air travel routes to South America, Africa, and Asia. Foynes, Ireland and Botwood, Newfoundland and Labrador were the termini for many early transatlantic flights. In areas where there were no airfields for land-based aircraft, flying boats could stop at small island, river, lake or coastal stations to refuel and resupply. The Pan Am Boeing 314 "Clipper" planes brought exotic destinations like the Far East within reach of air travelers and came to represent the romance of flight.

By 1931, mail from Australia was reaching Britain in just 16 days – less than half the time taken by sea. In that year, government tenders on both sides of the world invited applications to run new passenger and mail services between the ends of the British Empire, and Qantas and IAL were successful with a joint bid. A company under combined ownership was then formed, Qantas Empire Airways. The new ten-day service between Rose Bay, New South Wales (near Sydney) and Southampton was such a success with letter-writers that before long the volume of mail was exceeding aircraft storage space.

A solution to the problem was found by the British government, who in 1933 had requested aviation manufacturer Short Brothers to design a big new long-range monoplane for use by IAL. Partner Qantas agreed to the initiative and undertook to purchase six of the new Short S23 "C" class or "Empire" flying boats.

Delivering the mail as quickly as possible generated a lot of competition and some innovative designs. One variant of the Short Empire flying boats was the strange-looking "Maia and Mercury". It was a four-engined floatplane "Mercury" (the winged messenger) fixed on top of "Maia", a heavily modified Short Empire flying boat.[7] The larger Maia took off, carrying the smaller Mercury loaded to a weight greater than it could take off with. This allowed the Mercury to carry sufficient fuel for a direct trans-Atlantic flight with the mail. Unfortunately this was of limited usefulness, and the Mercury had to be returned from America by ship. The Mercury did set a number of distance records before in-flight refuelling was adopted.

Dornier Do X over a seaport town in the Baltic, 1930

Sir Alan Cobham devised a method of in-flight refuelling in the 1930s. In the air, the Short Empire could be loaded with more fuel than it could take off with. Short Empire flying boats serving the trans-Atlantic crossing were refueled over Foynes; with the extra fuel load, they could make a direct trans-Atlantic flight.[7] A Handley Page H.P.54 Harrow was used as the fuel tanker.[7]

The German Dornier Do X flying boat was noticeably different from its UK and U.S.-built counterparts. It had wing-like protrusions from the fuselage, called sponsons, to stabilize it on the water without the need for wing-mounted outboard floats. This feature was pioneered by Claudius Dornier during World War I on his Dornier Rs. I giant flying boat, and perfected on the Dornier Wal in 1924. The enormous Do X was powered by 12 engines and once carried 170 persons as a publicity stunt.[7] It flew to America in 1930–31,[7] crossing the Atlantic via an indirect route over 9 months. It was the largest flying boat of its time, but was severely underpowered and was limited by a very low operational ceiling. Only three were built, with a variety of different engines installed, in an attempt to overcome the lack of power. Two of these were sold to Italy.

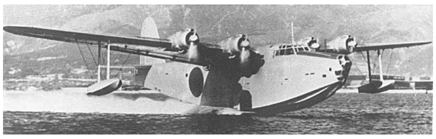
The Dornier Wal was "easily the greatest commercial success in the history of marine aviation".[17] Over 250 were built in Italy, Spain, Japan, The Netherlands and Germany. Numerous airlines operated the Dornier Wal on scheduled passenger and mail services.[18] Wals were used by explorers, for a number of pioneering flights, and by the military in many countries. Though having first flown in 1922, from 1934 to 1938 Wals operated the over-water sectors of the Deutsche Luft Hansa South Atlantic Airmail service.[19][20]

World War II

The military value of flying boats was well-recognized, and every country bordering on water operated them in a military capacity at the outbreak of the war. They were utilized in various tasks from anti-submarine patrol to air-sea rescue and gunfire spotting for battleships. Aircraft such as the PBM Mariner patrol bomber, PBY Catalina, Short Sunderland, and Grumman Goose recovered downed airmen and operated as scout aircraft over the vast distances of the Pacific Theater and the Atlantic. They also sank numerous submarines and found enemy ships. In May 1941 the German battleship *Bismarck* was discovered by a PBY Catalina flying out of Castle Archdale Flying boat base, Lower Lough Erne, Northern Ireland.[21][22]

PBY Catalina

The largest flying boat of the war was the Blohm & Voss BV 238, which was also the heaviest plane to fly during World War II and the largest aircraft built and flown by any of the Axis Powers.

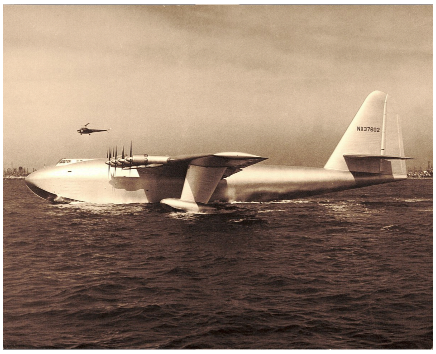


Kawanishi H8K, 1941–1945

In November 1939, IAL was restructured into three separate companies: British European Airways, British Overseas Airways Corporation (BOAC), and British South American Airways (which merged with BOAC in 1949), with the change being made official on 1 April 1940. BOAC continued to operate flying boat services from the (slightly) safer confines of Poole Harbour during wartime, returning to Southampton in 1947.[7] When Italy entered the war in June 1940, the Mediterranean was closed to allied planes and BOAC and Qantas operated the Horseshoe Route between Durban and Sydney using Short Empire flying boats.

The Martin Company produced the prototype XPB2M Mars based on their PBM Mariner patrol bomber, with flight tests between 1941 and 1943. The Mars was converted by the Navy into a transport aircraft designated the XPB2M-1R. Satisfied with the performance, 20 of the modified JRM-1 Mars were ordered. The first, named *Hawaii Mars*, was delivered in June 1945, but the Navy scaled back their order at the end of World War II, buying only the five aircraft which were then on the production line. The five Mars were completed, and the last delivered in 1947.[23]

Post-War



Hughes H-4 Hercules

After World War II the use of flying boats rapidly declined for several reasons. The ability to land on water became less of an advantage owing to the considerable increase in the number and length of land based runways during World War II. Further, as the reliability, speed, and range of land-based aircraft increased, the commercial competitiveness of flying boats diminished; their design compromised aerodynamic efficiency and speed to accomplish the feat of waterborne takeoff and landing. Competing with new civilian jet aircraft like the de Havilland Comet and Boeing 707 proved impossible.

The Hughes H-4 Hercules, in development in the U.S. during the war, was even larger than the BV 238 but it did not fly until 1947. The *Spruce Goose*, as the 180-ton H-4 was nicknamed, was the largest flying boat ever to fly. Carried out during Senate hearings into Hughes use of government funds on its construction, the short hop of about a mile at 70 ft above the water by the "Flying Lumberyard" was claimed by Hughes as vindication of his efforts. Cutbacks in expenditure after the war and the disappearance of its intended mission as a transatlantic transport left it no purpose.[24]

In 1944, the Royal Air Force began development of a small jet-powered flying boat that it intended to use as an air defence aircraft optimised for the Pacific, where the relatively calm sea conditions made the use of seaplanes easier. By making the aircraft jet powered, it was possible to design it with a hull rather than making it a floatplane. The Saunders-Roe SR.A/1 prototype first flew in 1947 and was relatively successful in terms of its performance and handling. However, by the end of the war, carrier based aircraft were becoming more sophisticated, and the need for the SR.A/1 evaporated.

During the Berlin Airlift (which lasted from June 1948 until August 1949) 10 Sunderlands and two Hythes were used to transport goods from Finkenwerder on the Elbe near Hamburg to isolated Berlin, landing on the Havelsee beside RAF Gatow until it iced over. The Sunderlands were particularly used for transporting salt, as their airframes were already protected against corrosion from seawater. Transporting salt in standard aircraft risked rapid and severe structural corrosion in the event of a spillage. In addition, three Aquila Airways flying boats were used during the airlift.[7] This is the only known operational use of flying boats within central Europe.

The U.S. Navy continued to operate flying boats (notably the Martin P5M Marlin) until the late 1960s. The Navy even attempted to build a jet-powered seaplane bomber, the Martin Seamaster.

BOAC ceased flying boat services out of Southampton in November 1950.

Bucking the trend, in 1948 Aquila Airways was founded to serve destinations that were still inaccessible to land-based aircraft.[7] This company operated Short S.25 and Short S.45 flying boats out of Southampton on routes to Madeira, Las Palmas, Lisbon, Jersey, Majorca, Marseille, Capri, Genoa, Montreux and Santa Margherita.[7] From 1950 to 1957, Aquila also operated a service from Southampton to Edinburgh and Glasgow.[7] The flying boats of Aquila Airways were also chartered for one-off trips, usually to deploy troops where scheduled services did not exist or where there were political considerations. The longest charter, in 1952, was from Southampton to the Falkland Islands.[7] In 1953 the flying boats were chartered for troop deployment trips to Freetown and Lagos and there was a special trip from Hull to Helsinki to relocate a ship's crew.[7] The airline ceased operations on 30 September 1958.[7]

The technically advanced Saunders-Roe Princess first flew in 1952 and later received a certificate of airworthiness. Despite being the pinnacle of flying boat development none were sold, though Aquila Airways reportedly attempted to buy them.[7] Of the three Princesses that were built, two never flew, and all were scrapped in 1967.

Ansett Australia operated a flying boat service from Rose Bay to Lord Howe Island until 1974, using Short Sandringhams.

Saunders-Roe Princess G-ALUN at the Farnborough SBAC Show in September 1953

Flying boats today

The shape of the Short Empire, a British flying boat of the 1930s was a harbinger of the shape of 20th century aircraft yet to come. Today, however, true flying boats have largely been replaced by seaplanes with floats and amphibian aircraft with wheels. The Beriev Be-200 twin-jet amphibious aircraft has been one of the closest "living" descendants of the earlier flying boats, along with the larger amphibious planes used for fighting forest fires. There are also several experimental/kit amphibians such as the Volmer Sportsman, Quikkit Glass Goose, Airmax Sea Max, Aeroprakt A-24, and Seawind 300C.

The ShinMaywa US-2 is a large STOL amphibious aircraft designed for air-sea rescue work. The US-2 is operated by the Japan Maritime Self Defense Force.

The Canadair CL-215 and successor Bombardier 415 are examples of modern flying boats and are used for forest fire suppression.

Dornier announced plans in May 2010 to build CD2 SeaStar composite flying boats in Quebec, Canada.

The Chinese state owned Aviation Industry Corporation of China is set to launch a massive new AVIC TA-600 amphibious airplane in 2016.[25]

The ICON A5 is an amphibious aircraft in the light-sport class.

Gallery

Chinese Harbin/Shuihong 5

U.S. PBY Catalina serving as an aerial firefighting plane

Japanese ShinMaywa US-2

Canadair CL-215

Canadair CL-415

Russian Beriev Be-200

ICON A5

See also

- Ground effect vehicle
- List of seaplanes and amphibious aircraft
- Maritime patrol aircraft

References

Notes

1. **^** E. R. Johnson, American Flying Boats and Amphibious Aircraft: An Illustrated History, McFarland and Company, Inc., ISBN 978-0-7864-3974-4
2. ^ ***a b c d e*** *Flying Boats & Seaplanes: A History from 1905*, Stéphane Nicolaou
3. **^** Naughton, Russell. Henri Fabre (1882–1984)." *Monash University Centre for Telecommunications and Information Engineering*, 15 May 2002. Retrieved: 9 May 2008
4. **^** Anonymous (2009) The establishment of the Navy Airforce, Fox2 Magazine (in Greek language) Archived 3 December 2013 at the Wayback Machine.
5. **^** *Nicolaou, Stephane (1998) [1996], Flying Boats & Seaplanes: A history from 1905, translated by Robin Sawers, Devon: Bay Books View Ltd, p. 9, ISBN 1901432203*
6. ^ ***a b c*** The Felixstowe Flying Boats, *Flight* 2 December 1955
7. ^ ***a b c d e f g h i j k l m n o p q*** Hull, Norman. *Flying Boats of the Solent: A Portrait of a Golden Age of Air Travel* (Aviation Heritage). Great Addington, Kettering, Northants, UK: Silver Link Publishing, 2002. ISBN 1-85794-161-6.
8. **^** *Carpenter, Jr, G. J. (Jack) (2005). "Photographs 1914". GLENN H. CURTISS Founder of The American Aviation Industry. Internet Archive - Way Back Machine. Archived from the original on 20 October 2006. Retrieved 15 December 2015.*
9. **^** Bruce *Flight* 2 December 1955, p.844.
0. **^** London 2003, pp. 16–17.
1. **^** Hallam 1919, pp. 21–22.
2. **^** "Felixstowe." Archived 1 September 2006 at the Wayback Machine. *NASM.* Retrieved: 20 May 2012.
3. **^** London 2003, pp. 24–25.
4. **^** Bruce *Flight* 2 December 1955, p. 846.
5. **^** "Felixstowe Flying-Boats." *Will Higgs Co, United Kingdom.* Retrieved: 24 December 2009.
6. **^** *"Engines of Our Ingenuity No. 1988: THE SARO PRINCESS".*
7. **^** Stéphane Nicolaou FLYING BOATS & SEAPLANES A History from 1905, Bay View Books Ltd Bideford Devon 1998 (English translation, originally published in French - copyright ETAI, Paris 1996)
8. **^** Gandt, Robert L. CHINA CLIPPER - The Age of the Great Flying Boats, Naval Institute Press, Annapolis Maryland 1991 ISBN 0-87021-209-5
9. **^** *"First Transatlantic air line", Popular Science, February 1933*
0. **^** James W. Graue & John Duggan "Deutsche Lufthansa South Atlantic Airmail Service 1934 - 1939", Zeppelin Study Group, Ickenham, UK 2000 ISBN 0-9514114-5-4
1. **^** *"Flying-boats in Fermanagh". Inland Waterways News. Inland Waterways Association of Ireland. Spring 2002. Archived from the original on 20 July 2012. Retrieved 20 May 2012.*
2. **^** *"Castle Archdale Country Park". Northern Ireland Environment Agency. Archived from the original on 1 May 2009. Retrieved 19 June 2009.*
3. **^** Goebel, Greg. "The Martin Mariner, Mars, & Marlin Flying Boats." *Vectorsite.* Retrieved: 20 May 2012.
4. **^** Its claim to true flying status is disputed as it made but one short flight in its life
5. **^** *Slepian, Katya. "Test pilot school a success for Martin Mars – Alberni Valley News". Alberni Valley News. Archived from the original on 4 March 2016. Retrieved 27 February 2016.*

Bibliography

- Davies, R.E.G. *Pan Am: An Airline and its Aircraft*. New York: Orion Books, 1987. ISBN 0-517-56639-7.
- Yenne, Bill. *Seaplanes & Flying Boats: A Timeless Collection from Aviation's Golden Age*. New York: BCL Press, 2003. ISBN 1-932302-03-4.

External links

Wikimedia Commons has media related to ***Flying boats***.

- When Boats Had Wings, June 1963 detail article *Popular Science*

Technical Aspects

Propeller

A **propeller** is a type of fan that transmits power by converting rotational motion into thrust. A pressure difference is produced between the forward and rear surfaces of the airfoil-shaped blade, and a fluid (such as air or water) is accelerated behind the blade. Propeller dynamics, like those of aircraft wings, can be modelled by Bernoulli's principle and Newton's third law. Most marine propellers are ***screw propellers*** with fixed helical blades rotating around a horizontal (or nearly horizontal) axis or propeller shaft.

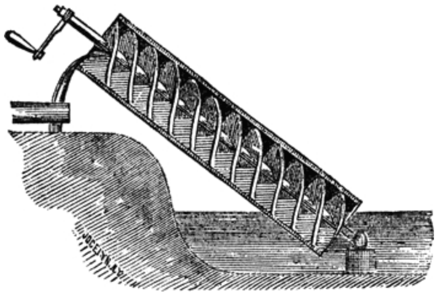
History

Early developments

The principle employed in using a screw propeller is used in sculling. It is part of the skill of propelling a Venetian gondola but was used in a less refined way in other parts of Europe and probably elsewhere. For example, propelling a canoe with a single paddle using a "pitch stroke" or side slipping a canoe with a "scull" involves a similar technique. In China, sculling, called "lu", was also used by the 3rd century AD.

In sculling, a single blade is moved through an arc, from side to side taking care to keep presenting the blade to the water at the effective angle. The innovation introduced with the screw propeller was the extension of that arc through more than 360° by attaching the blade to a rotating shaft. Propellers can have a single blade, but in practice there are nearly always more than one so as to balance the forces involved.

The origin of the screw propeller starts with Archimedes, who used a screw to lift water for irrigation and bailing boats, so famously that it became known as Archimedes' screw. It was probably an application of spiral movement in space (spirals were a special study of Archimedes) to a hollow segmented water-wheel used for irrigation by Egyptians for centuries. Leonardo da Vinci adopted the principle to drive his theoretical helicopter, sketches of which involved a large canvas screw overhead.


Archimedes' screw

In 1661, Toogood and Hays proposed using screws for waterjet propulsion, though not as a propeller.[1] Robert Hook in 1681 designed a horizontal watermill which was remarkably similar to the Kirsten-Boeing vertical axis propeller designed almost two and a half centuries later in 1928; two years later Hook modified the design to provide motive power for ships through water.[2] In 1752, the *Academie des Sciences* in Paris granted Burnelli a prize for a design of a propeller-wheel. At about the same time, the French mathematician Alexis-Jean-Pierre Paucton, suggested a water propulsion system based on the Archimedean screw.[3] In 1771, steam-engine inventor James Watt in a private letter suggested using "spiral oars" to propel boats, although he did not use them with his steam engines, or ever implement the idea.[4]

The first practical & applied use of a propeller on a submarine dubbed *Turtle* which was designed in New Haven, Connecticut, in 1775 by Yale student and inventor David Bushnell, with the help of the clock maker, engraver, and brass foundryman Isaac Doolittle, and with Bushnell's brother Ezra Bushnell and ship's carpenter and clock maker Phineas Pratt constructing the hull in Saybrook, Connecticut.[5][6] On the night of September 6, 1776, Sergeant Ezra Lee piloted *Turtle* in an attack on HMS *Eagle* in New York Harbor.[7][8] *Turtle* also has the distinction of being the first submarine used in battle. Bushnell later described the propeller in an October 1787 letter to Thomas Jefferson: "An oar formed upon the principle of the screw was fixed in the forepart of the vessel its axis entered the vessel and being turned one way rowed the vessel forward but being turned the other way rowed it backward. It was made to be turned by the hand or foot."[9] The brass propeller, like all the brass and moving parts on *Turtle*, was crafted by the "ingenious mechanic" Issac Doolittle of New Haven.[10]

In 1785, Joseph Bramah in England proposed a propeller solution of a rod going through the underwater aft of a boat attached to a bladed propeller, though he never built it.[11] In 1802, Edward Shorter proposed using a similar propeller attached to a rod angled down temporarily deployed from the deck above the waterline and thus requiring no water seal, and intended only to assist becalmed sailing vessels. He tested it on the transport ship *Doncaster* in Gibraltar and at Malta, achieving a speed of 1.5 mph (2.4 km/h).[12]

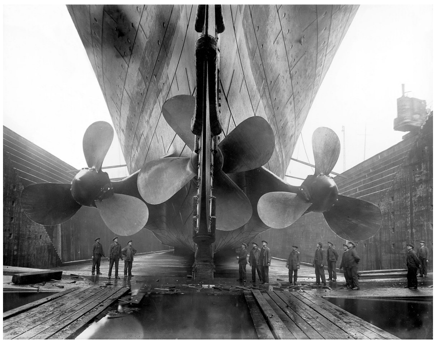
The lawyer and inventor John Stevens in the United States, built a 25-foot (7.6 m) boat with a rotary stem engine coupled to a four-bladed propeller, achieving a speed of 4 mph (6.4 km/h), but he abandoned propellers due to the inherent danger in using the high-pressure steam engines, and instead built paddle-wheeled boats.[13]

By 1827, Czech-Austrian inventor Josef Ressel had invented a screw propeller which had multiple blades fastened around a conical base. He had tested his propeller in February 1826 on a small ship that was manually driven. He was successful in using his bronze screw propeller on an adapted steamboat (1829). His ship, *Civetta* of 48 gross register tons, reached a speed of about 6 knots (11 km/h). This was the first ship successfully driven by an Archimedes screw-type propeller. After a new steam engine had an accident (cracked pipe weld) his experiments were banned by the Austro-Hungarian police as dangerous. Josef Ressel was at the time a forestry inspector for the Austrian Empire. But before this he received an Austro-Hungarian patent (license) for his propeller (1827). He died in 1857. This new method of propulsion was an improvement over the paddlewheel as it was not so affected by either ship motions or changes in draft as the vessel burned coal.[14]

John Patch, a mariner in Yarmouth, Nova Scotia developed a two-bladed, fan-shaped propeller in 1832 and publicly demonstrated it in 1833, propelling a row boat across Yarmouth Harbour and a small coastal schooner at Saint John, New Brunswick, but his patent application in the United States was rejected until 1849 because he was not an American citizen.[15] His efficient design drew praise in American scientific circles[16] but by this time there were multiple competing versions of the marine propeller.

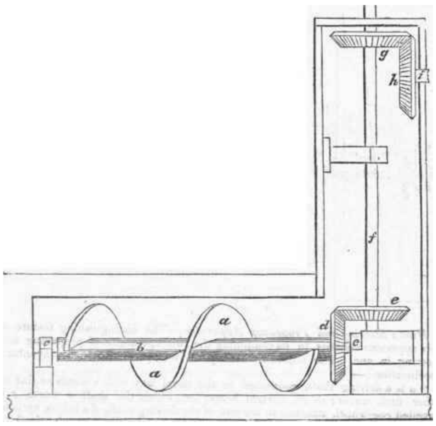
Screw propellers

Although there was much experimentation with screw propulsion until the 1830s, few of these inventions were pursued to the testing stage, and those that were proved unsatisfactory for one reason or another.[17]



Propellers of RMS Olympic, a sister ship to RMS Titanic and HMHS Britannic

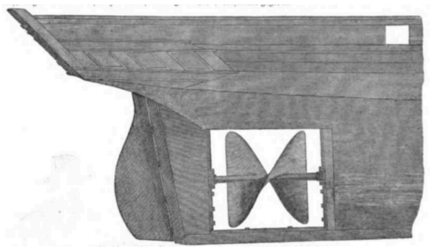
In 1835, two inventors in Britain, John Ericsson and Francis Pettit Smith, began working separately on the problem. Smith was first to take out a screw propeller patent on 31 May, while Ericsson, a gifted Swedish engineer then working in Britain, filed his patent six weeks later.[18] Smith quickly built a small model boat to test his invention, which was demonstrated first on a pond at his Hendon farm, and later at the Royal Adelaide Gallery of Practical Science in London, where it was seen by the Secretary of the Navy, Sir William Barrow. Having secured the patronage of a London banker named Wright, Smith then built a 30-foot (9.1 m), 6-horsepower (4.5 kW) canal boat of six tons burthen called *Francis Smith*, which was fitted with a wooden propeller of his own design and demonstrated on the Paddington Canal from November 1836 to September 1837. By a fortuitous accident, the wooden propeller of two turns was damaged during a voyage in February 1837, and to Smith's surprise the broken propeller, which now consisted of only a single turn, doubled the boat's previous speed, from about four miles an hour to eight.[18] Smith would subsequently file a revised patent in keeping with this accidental discovery.



Smith's original 1836 patent for a screw propeller of two full turns. He would later revise the patent, reducing the length to one turn.

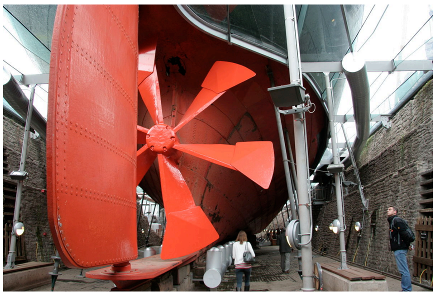
In the meantime, Ericsson built a 45-foot (14 m) screw-propelled steamboat, *Francis B. Ogden* in 1837, and demonstrated his boat on the River Thames to senior members of the British Admiralty, including Surveyor of the Navy Sir William Symonds. In spite of the boat achieving a speed of 10 miles an hour, comparable with that of existing paddle steamers, Symonds and his entourage were unimpressed. The Admiralty maintained the view that screw propulsion would be ineffective in ocean-going service, while

Symonds himself believed that screw propelled ships could not be steered efficiently.[19] Following this rejection, Ericsson built a second, larger screw-propelled boat, *Robert F. Stockton*, and had her sailed in 1839 to the United States, where he was soon to gain fame as the designer of the U.S. Navy's first screw-propelled warship, USS *Princeton*.[20]



Screw propeller of SS Archimedes

Apparently aware of the Navy's view that screw propellers would prove unsuitable for seagoing service, Smith determined to prove this assumption wrong. In September 1837, he took his small vessel (now fitted with an iron propeller of a single turn) to sea, steaming from Blackwall, London to Hythe, Kent, with stops at Ramsgate, Dover and Folkestone. On the way back to London on the 25th, Smith's craft was observed making headway in stormy seas by officers of the Royal Navy. The Admiralty's interest in the technology was revived, and Smith was encouraged to build a full size ship to more conclusively demonstrate the technology's effectiveness.[21]



A replica of SS Great Britain's first propeller was created for this museum ship. The real propeller was replaced with a four-bladed model in 1845. SS Great Britain was initially designed to have paddles but the design was modified after screw propellers were proven to be more effective and efficient.

SS *Archimedes* was built in 1838 by Henry Wimshurst of London, as the world's first steamship[22] to be driven by a screw propeller[23][24][25][26]

Archimedes had considerable influence on ship development, encouraging the adoption of screw propulsion by the Royal Navy, in addition to her influence on commercial vessels. Trials with Smith's *Archimedes* led to the famous tug-of-war competition in 1845 between the screw-driven HMS *Rattler* and the paddle steamer HMS *Alecto*; the former pulling the latter backward at 2.5 knots (4.6 km/h).

She also had a direct influence on the design of another innovative vessel, Isambard Kingdom Brunel's SS *Great Britain* in 1843, then the world's largest ship and the first screw-propelled steamship to cross the Atlantic Ocean in August 1845.

HMS *Terror* and HMS *Erebus* were both heavily modified to become the first Royal Navy ships to have steam-powered engines and screw propellers. Both participated in the doomed expedition, last seen by Europeans in July 1845 near Baffin Bay.

Propeller design stabilized in the 1880s.

Aircraft propellers

The twisted aerofoil shape of modern aircraft propellers was pioneered by the Wright brothers. While some earlier engineers had attempted to model air propellers on marine propellers, the Wrights realized that a propeller is essentially the same as a wing, and were able to use data from their earlier wind tunnel experiments on wings. They also introduced a twist along the length of the blades. This was necessary to ensure the angle of attack of the blades was kept relatively constant along their length.[27] Their original propeller blades were only about 5% less efficient than the modern equivalent, some 100 years later.[28] The understanding of low speed propeller aerodynamics was fairly complete by the 1920s, but later requirements to handle more power in smaller diameter have made the problem more complex.

Alberto Santos Dumont, another early pioneer, applied the knowledge he gained from experiences with airships to make a propeller with a steel shaft and aluminium blades for his 14 bis biplane. Some of his designs used a bent aluminium sheet for blades, thus creating an airfoil shape. They were heavily undercambered, and this plus the absence of lengthwise twist made them less efficient than the Wright propellers. Even so, this was perhaps the first use of aluminium in the construction of an airscrew.

Propeller theory

History

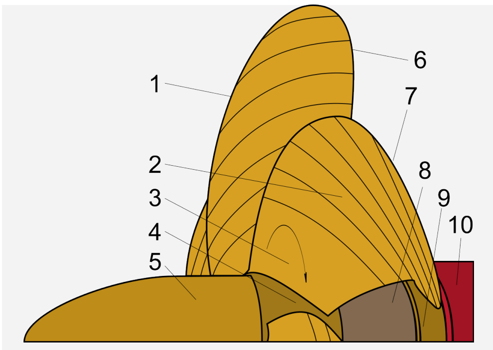
In the second half of the nineteenth century, several theories were developed. The momentum theory or disk actuator theory – a theory describing a mathematical model of an ideal propeller – was developed by W.J.M. Rankine (1865), Alfred George Greenhill (1888) and R.E. Froude (1889). The propeller is modelled as an infinitely thin disc, inducing a constant velocity along the axis of rotation. This disc creates a flow around the propeller. Under certain mathematical premises of the fluid, there can be extracted a mathematical connection between power, radius of the propeller, torque and induced velocity. Friction is not included.

The blade element theory (BET) is a mathematical process originally designed by William Froude (1878), David W. Taylor (1893) and Stefan Drzewiecki to determine the behaviour of propellers. It involves breaking an airfoil down into several small parts then determining the forces on them. These forces are then converted into accelerations, which can be integrated into velocities and positions.

Theory of operation

A propeller is the most common propulsor on ships, imparting momentum to a fluid which causes a force to act on the ship. The ideal efficiency of any propulsor is that of an actuator disc in an ideal fluid. This is called the Froude efficiency and is a natural limit which cannot be exceeded by any device, no matter how good it is. Any propulsor which has virtually zero slip in the water, whether this is a very large propeller or a huge drag device, approaches 100% Froude efficiency. The essence of the actuator-disc theory is that if the slip is defined as the ratio of fluid velocity increase through the disc to vehicle velocity, the Froude efficiency is equal to 1/(slip + 1)[29]. Thus a lightly loaded propeller with a large swept area can have a high Froude efficiency.

Marine propeller nomenclature



1) Trailing edge	6) Leading edge
2) Face	7) Back
3) Fillet area	8) Propeller shaft
4) Hub or Boss	9) Stern tube bearing
5) Hub or Boss Cap	10) Stern tube

An actual propeller has blades made up of sections of helicoidal surfaces which can be thought to 'screw' through the fluid (hence the common reference to propellers as "screws"). Actually the blades are twisted airfoils or hydrofoils and each section contributes to the total thrust. Two to five blades are most common, although designs which are intended to operate at reduced noise will have more blades and one-bladed ones with a counterweight have also been used. Lightly loaded propellers for light aircraft and human-powered boats mostly have two blades, motor boats mostly have three blades. The blades are attached to a *boss* (hub), which should be as small as the needs of strength allow – with fixed-pitch propellers the blades and boss are usually a single casting.

An alternative design is the controllable-pitch propeller (CPP, or CRP for controllable-reversible pitch), where the blades are rotated normally to the drive shaft by additional machinery – usually hydraulics – at the hub and control linkages running down the shaft. This allows the drive machinery to operate at a constant speed while the propeller loading is changed to match operating conditions. It also eliminates the need for a reversing gear and allows for more rapid change to thrust, as the revolutions are constant. This type of propeller is most common on ships such as tugs where there can be enormous differences in propeller loading when towing compared to running free. The downsides of a CPP/CRP include: the large hub which decreases the torque required to cause cavitation, the mechanical complexity which limits transmission power and the extra blade shaping requirements forced upon the propeller designer.

For smaller motors there are self-pitching propellers. The blades freely move through an entire circle on an axis at right angles to the shaft. This allows hydrodynamic and centrifugal forces to 'set' the angle the blades reach and so the pitch of the propeller.

A propeller that turns clockwise to produce forward thrust, when viewed from aft, is called right-handed. One that turns anticlockwise is said to be left-handed. Larger vessels often have twin screws to reduce *heeling torque*, counter-rotating propellers, the starboard screw is usually right-handed and the port left-handed, this is called outward turning. The opposite case is called inward turning. Another possibility is contra-rotating propellers, where two propellers rotate in opposing directions on a single shaft, or on separate shafts on nearly the same axis. Contra-rotating propellers offer increased efficiency by capturing the energy lost in the tangential velocities imparted to the fluid by the forward propeller (known as "propeller swirl"). The flow field behind the aft propeller of a contra-rotating set has very little "swirl", and this reduction in energy loss is seen as an increased efficiency of the aft propeller.

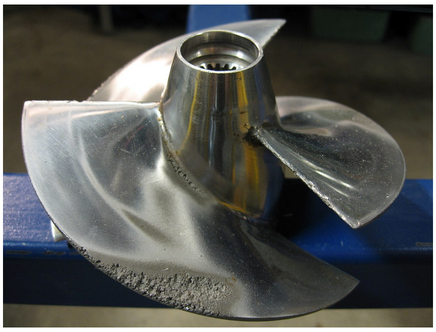
An azimuthing propeller is a propeller that turns around the vertical axis. The individual airfoil-shaped blades turn as the propeller moves so that they are always generating lift in the vessel's direction of movement. This type of propeller can reverse or change its direction of thrust very quickly.

Fixed-wing aircraft are also subject to the P-factor effect, in which a rotating propeller will yaw an aircraft slightly to one side because the relative wind it produces is asymmetrical. It is particularly noticeable when climbing, but is usually simple to compensate for with the aircraft's rudder. A more serious situation can exist if a multi-engine aircraft loses power to one of its engines, in particular the one which is positioned on the side that enhances the P-factor. This power plant is called the critical engine and its loss will require more control compensation by the pilot.

Marine propeller cavitation

Cavitation is the formation of vapor bubbles in water near a moving propeller blade in regions of low pressure due to Bernoulli's principle. It can occur if an attempt is made to transmit too much power through the screw, or if the propeller is operating at a very high speed. Cavitation can waste power, create vibration and wear, and cause damage to the propeller. It can occur in many ways on a propeller. The two most common types of propeller cavitation are suction side surface cavitation and tip vortex cavitation.

Cavitating propeller in water tunnel experiment



Cavitation damage evident on the propeller of a personal watercraft.

Suction side surface cavitation forms when the propeller is operating at high rotational speeds or under heavy load (high blade lift coefficient). The pressure on the upstream surface of the blade (the "suction side") can drop below the vapor pressure of the water, resulting in the formation of a vapor pocket. Under such conditions, the change in pressure between the downstream surface of the blade (the "pressure side") and the suction side is limited, and eventually reduced as the extent of cavitation is increased. When most of the blade surface is covered by cavitation, the pressure difference between the pressure side and suction side of the blade drops considerably, as does the thrust produced by the propeller. This condition is called "thrust breakdown". Operating the propeller under these conditions wastes energy, generates considerable noise, and as the vapor bubbles collapse it rapidly erodes the screw's surface due to localized shock waves against the blade surface.

Tip vortex cavitation is caused by the extremely low pressures formed at the core of the tip vortex. The tip vortex is caused by fluid wrapping around the tip of the propeller; from the pressure side to the suction side. This video demonstrates tip vortex cavitation. Tip vortex cavitation typically occurs before suction side surface cavitation and is less damaging to the blade, since this type of cavitation doesn't collapse on the blade, but some distance downstream.

Cavitation can be used as an advantage in design of very high performance propellers, in form of the supercavitating propeller. In this case, the blade section is designed such that the pressure side stays wetted while the suction side is completely covered by cavitation vapor. Because the suction side is covered with vapor instead of water it encounters very low viscous friction, making the supercavitating (SC) propeller comparably efficient at high speed. The shaping of SC blade sections however, make it inefficient at low speeds, when the suction side of the blade is wetted. (See also fluid dynamics).

A similar, but quite separate issue, is *ventilation*, which occurs when a propeller operating near the surface draws air into the blades, causing a similar loss of power and shaft vibration, but without the related potential blade surface damage caused by cavitation. Both effects can be mitigated by increasing the submerged depth of the propeller: cavitation is reduced because the hydrostatic pressure increases the margin to the vapor pressure, and ventilation because it is further from surface waves and other air pockets that might be drawn into the slipstream.

The blade profile of propellers designed to operate in a ventilated condition is often not of an aerofoil section and is a blunt ended taper instead. These are often known as "chopper" type propellers.

14-ton propeller from Voroshilov, a Kirov-class cruiser on display in Sevastopol

Forces acting on a foil

The force (F) experienced by a foil is determined by its area (A), fluid density (ρ), velocity (V) and the angle of the foil to the fluid flow, called *angle of attack* (α), where:

$$\frac{F}{\rho A V^2} = f(R_n, \alpha)$$

The force has two parts – that normal to the direction of flow is *lift* (L) and that in the direction of flow is *drag* (D). Both can be expressed mathematically:

and

where C_L and C_D are lift coefficient and drag coefficient respectively.

Each coefficient is a function of the angle of attack and Reynolds number. As the angle of attack increases lift rises rapidly from the *no lift angle* before slowing its increase and then decreasing, with a sharp drop as the *stall angle* is reached and flow is disrupted. Drag rises slowly at first and as the rate of increase in lift falls and the angle of attack increases drag increases more sharply.

For a given strength of circulation (), . The effect of the flow over and the circulation around the foil is to reduce the velocity over the face and increase it over the back of the blade. If the reduction in pressure is too much in relation to the ambient pressure of the fluid, *cavitation* occurs, bubbles form in the low pressure area and are moved towards the blade's trailing edge where they collapse as the pressure increases, this reduces propeller efficiency and increases noise. The forces generated by the bubble collapse can cause permanent damage to the surfaces of the blade.

Propeller thrust Equation

Single blade

Taking an arbitrary radial section of a blade at *r*, if revolutions are *N* then the rotational velocity is . If the blade was a complete screw it would advance through a solid at the rate of *NP*, where *P* is the pitch of the blade. In water the advance speed is rather lower, , the difference, or *slip ratio*, is:

where is the *advance coefficient*, and is the *pitch ratio*.

The forces of lift and drag on the blade, *dA*, where force normal to the surface is *dL*:

where:

These forces contribute to thrust, *T*, on the blade:

where:

As ,

From this total thrust can be obtained by integrating this expression along the blade. The transverse force is found in a similar manner:

Substituting for and multiplying by *r*, gives torque as:

which can be integrated as before.

The total thrust power of the propeller is proportional to and the shaft power to . So efficiency is . The blade efficiency is in the ratio between thrust and torque:

showing that the blade efficiency is determined by its momentum and its qualities in the form of angles and , where is the ratio of the drag and lift coefficients.

This analysis is simplified and ignores a number of significant factors including interference between the blades and the influence of tip vortices.

Thrust and torque

The thrust, *T*, and torque, *Q*, depend on the propeller's diameter, *D*, revolutions, *N*, and rate of advance, , together with the character of the fluid in which the propeller is operating and gravity. These factors create the following non-dimensional relationship:

where is a function of the advance coefficient, is a function of the Reynolds' number, and is a function of the Froude number. Both and are likely to be small in comparison to under normal operating conditions, so the expression can be reduced to:

For two identical propellers the expression for both will be the same. So with the propellers , and using the same subscripts to indicate each propeller:

For both Froude number and advance coefficient:

where is the ratio of the linear dimensions.

Thrust and velocity, at the same Froude number, give thrust power:

For torque:

Actual performance

When a propeller is added to a ship its performance is altered; there is the mechanical losses in the transmission of power; a general increase in total resistance; and the hull also impedes and renders non-uniform the flow through the propeller. The ratio between a propeller's efficiency attached to a ship () and in open water () is termed *relative rotative efficiency.*

The *overall propulsive efficiency* (an extension of *effective power* ()) is developed from the *propulsive coefficient* (), which is derived from the installed shaft power () modified by the effective power for the hull with appendages (), the propeller's thrust power (), and the relative rotative efficiency.

/ = hull efficiency =

/ = propeller efficiency =

/ = relative rotative efficiency =

/ = shaft transmission efficiency

Producing the following:

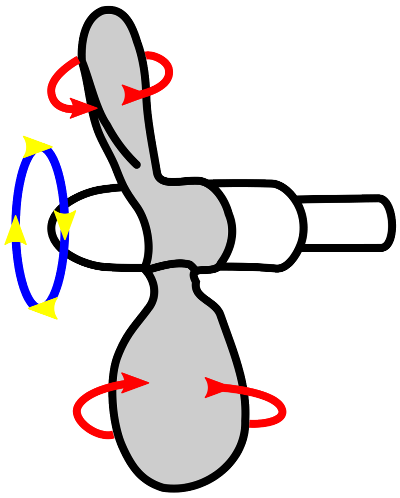
The terms contained within the brackets are commonly grouped as the *quasi-propulsive coefficient* (,). The is produced from small-scale experiments and is modified with a load factor for full size ships.

Wake is the interaction between the ship and the water with its own velocity relative to the ship. The wake has three parts: the velocity of the water around the hull; the boundary layer between the water dragged by the hull and the surrounding flow; and the waves created by the movement of the ship. The first two parts will reduce the velocity of water into the propeller, the third will either increase or decrease the velocity depending on whether the waves create a crest or trough at the propeller.

Types of marine propellers

Controllable-pitch propeller

One type of marine propeller is the controllable-pitch propeller. This propeller has several advantages with ships. These advantages include: the least drag depending on the speed used, the ability to move the sea vessel backwards, and the ability to use the "vane"-stance, which gives the least water resistance when not using the propeller (e.g. when the sails are used instead).



A controllable-pitch propeller

Skewback propeller

An advanced type of propeller used on German Type 212 submarines is called a **skewback propeller**. As in the scimitar blades used on some aircraft, the blade tips of a skewback propeller are swept back against the direction of rotation. In addition, the blades are tilted rearward along the longitudinal axis, giving the propeller an overall cup-shaped appearance. This design preserves thrust efficiency while reducing cavitation, and thus makes for a quiet, stealthy design.[30]

A small number of ships use propellers with winglets similar to those on some airplanes, reducing tip vortices and improving efficiency.[31][32][33][34][35]

Modular propeller

A modular propeller provides more control over the boat's performance. There is no need to change an entire prop, when there is an opportunity to only change the pitch or the damaged blades. Being able to adjust pitch will allow for boaters to have better performance while in different altitudes, water sports, and/or cruising.[36]

Voith Schneider propeller

Voith Schneider Propellers use four untwisted straight blades turning around a vertical axis instead of helical blades and can provide thrust in any direction at any time, at the cost of higher mechanical complexity.

Protection of small engines


A failed rubber bushing in an outboard's propeller

For smaller engines, such as outboards, where the propeller is exposed to the risk of collision with heavy objects, the propeller often includes a device that is designed to fail when overloaded; the device or the whole propeller is sacrificed so that the more expensive transmission and engine are not damaged.

Typically in smaller (less than 10 hp or 7.5 kW) and older engines, a narrow shear pin through the drive shaft and propeller hub transmits the power of the engine at normal loads. The pin is designed to shear when the propeller is put under a load that could damage the engine. After the pin is sheared the engine is unable to provide propulsive power to the boat until a new shear pin is fitted.[37]

In larger and more modern engines, a rubber bushing transmits the torque of the drive shaft to the propeller's hub. Under a damaging load the friction of the bushing in the hub is overcome and the rotating propeller slips on the shaft, preventing overloading of the engine's components.[38] After such an event the rubber bushing may be damaged. If so, it may continue to transmit reduced power at low revolutions, but may provide no power, due to reduced friction, at high revolutions. Also, the rubber bushing may perish over time leading to its failure under loads below its designed failure load.

Whether a rubber bushing can be replaced or repaired depends upon the propeller; some cannot. Some can, but need special equipment to insert the oversized bushing for an interference fit. Others can be replaced easily. The "special equipment" usually consists of a funnel, a press and rubber lubricant (soap). If one does not have access to a lathe, an improvised funnel can be made from steel tube and car body filler; as the filler is only subject to compressive forces it is able to do a good job. Often, the bushing can be drawn into place with nothing more complex than a couple of nuts, washers and a threaded rod. A more serious problem with this type of propeller is a "frozen-on" spline bushing, which makes propeller removal impossible. In such cases the propeller must be heated in order to deliberately destroy the rubber insert. Once the propeller is removed, the splined tube can be cut away with a grinder and a new spline bushing is then required. To prevent a recurrence of the problem, the splines can be coated with anti-seize anti-corrosion compound.

In some modern propellers, a hard polymer insert called a *drive sleeve* replaces the rubber bushing. The splined or other non-circular cross section of the sleeve inserted between the shaft and propeller hub transmits the engine torque to the propeller, rather than friction. The polymer is weaker than the components of the propeller and engine so it fails before they do when the propeller is overloaded.[39] This fails completely under excessive load, but can easily be replaced.

See also

- Screw-propelled vehicle

Propeller characteristics

- Advance ratio
- Axial fan design

Propeller phenomena

- Propeller walk
- Cavitation

Propeller variations

Cleaver

A cleaver is a type of propeller design especially used for boat racing. Its leading edge is formed round, while the trailing edge is cut straight. It provides little bow lift, so that it can be used on boats that do not need much bow lift, for instance hydroplanes, that naturally have enough hydrodynamic bow lift. To compensate for the lack of bow lift, a hydrofoil may be installed on the lower unit. Hydrofoils reduce bow lift and help to get a boat out of the hole and onto plane.

Other

- Azimuth thruster
  - Azipod
- Helix
- Impeller
- Kitchen rudder
- Ducted propeller
  - Kort nozzle
  - Pump-jet
- Paddle steamer
- Pleuger rudder
- Propulsor
- Voith-Schneider
- Cleaver
- Bow/stern thruster
- Folding propeller
- Modular propeller
- Supercavitating propeller

Materials and manufacture

Construction of Wooden Propellers 1 2 3, NASA Langley

- Balancing machine
- Composite materials

Notes

1. **^** Carlton, John, *Marine Propellers and Propulsion* Butterworth-Heinemann, 2012, p. 363
2. **^** Carlton, p. 1
3. **^** <Carlton, p. 1
4. **^** Murihead, James Patrick, *The Life of James Watt, with Selections from His Correspondence ... With Portraits and Woodcuts*, London: John Murray,1858, p. 208
5. **^** Stein, Stephen K. *The Sea in World History: Exploration, Travel, and Trade [2 volumes]*, Editor Stephen K. Stein, ABC-CLIO, 2017, Volume 1, p. 600
6. **^** Manstan, Roy R.; Frese, Frederic J., *Turtle: David Bushnell's Revolutionary Vessel*, Yardley, Pa: Westholme Publishing. ISBN 978-1-59416-105-6. OCLC 369779489, 2010, pp. xiii, 52, 53
7. **^** Tucker, Spencer, *Almanac of American Military History*, ABC-CLIO, 2013, Volume 1, p. 305
8. **^** Mansten pp. xiii, xiv
9. **^** Nicholson, William, *A Journal of Natural Philosophy, Chemistry and the Arts*, Volume 4, G. G. and J. Robinson, 1801, p. 221
0. **^** Manstan, p.150
1. **^** Carlton, pp. 1–2
2. **^** Carlton, p.2
3. **^** Carlton, p.2
4. **^** Paul Augustin Normand, *La Genèse de l'Hélice Propulsive (The Genesis of the Screw Propulsor)*. Paris: Académie de Marine, 1962, pp. 31–50.
5. **^** Mario Theriault, *Great Maritime Inventions* Goose Lane Publishing (2001) pp. 58–59
6. **^** "Patch's Propeller", *Scientific America*, Vol. 4, No. 5 (October 10, 1848) p. 33, featured in *The Archimedes Screw* website retrieved 31 January 2010 Archived 8 July 2011 at the Wayback Machine.
7. **^** *Smith, Edgar C. (1905). A Short history of Naval and Marine Engineering. University Press, Cambridge. pp. 66–67.*
8. ^ ***a b*** Bourne, p. 84.
9. **^** In the case of *Francis B. Ogden*, Symonds was correct. Ericsson had made the mistake of placing the rudder forward of the propellers, which made the rudder ineffective. Symonds believed that Ericsson tried to disguise the problem by towing a barge during the test.
0. **^** Bourne, pp. 87–89.
1. **^** Bourne, p. 85.
2. **^** The emphasis here is on *ship*. There were a number of successful propeller-driven vessels prior to *Archimedes*, including Smith's own *Francis Smith* and Ericsson's *Francis B. Ogden* and *Robert F. Stockton*. However, these vessels were *boats* – designed for service on inland waterways – as opposed to *ships*, built for seagoing service.
3. **^** "The type of screw propeller that now propels the vast majority of boats and ships was patented in 1836, first by the British engineer Francis Pettit Smith, then by the Swedish engineer John Ericsson. Smith used the design in the first successful screw-driven steamship, *Archimedes*, which was launched in 1839.". Marshall Cavendish, p. 1335.
4. **^** "The propeller was invented in 1836 by Francis Pettit Smith in Britain and John Ericsson in the United States. It first powered a seagoing ship, appropriately called *Archimedes*, in 1839." Macauley and Ardley, p. 378.
5. **^** "In 1839, the Messrs. Rennie constructed the engines, machinery and propeller, for the celebrated *Archimedes*, from which may

be said to date the introduction of the screw system of propulsion ...". *Mechanics Magazine*, p. 220.

6. ^ "It was not until 1839 that the principle of propelling steamships by a screw blade was fairly brought before the world, and for this we are indebted, as almost every adult will remember, to Mr. F. P. Smith of London. He was the man who first made the screw propeller practically useful. Aided by spirited capitalists, he built a large steamer named the "Archimedes", and the results obtained from her at once arrested public attention.". MacFarlane, p. 109.
7. ^ *Pilot's Handbook of Aeronautical Knowledge. Oklahoma City: U.S. Federal Aviation Administration. 2008. pp. 2–7. FAA-8083-25A.*
8. ^ Ash, Robert L., Colin P. Britcher and Kenneth W. Hyde. "Wrights: How two brothers from Dayton added a new twist to airplane propulsion." *Mechanical Engineering: 100 years of Flight*, 3 July 2007.
9. ^ *Schmidt, Theo. "Propeller simulation with PropSim" (PDF). Human Power Number 48.*
0. ^ *"SILENT propellers". www.francehelices.fr. JMCWebCreation and Co. 2009. Retrieved July 21, 2017.*
1. ^ Godske, Bjørn. "Energy saving propeller" (in Danish) *Ingeniøren*, 23 April 2012. Accessed: 15 March 2014. English translation
2. ^ Godske, Bjørn. "Kappel-propellers pave the way for success at MAN" (in Danish) *Ingeniøren*, 15 March 2014. Accessed: 15 March 2014. English translation
3. ^ "Kappel agreement secures access to major market" 30 August 2013.
4. ^ "KAPRICCIO Project" European Union. Accessed: 15 March 2014.
5. ^ "Industry Pays Tribute to Innovation Awards Winners" *Marine link*, 3 October 2002. Accessed: 15 March 2014. Quote: "Winner: the energy-saving Kappel propeller concept from the European Commission-funded Kapriccio propulsion research project. Blades curved towards the tips on the suction side reduce energy losses, fuel consumption, noise and vibration"
6. ^ *Smrcka, Karel (March 18, 2005). "A new start for marine propellers". Engineering News. Retrieved July 21, 2017.*
7. ^ *Getchell, David (1994), The Outboard Boater's Handbook, ISBN 9780070230538*
8. ^ *Ministry Of Defence (Navy), Great Britain (1995), Admiralty Manual of Seamanship, ISBN 9780117726963*
9. ^ US, "Torsionally twisting propeller drive sleeve and adapter", published March 8, 1994, issued January 16, 1996

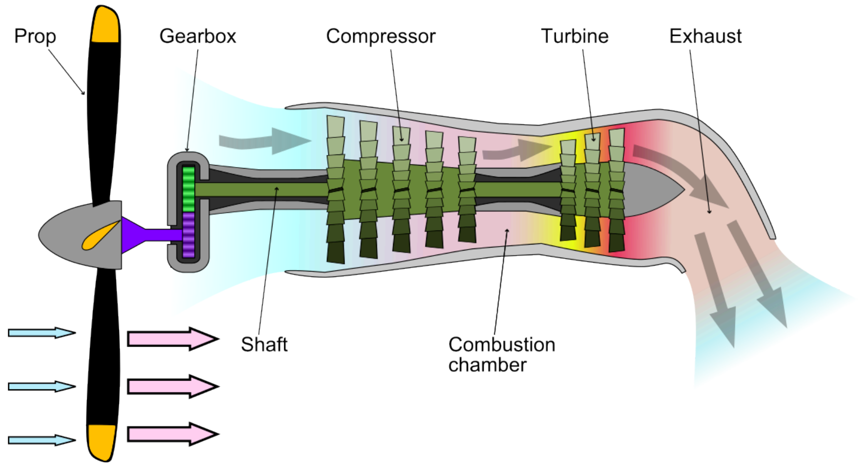
External links

Wikimedia Commons has media related to ***Propellers***.

- Titanic's Propellers
- Theory calculation propellers and wings: detailed article with blade element theory software application
- "What You Should Know About Propellers For Our Fighting Planes", November 1943, Popular Science extremely detailed article with numerous drawings and cutaway illustrations
- Archimedes Screw History: The story of marine propulsion
- propellers history: The story of propellers
- [1]: Wartsila Marine Propellers

Turboprop

A **turboprop** engine is a turbine engine that drives an aircraft propeller.[1]



Schematic diagram showing the operation of a turboprop engine

In its simplest form a turboprop consists of an intake, compressor, combustor, turbine, and a propelling nozzle. Air is drawn into the intake and compressed by the compressor. Fuel is then added to the compressed air in the combustor, where the fuel-air mixture then combusts. The hot combustion gases expand through the turbine. Some of the power generated by the turbine is used to drive the compressor. The rest is transmitted through the reduction gearing to the propeller. Further expansion of the gases occurs in the propelling nozzle, where the gases exhaust to atmospheric pressure. The propelling nozzle provides a relatively small proportion of the thrust generated by a turboprop.

A Fairchild F-27 representative of the 2nd generation of modern Rolls-Royce Dart turboprop powered aircraft, after the initial success of the 1950s era Vickers Viscount

In contrast to a turbojet, the engine's exhaust gases do not generally contain enough energy to create significant thrust, since almost all of the engine's power is used to drive the propeller.

Technological aspects

An ATR-72, a typical modern turboprop aircraft

Exhaust thrust in a turboprop is sacrificed in favour of shaft power, which is obtained by extracting additional power (up to that necessary to drive the compressor) from turbine expansion. Owing to the additional expansion in the turbine system, the residual energy in the exhaust jet is low.[2][3][4] Consequently, the exhaust jet typically produces around or less than 10% of the total thrust.[5] A higher proportion of the thrust comes from the propeller at low speeds and less at higher speeds.[6]

Turboprops can have bypass ratios up to 50-100[7][8][9] although the propulsion airflow is less clearly defined for propellers than for fans.[10][11]

The propeller is coupled to the turbine through a reduction gear that converts the high RPM/low torque output to low RPM/high torque. The propeller itself is normally a constant speed (variable pitch) type similar to that used with larger reciprocating aircraft engines.

Unlike the small diameter fans used in turbofan jet engines, the propeller has a large diameter that lets it accelerate a large volume of air. This permits a lower airstream 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,[12][13] a low disc loading (thrust per disc area) increases the aircraft's energy efficiency, and this reduces the fuel use.[14][15]

Propellers lose efficiency as aircraft speed increases, so turboprops are normally not used on high-speed aircraft[2][3][4] above Mach 0.6-0.7.[5] However, propfan engines, which are very similar to turboprop engines, can cruise at flight speeds approaching Mach 0.75. To increase propeller efficiency, a mechanism can be used to alter their pitch relative to the airspeed. A variable-pitch propeller, also called a controllable-pitch propeller, can also be used to generate negative thrust while decelerating on the runway. Additionally, in the event of an engine outage, the pitch can be adjusted to a vaning pitch (called feathering), thus minimizing the drag of the non-functioning propeller.

While most modern turbojet and turbofan engines use axial-flow compressors, turboprop engines usually contain at least one stage of centrifugal compression. Centrifugal compressors have the advantage of being simple and lightweight, at the expense of a streamlined shape.

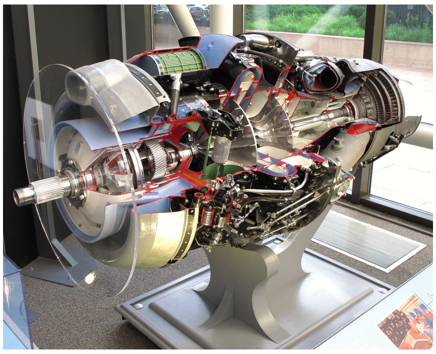
While the power turbine may be integral with the gas generator section, many turboprops today feature a free power turbine on a separate coaxial shaft. This enables the propeller to rotate freely, independent of compressor speed.[16] Residual thrust on a turboshaft is avoided by further expansion in the turbine system and/or truncating and turning the exhaust 180 degrees, to produce two opposing jets. Apart from the above, there is very little difference between a turboprop and a turboshaft.[9]

History

Alan Arnold Griffith had published a paper on turbine design in 1926. Subsequent work at the Royal Aircraft Establishment investigated axial turbine designs that could be used to supply power to a shaft and thence a propeller. From 1929, Frank Whittle began work on centrifugal turbine designs that would deliver pure jet thrust.[17]

Kuznetsov NK-12M Turboprop, on a Tu-95

The world's first turboprop was designed by the Hungarian mechanical engineer György Jendrassik.[18] Jendrassik published a turboprop idea in 1928, and on 12 March 1929 he patented his invention. In 1938, he built a small-scale (100 Hp; 74.6 kW) experimental gas turbine.[19] The larger Jendrassik Cs-1, with a predicted output of 1,000 bhp, was produced and tested at the Ganz Works in Budapest between 1937 and 1941. It was of axial-flow design with 15 compressor and 7 turbine stages, annular combustion chamber and many other modern features. First run in 1940, combustion problems limited its output to 400 bhp. In 1941,the engine was abandoned due to war, and the factory was turned over to conventional engine production. The world's first turboprop engine that went into mass production was designed by a German engineer, Max Adolf Mueller, in 1942.[20]



Rolls-Royce Dart turboprop engine

The first mention of turboprop engines in the general public press was in the February 1944 issue of the British aviation publication *Flight*, which included a detailed cutaway drawing of what a possible future turboprop engine could look like. The drawing was very close to what the future Rolls-Royce Trent would look like.[21] The first British turboprop engine was the Rolls-Royce RB.50 Trent, a converted Derwent II fitted with reduction gear and a Rotol 7 ft 11 in (2.41 m) five-bladed propeller. Two Trents were fitted to Gloster Meteor *EE227* — the sole "Trent-Meteor" — which thus became the world's first turboprop-powered aircraft, albeit a test-bed not intended for production.[22][23] It first flew on 20 September 1945. From their experience with the Trent, Rolls-Royce developed the Rolls-Royce Clyde, the first turboprop engine to be fully type certificated for military and civil use,[24] and the Dart, which became one of the most reliable turboprop engines ever built. Dart production continued for more than fifty years. The Dart-powered Vickers Viscount was the first turboprop aircraft of any kind to go into production and sold in large numbers.[25] It was also the first four-engined turboprop. Its first flight was on 16 July 1948. The world's first single engined turboprop aircraft was the Armstrong Siddeley Mamba-powered Boulton Paul Balliol, which first flew on 24 March 1948.[26]

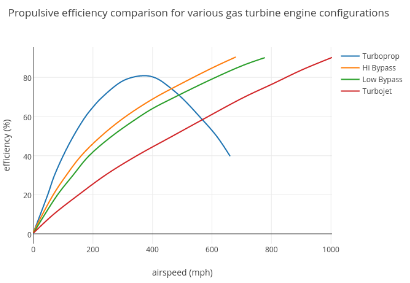
The Soviet Union built on German World War II development by Junkers Motorenwerke, while BMW, Heinkel-Hirth and Daimler-Benz also developed and partially tested designs. While the Soviet Union had the technology to create the airframe for a jet-powered strategic bomber comparable to Boeing's B-52 Stratofortress, they instead produced the Tupolev Tu-95 Bear, powered with four Kuznetsov NK-12 turboprops, mated to eight contra-rotating propellers (two per nacelle) with supersonic tip speeds to achieve maximum cruise speeds in excess of 575 mph, faster than many of the first jet aircraft and comparable to jet cruising speeds for most missions. The Bear would serve as their most successful long-range combat and surveillance aircraft and symbol of Soviet power projection throughout the end of the 20th century. The USA would incorporate contra-rotating turboprop engines, such as the ill-fated twin-turbine Allison T40 — essentially a twinned up pair of Allison T38 turboprop engines driving contra-rotating propellers — into a series of experimental aircraft during the 1950s, with aircraft powered with the T40, like the Convair R3Y Tradewind flying boat never entering U.S. Navy service.

The first American turboprop engine was the General Electric XT31, first used in the experimental Consolidated Vultee XP-81.[27] The XP-81 first flew in December 1945, the first aircraft to use a combination of turboprop and turbojet power. The technology of the Allison's earlier T38 design evolved into the Allison T56, with quartets of the T56s being used to power the Lockheed Electra airliner, its military maritime patrol derivative the P-3 Orion, and the widely produced C-130 Hercules military transport aircraft. One of the most produced turboprop engines used in civil aviation is the Pratt & Whitney Canada PT6 engine.

The first turbine-powered, shaft-driven helicopter was the Kaman K-225, a development of Charles Kaman's K-125 synchropter, which used a Boeing T50 turboshaft engine to power it on 11 December 1951.[28]

Usage

Compared to turbofans, turboprops are most efficient at flight speeds below 725 km/h (450 mph; 390 knots) because the jet velocity of the propeller (and exhaust) is relatively low. Modern turboprop airliners operate at nearly the same speed as small regional jet airliners but burn two-thirds of the fuel per passenger.[29] However, compared to a turbojet (which can fly at high altitude for enhanced speed and fuel efficiency) a propeller aircraft has a lower ceiling.



Propulsive efficiency comparison for various gas turbine engine configurations

The most common application of turboprop engines in civilian aviation is in small commuter aircraft, where their greater power and reliability offsets their higher initial cost and fuel consumption. Turboprop-powered aircraft have become popular for bush airplanes such as the Cessna Caravan and Quest Kodiak as jet fuel is easier to obtain in remote areas than avgas. Due to the high price of turboprop engines, they are mostly used where high-performance short-takeoff and landing (STOL) capability and efficiency at modest flight speeds are required.

Turboprop engines are generally used on small subsonic aircraft, but the Tupolev Tu-114 can reach 470 kt (870 km/h, 541 mph). Large military and civil aircraft, such as the Lockheed L-188 Electra and the Tupolev Tu-95, have also used turboprop power. The Airbus A400M is powered by four Europrop TP400 engines, which are the third most powerful turboprop engines ever produced, after the eleven megawatt-output Kuznetsov NK-12 and 10.4 MW-output Progress D-27.

Some commercial aircraft with turboprop engines include the Bombardier Dash 8, ATR 42, ATR 72, BAe Jetstream 31, Beechcraft 1900, Embraer EMB 120 Brasilia, Fairchild Swearingen Metroliner, Dornier 328, Saab 340 and 2000, Xian MA60, Xian MA600, and Xian MA700, Fokker 27, 50 and 60.

Reliability

Between 2012 and 2016, the ATSB observed 417 events with turboprop aircraft, 83 per year, over 1.4 million flight hours: 2.2 per 10,000 hours. Three were “high risk” involving engine malfunction and unplanned landing in single-engine Cessna 208 Caravans, four “medium risk” and 96% “low risk”. Two occurrences resulted in minor injuries due to engine malfunction and terrain collision in agricultural aircraft and five accidents involved aerial work: four in agriculture and one in an air ambulance.[30]

Current engines

Jane's All the World's Aircraft. 2005–2006.

Manufacturer	Country	Designation	Dry weight (kg)	Takeoff rating (kW)	Application
DEMC	People's Republic of China	WJ5E	720	2130	Harbin SH-5, Xi'an Y-7
Europrop International	European Union	TP400-D6	1800	8203	Airbus A400M
General Electric	United States	CT7-5A	365	1294	
General Electric	United States	CT7-9	365	1447	CASA/IPTN CN-235, Let L-610, Saab 340, Sukhoi Su-80
General Electric	United States Czech Republic	H80 Series[31]	200	550 - 625	Thrush Model 510, Let 410NG, Let L-410 Turbolet UVP-E, CAIGA Primus 150, Nextant G90XT
General Electric	United States	T64-P4D	538	2535	Aeritalia G.222, de Havilland Canada DHC-5 Buffalo, Kawasaki P-2J

Honeywell	United States	TPE331 Series	150 - 275	478 - 1650	Aero/Rockwell Turbo Commander 680/690/ 840/960/1000, Antonov An-38, Ayres Thrush, BAe Jetstream 31/32, BAe Jetstream 41, CASA C-212 Aviocar, Cessna 441 Conquest II, Dornier Do 228, Fairchild Swearingen Metroliner, General Atomics MQ-9 Reaper, GrumGeman, Mitsubishi MU-2, North American Rockwell OV-10 Bronco, Piper PA-42 Cheyenne, RUAG Do 228NG, Short SC.7 Skyvan, Short Tucano, Swearingen Merlin, Fairchild Swearingen Metroliner
Honeywell	United States	LTP 101-700	147	522	Air Tractor AT-302, Piag-gio P.166
KKBM	Russia	NK-12MV	1900	11033	Antonov An-22, Tupolev Tu-95, Tupolev Tu-114
Progress	Ukraine	TV3-117VMA-SB2	560	1864	Antonov An-140
Klimov	Russia	TV7-117S	530	2100	Ilyushin Il-112, Ilyushin Il-114
Progress	Ukraine	AI20M	1040	2940	Antonov An-12, Antonov An-32, Ilyushin Il-18
Progress	Ukraine	AI24T	600	1880	Antonov An-24, Antonov An-26, Antonov An-30

LHTEC	United States	LHTEC T800	517	2013	AgustaWestland Super Lynx 300 (CTS800-4N), AgustaWestland AW159 Lynx Wildcat (CTS800-4N), Ayres LM200 Loadmaster (LHTEC CTP800-4T) (aircraft not built), Sikorsky X2 (T800-LHT-801), TAI/AgustaWestland T-129 (CTS800-4A)
OMKB	Russia	TVD-20	240	1081	Antonov An-3, Antonov An-38
Pratt & Whitney Canada	Canada	PT-6 Series	149 - 260	430 - 1500	Air Tractor AT-502, Air Tractor AT-602, Air Tractor AT-802, Beechcraft Model 99, Beechcraft King Air, Beechcraft Super King Air, Beechcraft 1900, Beechcraft T-6 Texan II, Cessna 208 Caravan, Cessna 425 Corsair/Conquest I, de Havilland Canada DHC-6 Twin Otter, Harbin Y-12, Embraer EMB 110 Bandeirante, Let L-410 Turbolet, Piaggio P.180 Avanti, Pilatus PC-6 Porter, Pilatus PC-12, Piper PA-42 Cheyenne, Piper PA-46-500TP Meridian, Shorts 360, Daher TBM 700, Daher TBM 850, Daher TBM 900, Embraer EMB 314 Super Tucano
Pratt & Whitney Canada	Canada	PW120	418	1491	ATR 42-300/320
Pratt & Whitney Canada	Canada	PW121	425	1603	ATR 42-300/320, Bombardier Dash 8 Q100
Pratt & Whitney Canada	Canada	PW123 C/D	450	1603	Bombardier Dash 8 Q300
Pratt & Whitney Canada	Canada	PW126 C/D	450	1950	BAe ATP

Pratt & Whitney Canada	Canada	PW127	481	2051	ATR 72
Pratt & Whitney Canada	Canada	PW150A	717	3781	Bombardier Dash 8 Q400
PZL	Poland	TWD-10B	230	754	PZL M28
RKBM	Russia	TVD-1500S	240	1044	Sukhoi Su-80
Rolls-Royce	United Kingdom	Dart Mk 536	569	1700	Avro 748, Fokker F27, Vickers Viscount
Rolls-Royce	United Kingdom	Tyne 21	569	4500	Aeritalia G.222, Breguet Atlantic, Transall C-160
Rolls-Royce	United Kingdom	250-B17	88.4	313	Fuji T-7, Britten-Norman Turbine Islander, O&N Cessna 210, Soloy Cessna 206, Propjet Bonanza
Rolls-Royce	United Kingdom	Allison T56	828 - 880	3424 - 3910	P-3 Orion, E-2 Hawkeye, C-2 Greyhound, C-130 Hercules
Rolls-Royce	United Kingdom	AE2100A	715.8	3095	Saab 2000
Rolls-Royce	United Kingdom	AE2100J	710	3424	ShinMaywa US-2
Rolls-Royce	United Kingdom	AE2100D2, D3	702	3424	Alenia C-27J Spartan, Lockheed Martin C-130J Super Hercules
Rybinsk	Russia	TVD-1500V	220	1156	
Saturn	Russia	TAL-34-1	178	809	
Turbomeca	France	Arrius 1D	111	313	Socata TB 31 Omega

Turbomeca	France	Arrius 2F	103	376	
Walter	Czech Republic	M601 Series[32]	200	560	Let L-410 Turbolet, Aerocomp Comp Air 10 XL, Aerocomp Comp Air 7, Ayres Thrush, Dornier Do 28, Lancair Propjet, Let Z-37T, Let L-420, Myasishchev M-101T, PAC FU-24 Fletcher, Progress Rysachok, PZL-106 Kruk, PZL-130 Orlik, SM-92T Turbo Finist
Walter	Czech Republic	M602A	570	1360	Let L-610
Walter	Czech Republic	M602B	480	1500	

See also

- Jet engine
- Jet aircraft
- Jetboat
- Propfan
- Ramjet
- Scimitar propeller
- Supercharger
- Tiltrotor
- Turbocharger
- Turbofan
- Turbojet
- Turboshaft

References

Notes

1. **^** "Turboprop", *Pilot's Handbook of Aeronautical Knowledge*, Federal Aviation Administration, 2009.
2. ^ ***a b*** "Turboprop Engine" *Glenn Research Center (NASA)*
3. ^ ***a b*** "Turboprop Thrust" *Glenn Research Center (NASA)*
4. ^ ***a b*** *"Variations of Jet Engines". smu.edu. Retrieved 31 August 2016.*

5. ^ ***a b*** ""The turbofan engine", page 7. SRM University, Department of aerospace engineering.
6. **^** *J. Russell (2 Aug 1996). Performance and Stability of Aircraft. Butterworth-Heinemann. p. 16. ISBN 0080538649.*
7. **^** Ilan Kroo and Juan Alonso. "Aircraft Design: Synthesis and Analysis, Propulsion Systems: Basic Concepts Archived 18 April 2015 at the Wayback Machine." Stanford University School of Engineering, Department of Aeronautics and Astronautics Main page Archived 23 February 2001 at the Wayback Machine.
8. **^** Prof. Z. S. Spakovszky. "11.5 Trends in thermal and propulsive efficiency" *MIT turbines*, 2002. Thermodynamics and Propulsion
9. ^ ***a b*** Nag, P.K. "Basic And Applied Thermodynamics Archived 19 April 2015 at the Wayback Machine." p550. Published by Tata McGraw-Hill Education. Quote: "If the cowl is removed from the fan the result is a turboprop engine. Turbofan and turboprop engines differ mainly in their bypass ratio: 5 or 6 for turbofans and as high as 100 for turboprop."
0. **^** "Propeller thrust" *Glenn Research Center (NASA)*
1. **^** Philip Walsh, Paul Fletcher. "Gas Turbine Performance", page 36. John Wiley & Sons, 15 April 2008. Quote: "It has better fuel consumption than a turbojet or turbofan, due to a high propulsive efficiency.., achieving thrust by a high mass flow of air from the propeller at low jet velocity. Above 0.6 Mach number the turboprop in turn becomes uncompetitive, due mainly to higher weight and frontal area."
2. **^** Paul Bevilaqua. The shaft driven Lift Fan propulsion system for the Joint Strike Fighter page 3. Presented 1 May 1997. DTIC.MIL Word document, 5.5 MB. Accessed: 25 February 2012.
3. **^** Bensen, Igor. "How they fly - Bensen explains all" *Gyrocopters UK*. Accessed: 10 April 2014.
4. **^** Johnson, Wayne. Helicopter theory pp3+32, *Courier Dover Publications*, 1980. Accessed: 25 February 2012. ISBN 0-486-68230-7
5. **^** Wieslaw Zenon Stepniewski, C. N. Keys. Rotary-wing aerodynamics p3, Courier Dover Publications, 1979. Accessed: 25 February 2012. ISBN 0-486-64647-5
6. **^** *"An Engine Ahead of Its Time". PT6 Nation. Pratt & Whitney Canada.*
7. **^** Gunston Jet, p. 120
8. **^** Gunston World, p.111
9. **^** *"Magyar feltalálók és találmányok - JENDRASSIK GYÖRGY (1898 - 1954)". SZTNH. Retrieved 2012-05-31.*
0. **^** Green, W. and Swanborough, G.; "Plane Facts", 'Max'Air Enthusiast ***Vol. 1*** *No. 1 (1971), Page 53.*
1. **^** "Our Contribution - How Flight Introduced and Made Familiar With Gas Turbines and Jet Propulsion" *Flight*, 11 May 1951, p. 569.
2. **^** James p. 251-2
3. **^** Green p.18-9
4. **^** *"rolls-royce trent - armstrong siddeley - 1950 - 2035 - Flight Archive". flightglobal.com. Retrieved 31 August 2016.*
5. **^** Green p.82
6. **^** Green p.81
7. **^** Green p.57
8. **^** *"Smithsonian National Air and Space Museum - Collections - Kaman K-225 (Long Description)". National Air and Space Museum. Retrieved 4 April 2013.*
9. **^** *"More turboprops coming to the market - maybe - CAPA - Centre for Aviation". centreforaviation.com. Retrieved 31 August 2016.*
0. **^** *Gordon Gilbert (June 25, 2018). "ATSB Study Finds Turboprop Engines Safe, Reliable".*
1. **^** *"The H-Series Engine | Engines | B&GA | GE Aviation". www.geaviation.com. Retrieved 2016-06-01.*
2. **^** *[1], PragueBest s.r.o. "History | GE Aviation". www.geaviation.cz. Retrieved 2016-06-01.*

Bibliography

- Green, W. and Cross, R.*The Jet Aircraft of the World* (1955). London: MacDonald
- *Gunston, Bill (2006). The Development of Jet and Turbine Aero Engines, 4th Edition.*

Sparkford, Somerset, England, UK: Patrick Stephens, Haynes Publishing. IS-BN 0-7509-4477-3.

- *Gunston, Bill (2006). World Encyclopedia of Aero Engines, 5th Edition. Phoenix Mill, Gloucestershire, England, UK: Sutton Publishing Limited. ISBN 0-7509-4479-X.*
- James, D.N. *Gloster Aircraft since 1917* (1971). London: Putnam & Co. IS-BN 0-370-00084-6

Further reading

- *Van Sickle, Neil D.; et al. (1999). "Turboprop Engines". Van Sickle's modern airmanship. McGraw-Hill Professional. p. 205. ISBN 978-0-07-069633-4.*

External links

- Jet Turbine Planes by LtCol Silsbee USAAF, Popular Science, December 1945, first article on turboprops printed
- Wikibooks: Jet propulsion
- "Development of the Turboprop" a 1950 *Flight* article on UK and US turboprop engines

Wing configuration


The Spitfire wing may be classified as: "a conventional low-wing cantilever monoplane with unswept elliptical wings of moderate aspect ratio and slight dihedral".

The **wing configuration** of a fixed-wing aircraft (including both gliders and powered aeroplanes or airplanes) is its arrangement of lifting and related surfaces.

Aircraft designs are often classified by their wing configuration. For example, the Supermarine Spitfire is a conventional low wing cantilever monoplane of straight elliptical planform with moderate aspect ratio and slight dihedral.

Many variations have been tried. Sometimes the distinction between them is blurred, for example the wings of many modern combat aircraft may be described either as cropped compound deltas with (forwards or backwards) swept trailing edge, or as sharply tapered swept wings with large leading edge root extensions (or LERX). Some are therefore duplicated here under more than one heading. This is particularly so for variable geometry and combined (closed) wing types.

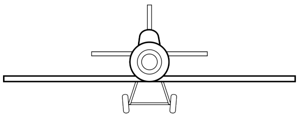
Most of the configurations described here have flown (if only very briefly) on full-size aircraft. A few significant theoretical designs are also noted.

Note on terminology: Most fixed-wing aircraft have left hand and right hand wings in a symmetrical arrangement. Strictly, such a pair of wings is called a wing plane or just plane. However, in certain situations it is common to refer to a plane as a wing, as in "a biplane has two wings", or to refer to the whole thing as a wing, as in "a biplane wing has two planes". Where the meaning is clear, this article follows common usage, only being more precise where needed to avoid real ambiguity or incorrectness.

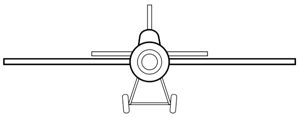
Number and position of main planes

Fixed-wing aircraft can have different numbers of wings:

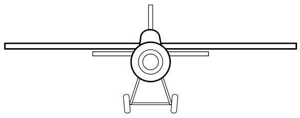
- **Monoplane**: one wing plane. Since the 1930s most aeroplanes have been monoplanes. The wing may be mounted at various positions relative to the fuselage:
    - **Low wing**: mounted near or below the bottom of the fuselage.
    - **Mid wing**: mounted approximately halfway up the fuselage.
    - **Shoulder wing**: mounted on the upper part or "shoulder" of the fuselage, slightly below the top of the fuselage. A shoulder wing is sometimes considered a subtype of high wing.[1][2]
    - **High wing**: mounted on the upper fuselage. When contrasted to the shoulder wing, applies to a wing mounted on a projection (such as the cabin roof) above the top of the main fuselage.
    - **Parasol wing**: raised clear above the top of the fuselage, typically by cabane struts, pylon(s) or pedestal(s).



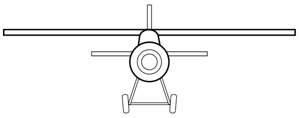
Low wing



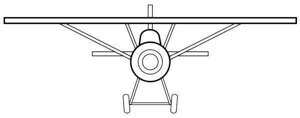
Mid wing



Shoulder wing



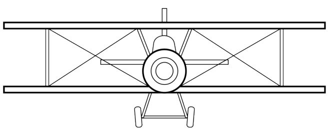
High wing



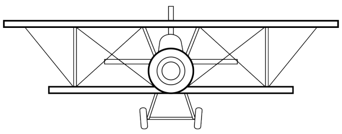
Parasol wing

A fixed-wing aircraft may have more than one wing plane, stacked one above another:

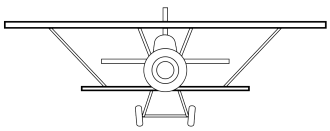
- **Biplane**: two wing planes of similar size, stacked one above the other. The biplane is inherently lighter and stronger than a monoplane and was the most common configuration until the 1930s. The very first Wright Flyer I was a biplane.
  - **Unequal-span biplane**: a biplane in which one wing (usually the lower) is shorter than the other, as on the Curtiss JN-4 Jenny of the First World War.
  - **Sesquiplane**: literally "one-and-a-half planes" is a type of biplane in which the lower wing is significantly smaller than the upper wing, either in span or chord or both. The Nieuport 17 of World War I was notably successful.
  - **Inverted sesquiplane**: has a significantly smaller upper wing. The Fiat CR.1 was in production for many years.



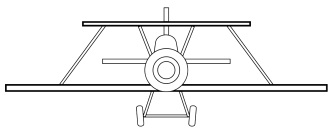
Biplane



Unequal-span biplane

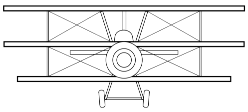


Sesquiplane

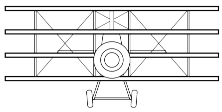


Inverted sesquiplane

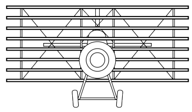
- **Triplane**: three planes stacked one above another. Triplanes such as the Fokker Dr.I enjoyed a brief period of popularity during the First World War due to their manoeuvrability, but were soon replaced by improved biplanes.
- **Quadruplane**: four planes stacked one above another. A small number of the Armstrong Whitworth F.K.10 were built in the First World War but never saw service.
- **Multiplane**: many planes, sometimes used to mean more than one or more than some arbitrary number. The term is occasionally applied to arrangements stacked in tandem as well as vertically. The 1907 Multiplane of Horatio Frederick Phillips flew successfully with two hundred wing foils. See also the tandem wing, below.



Triplane

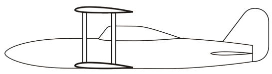


Quadruplane

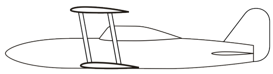


Multiplane

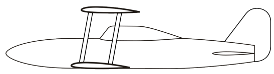
A **staggered** design has the upper wing slightly forward of the lower. Long thought to reduce the interference caused by the low pressure air over the lower wing mixing with the high pressure air under the upper wing; however the improvement is minimal and its primary benefit is to improve access to the fuselage. It is common on many successful biplanes and triplanes. Backwards stagger is also seen in a few examples such as the Beechcraft Staggerwing.



Unstaggered biplane



Forwards stagger

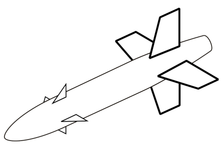


Backwards stagger

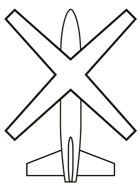
A **tandem wing** design has two wings, one behind the other: see Tailplanes and foreplanes below. Some early types had tandem stacks of multiple planes, such as the nine-wing Caproni Ca.60 flying boat with three triplane stacks in tandem.

A **cruciform wing** is a set of four individual wings arranged in the shape of a cross. The cross may take either of two forms:

- Wings equally spaced around the cross-section of the fuselage, lying in two planes at right angles, as on a typical missile.
- Wings lying together in a single horizontal plane about a vertical axis, as in the cruciform rotor wing or X-wing.



Cruciform wing weapon



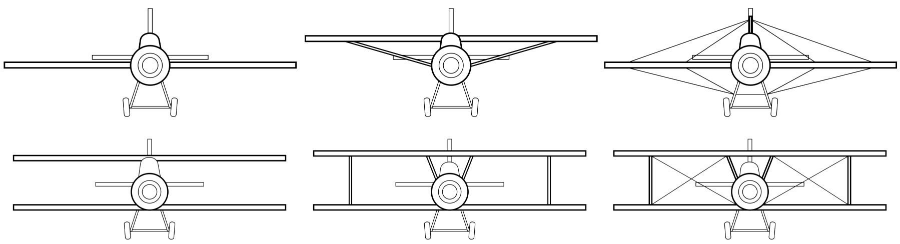
Cruciform rotor wing or X wing rotor

Wing support

To support itself a wing has to be rigid and strong and consequently may be heavy. By adding external bracing, the weight can be greatly reduced. Originally such bracing was always present, but it causes a large amount of drag at higher speeds and has not been used for faster designs since the early 1930s.

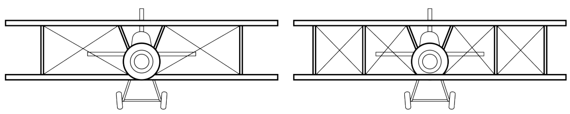
The types are:

- **Cantilevered**: self-supporting. All the structure is buried under the aerodynamic skin, giving a clean appearance with low drag.
- **Braced**: the wings are supported by external structural members. Nearly all multi-plane designs are braced. Some monoplanes, especially early designs such as the Fokker Eindecker, are also braced to save weight. Braced wings are of two types:
    - **Strut braced**: one or more stiff struts help to support the wing, as on the Fokker D.VII. A strut may act in compression or tension at different points in the flight regime.
    - **Wire braced**: alone (as on the Boeing P-26 Peashooter) or, more usually, in addition to struts, tension wires also help to support the wing. Unlike a strut, a wire can act only in tension.



Cantilever Strut braced Wire braced

A braced multiplane may have one or more "bays", which are the compartments created by adding interplane struts; the number of bays refers to one side of the aircraft's wing panels only. For example, the de Havilland Tiger Moth is a single-bay biplane where the Bristol F.2 Fighter is a two-bay biplane.[3]

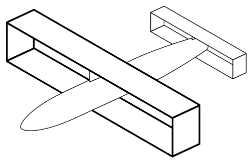


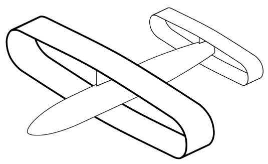
Single-bay biplane Two-bay biplane

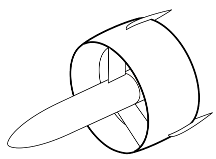
- **Closed wing**: two wing planes are merged or joined structurally at or near the tips in some way.[4] This stiffens the structure and can reduce aerodynamic losses at the tips. Variants include:
    - **Box wing**: upper and lower planes are joined by a vertical fin between their tips. The first officially witnessed unaided takeoff and flight, Santos-Dumont´s 14-bis, used this configuration and some Dunne biplanes were of this type as well. Tandem box wings have also been studied (see *Joined wing* description below).
    - **Annular box wing**: A type of box wing whose vertical fins curve continuously,

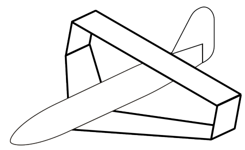
blending smoothly into the wing tips. An early example was the Blériot III, which featured two annular wings in tandem.

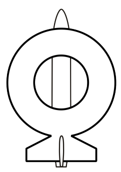
- **Annular (cylindrical)**: the wing is shaped like a cylinder. The Coléoptère had concentric wing and fuselage. It took off and landed vertically, but never achieved transition to horizontal flight. Examples with the wing mounted on top of the fuselage have been proposed but never built.[5]
- **Annular (planar)**: the wing is shaped like a disc with a hole in it. A number of Lee-Richards annular monoplanes flew shortly before the First World War.[6]
- **Joined wing**: a tandem layout in which the front low wing sweeps back and/or the rear high wing sweeps forwards such that they join at or near the tips to form a continuous surface in a hollow diamond or triangle shape. The *Ligeti Stratos* is a rare example.[7]
  - **Rhomboidal wing**: a joined wing consisting of four surfaces in a diamond arrangement. The Edwards Rhomboidal biplane of 1911 had both wings in the same plane and failed to fly.[8]

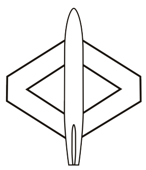

Box wing


Annular box wing


Cylindrical wing

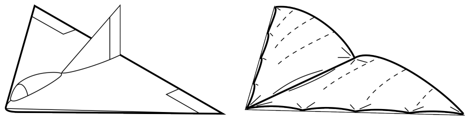

Joined wing


Flat annular wing


Rhomboidal wing

Wings can also be characterised as:

- **Rigid**: stiff enough to maintain the aerofoil profile in varying conditions of airflow. A rigid wing may have external bracing and/or a fabric covering.
- **Flexible**:
  - The surface may be flexible, typically a thin membrane. Requires external bracing and/or wind pressure to maintain the aerofoil shape. Common types include the Rogallo wing, parafoil and most kites.
  - An otherwise rigid structure may be designed to flex, either because it is inherently aeroelastic as in the aeroisoclinic wing, or because shape changes are actively introduced.



Rigid delta wing Flexible Rogallo wing

Wing planform

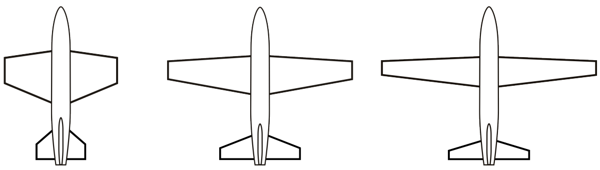
The wing planform is the silhouette of the wing when viewed from above or below.

See also **Variable geometry** types which vary the wing planform during flight.

Aspect ratio

The aspect ratio is the span divided by the mean or average chord.[9] It is a measure of how long and slender the wing appears when seen from above or below.

- **Low aspect ratio**: short and stubby wing. More efficient structurally and higher instantaneous roll rate. They tend to be used by fighter aircraft, such as the Lockheed F-104 Starfighter, and by very high-speed aircraft including the North American X-15.
- **Moderate aspect ratio**: general-purpose wing, very widely used, for example on the Douglas DC-3 transport).
- **High aspect ratio**: long and slender wing. More efficient aerodynamically, having less induced drag. They tend to be used by high-altitude subsonic aircraft such as airliners like the Bombardier Dash 8 and by high-performance sailplanes such as the Glaser-Dirks DG-500.



Low aspect ratioModerate aspect ratio High aspect ratio

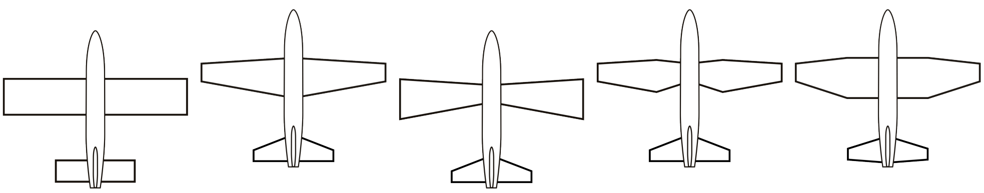
Most Variable geometry configurations vary the aspect ratio in some way, either deliberately or as a side effect.

Chord variation along span

The wing chord may be varied along the span of the wing, for both structural and aerodynamic reasons.

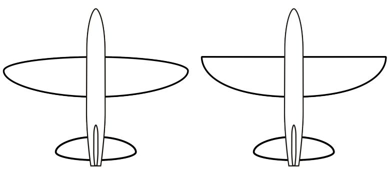
- **Constant chord**: parallel leading & trailing edges. Simplest to make, and common where low cost is important, such as on the Piper J-3 Cub but inefficient as the outer section generates little lift while adding both weight and drag. Sometimes known as the *Hershey Bar* wing in North America due to its similarity in shape to a chocolate bar.[10]

- **Tapered**: wing narrows towards the tip. Structurally and aerodynamically more efficient than a constant chord wing, and easier to make than the elliptical type.
    - **Trapezoidal**: a tapered wing with straight leading and trailing edges: may be unswept or swept.[11][12][13] The **straight tapered** wing is one of the most common wing planforms, as seen on the Messerschmitt Bf 109.
    - **Inverse tapered**: wing is widest near the tip. Structurally inefficient, leading to high weight. Flown experimentally on the XF-91 Thunderceptor in an attempt to overcome the stall problems of swept wings.
    - **Compound tapered**: taper reverses towards the root. Typically braced to maintain stiffness. Used on the Westland Lysander army cooperation aircraft to increase visibility for the crew.
- **Constant chord with tapered outer section**: common variant seen for example on many Cessna types.



Constant chord | Tapered (Trapezoidal) | Reverse tapered | Compound tapered | Constant chord, tapered outer

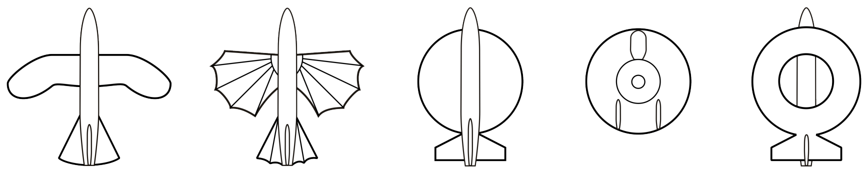
- **Elliptical**: leading and trailing edges are curved such that the chord length varies elliptically with respect to span. Theoretically the most efficient, but difficult to make. Famously used on the Supermarine Spitfire. (Note that in aerodynamics theory, the term "elliptical" describes the optimal lift distribution over a wing and not its shape).
    - **Semi-elliptical**: only the leading or trailing edge is elliptical with the other being straight, as with the elliptical trailing edges of the Seversky P-35.[14]



Elliptical | Semi-elliptical

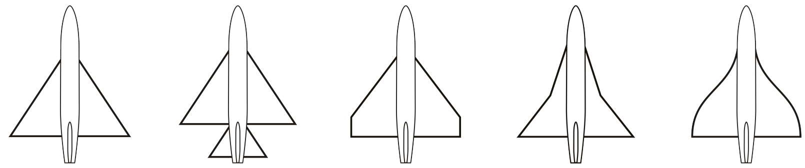
- **Bird wing**: a curved shape appearing similar to a bird's outstretched wing. Popular during the pioneer years, and achieved some success on the Etrich Taube where its planform was inspired by the *zanonia* (*Alsomitra macrocarpa*) seed.

- **Bat wing**: a form with radial ribs. The 1901 Whitehead No. 21 has been the subject of claims to the first controlled powered flight.
- **Circular**: approximately circular planform. The Vought XF5U used large propellers near the tips which Vought claimed dissipated its wingtip vortices and had an integral tail plane for stability.
    - **Flying saucer**: circular flying wing. Inherently unstable, as the Avrocar demonstrated.
    - **Disc wing**: a variant in which the entire disc rotates.[15] Popular on toys such as the Frisbee.
    - **Flat annular wing**: the circle has a hole in, forming a closed wing (see above). The Lee-Richards annular monoplanes flew shortly before the First World War.[16]



Birdlike Batlike Circular Flying saucer Flat annular

- **Delta**: triangular planform with swept leading edge and straight trailing edge. Offers the advantages of a swept wing, with good structural efficiency and low frontal area. Disadvantages are the low wing loading and high wetted area needed to obtain aerodynamic stability. Variants are:
    - **Tailless delta**: a classic high-speed design, used for example in the Dassault Mirage III series.
    - **Tailed delta**: adds a conventional tailplane, to improve handling. Used on the Mikoyan-Gurevich MiG-21.
    - **Cropped delta**: wing tips are cut off. This helps avoid tip drag at high angles of attack. The Fairey Delta 1 also had a tail. At the extreme, merges into the "tapered swept" configuration.
    - **Compound delta** or **double delta**: inner section has a (usually) steeper leading edge sweep as on the Saab Draken. This improves the lift at high angles of attack and delays or prevents stalling. By contrast, the Saab Viggen has an inner section of reduced sweep to avoid interference from its canard foreplane.
    - **Ogival delta**: a smoothly blended "wineglass" double-curve encompassing the leading edges and tip of a cropped compound delta. Seen in tailless form on the Concorde supersonic transports.



Tailless delta Tailed delta Cropped delta Compound delta Ogival delta

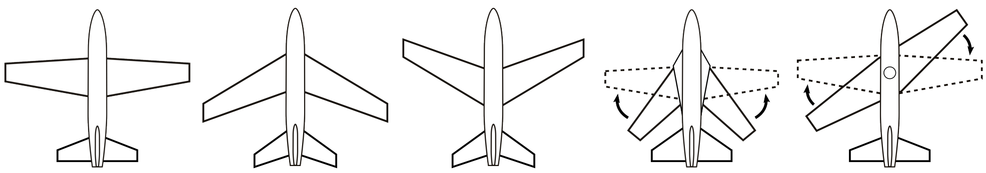
Wing sweep

Wings may be swept back, or occasionally forwards, for a variety of reasons. A small degree of sweep is sometimes used to adjust the centre of lift when the wing cannot be attached in the ideal position for some reason, such as a pilot's visibility from the cockpit. Other uses are described below.

- **Straight**: extends at right angles to the line of flight. The most structurally-efficient wing, it has been common for low-speed designs since the very first days of the Wright Flyer.
- **Swept back** (aka "swept wing"): The wing sweeps rearwards from the root to the tip. In early tailless examples, such as the Dunne aircraft, this allowed the outer wing section to act like a conventional empennage (tail) to provide aerodynamic stability. At transonic speeds swept wings have lower drag, but can handle badly in or near a stall and require high stiffness to avoid aeroelasticity at high speeds. Common on high-subsonic and early supersonic designs such as the Hawker Hunter.
- **Forward swept**: the wing angles forward from the root. Benefits are similar to backwards sweep, also it avoids the stall problems and has reduced tip losses allowing a smaller wing, but requires even greater stiffness to avoid aeroelastic flutter as on the Sukhoi Su-47. The HFB 320 Hansa Jet used forward sweep to prevent the wing spar passing through the cabin. Small shoulder-wing aircraft may use forward sweep to maintain a correct CoG.

Some types of **variable geometry** vary the wing sweep during flight:

- **Swing-wing**: also called "variable sweep wing". The left and right hand wings vary their sweep together, usually backwards. Seen in a few types of military aircraft, such as the General Dynamics F-111 Aardvark.
- **Oblique wing**: a single full-span wing pivots about its midpoint, so that one side sweeps back and the other side sweeps forward. Flown on the NASA AD-1 research aircraft.

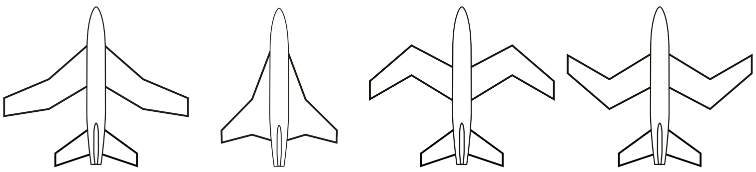


Straight Swept Forward swept Variable sweep (swing-wing) Variable-geometry oblique wing

Sweep variation along span

The angle of a swept wing may also be varied, or cranked, along the span:

- **Crescent**: wing outer section is swept less sharply than the inner section, to obtain a best compromise between transonic shock delay and spanwise flow control. Used on the Handley Page Victor.[17]
- **Cranked arrow**: aerodynamically identical to the compound delta, but with the trailing edge also kinked inwards. Trialled experimentally on the General Dynamics F-16XL.
- **M-wing**: the inner wing section sweeps forward, and the outer section sweeps backwards. Allows the wing to be highly swept while minimising the undesirable effects of aeroelastic bending. Periodically studied, but never used on an aircraft.[18][19][20]
- **W-wing**: A reversed M-wing. Proposed for the Blohm & Voss P.188 but studied even less than the M-wing and in the end never used.[18][20]

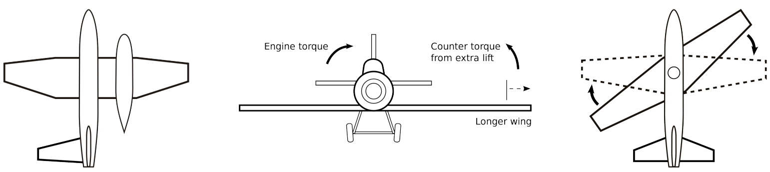


Crescent Cranked arrow M-wing W-wing

Asymmetrical

On a few asymmetrical aircraft the left and right hand sides are not mirror-images of each other:

- **Asymmetric layout**: the Blohm & Voss BV 141 had separate fuselage and crew nacelle offset on either side to give the crew a good field of view.
- **Asymmetric span**: on several Italian fighters such as the Ansaldo SVA, one wing was slightly longer than the other to help counteract engine torque.
- **Oblique wing**: one wing sweeps forward and the other back. The NASA AD-1 had a full-span wing structure with variable sweep.

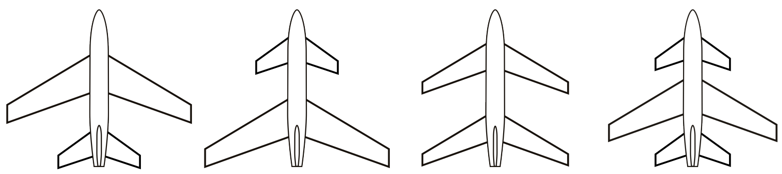


Asymmetrical Torque counteraction by asymmetric span Variable-geometry oblique wing

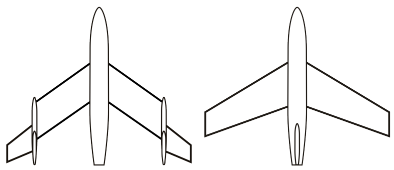
Tailplanes and foreplanes

The classic aerofoil section wing is unstable in pitch, and requires some form of horizontal stabilizing surface. Also it cannot provide any significant pitch control, requiring a separate control surface (elevator) mounted elsewhere.

- **Conventional**: "tailplane" surface at the rear of the aircraft, forming part of the tail or empennage. It did not become the convention for some years after the Wrights, with the Blériot VII of 1907 being the first successful example.
- **Canard**: "foreplane" surface at the front of the aircraft. Common in the pioneer years, but from the outbreak of World War I no production model appeared until the Saab Viggen in 1967.
- **Tandem**: two main wings, one behind the other. Both provide lift; the aft wing provides pitch stability (as a usual tailplane). An example is the Rutan Quickie. To provide longitudinal stability, the wings must differ in aerodynamic characteristics: typically the wing loading and/or the aerofoils differ between the two wings.
- **Three surface**:[21] both conventional tail and canard auxiliary surfaces. Modern examples include the Sukhoi Su-33, while pioneer examples include the Voisin-Farman I.
- **Outboard tail**: split in two, with each half mounted on a short boom just behind and outboard of a wing tip. It comprises **outboard horizontal stabilizers (OHS)** and may or may not include additional boom-mounted vertical stabilizers (fins). In this position, the tail surfaces interact constructively with the wingtip vortices to significantly reduce drag. Used for the Scaled Composites SpaceShipOne.
- **Tailless**: no separate surface, at front or rear. The lifting and stabilizing surfaces may be combined in a single plane, as on the Short SB.4 Sherpa whose whole wing tip sections acted as elevons. Alternatively the aerofoil profile may be modified to provide inherent stability, as on the Dunne D.5. Aircraft having a tailplane but no vertical tail fin have also been described as "tailless".



Conventional tail   Canard   Tandem   Three surface



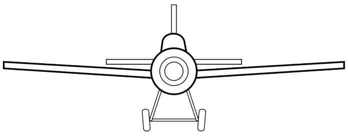
Outboard tail   Tailless

Dihedral and anhedral

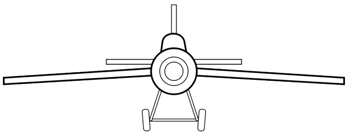
Angling the wings up or down spanwise from root to tip can help to resolve various design issues, such as stability and control in flight.

- **Dihedral**: the tips are higher than the root as on the Santos-Dumont 14-bis, giving a shallow 'V' shape when seen from the front. Adds lateral stability.
- **Anhedral**: the tips are lower than the root, as on the first Wright Flyer; the opposite of dihedral. Used to reduce stability where some other feature results in too much stability.

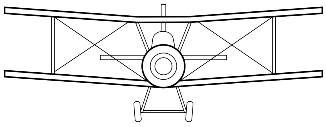
Some biplanes have different degrees of dihedral/anhedral on different wings. The Sopwith Camel had a flat upper wing and dihedral on the lower wing, while the Hanriot HD-1 had dihedral on the upper wing but none on the lower.



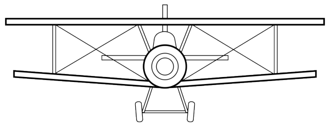
Dihedral



Anhedral



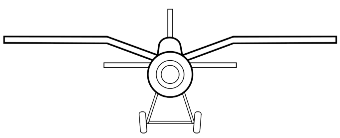
Biplane with dihedral on both wings



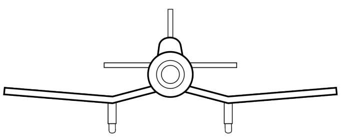
Biplane with dihedral on lower wing

In a **cranked** or **polyhedral** wing the dihedral angle varies along the span. (Note that the description "cranked" varies in usage.[22][23][24][25] See also **Cranked arrow** planform.)

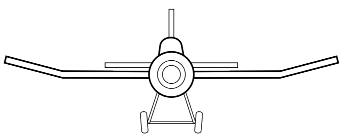
- **Gull wing**: sharp dihedral on the wing root section, little or none on the main section, as on the PZL P.11 fighter. Sometimes used to improve visibility forwards and upwards and may be used as the upper wing on a biplane as on the Polikarpov I-153.
- **Inverted gull**: anhedral on the root section, dihedral on the main section. The opposite of a gull wing. May be used to reduce the length of wing-mounted undercarriage legs while allowing a raised fuselage, as on the German Junkers Ju 87 *Stuka* dive bomber.
- **Cranked tip**: tip section dihedral differs from the main wing. The tips may have upwards dihedral as on the F-4 Phantom II or downwards anhedral as on the Northrop XP-56 Black Bullet.



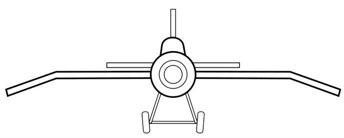
Gull wing



Inverted gull wing

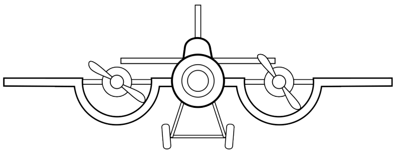


Dihedral tips



Anhedral tips

- The **channel wing** includes a section of the wing forming a partial duct around or immediately behind a propeller. Flown since 1942 in prototype form only, most notably on the Custer Channel Wing aircraft.

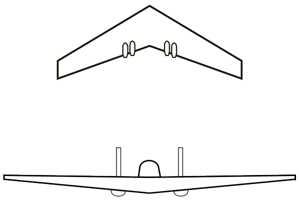


Channel wing

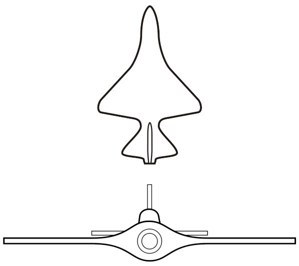
Wings vs. bodies

Some designs have no clear join between wing and fuselage, or body. This may be because one or other of these is missing, or because they merge into each other:

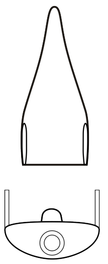
- **Flying wing**: the aircraft has no distinct fuselage or horizontal tail (although fins and pods, blisters, etc. may be present) such as on the B-2 stealth bomber.
- **Blended body** or **blended wing-body**: a smooth transition occurs between wing and fuselage, with no hard dividing line. Reduces wetted area and can also reduce interference between airflow over the wing root and any adjacent body, in both cases reducing drag. The Lockheed SR-71 spyplane exemplifies this approach.
- **Lifting body**: the aircraft lacks identifiable wings but relies on the fuselage (usually at high speeds or high angles of attack) to provide aerodynamic lift as on the X-24.



Flying wing



Blended body



Lifting body

Some designs may fall into multiple categories depending on interpretation, for example the same design could be seen either as a lifting body with a broad fuselage, or as a low-aspect-ratio flying wing with a deep center chord.

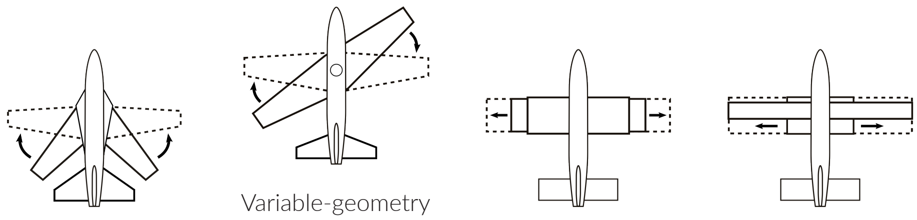
Variable geometry

A **variable geometry** aircraft is able to change its physical configuration during flight.

Some types of variable geometry craft transition between fixed wing and rotary wing configurations. For more about these hybrids, see powered lift.

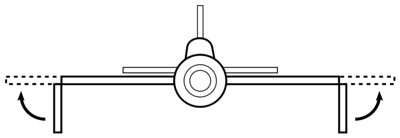
Variable planform

- **Variable-sweep wing** or **Swing-wing**. The left and right hand wings vary their sweep together, usually backwards. The first successful wing sweep in flight was carried out by the Bell X-5 in the early 1950s. In the Beech Starship, only the canard foreplanes have variable sweep.
- **Oblique wing**: a single full-span wing pivots about its midpoint, as used on the NASA AD-1, so that one side sweeps back and the other side sweeps forward.
- **Telescoping wing**: the outer section of wing telescopes over or within the inner section of wing, varying span, aspect ratio and wing area, as used on the FS-29 TF glider.[26]
- **Detachable wing**. The WS110A study proposed a long wing for efficient subsonic cruise, which then ejects the outer panels to leave a short-span wing for a short supersonic "dash" to its targets. See Slip wing.
- **Extending wing** or **expanding wing**: part of the wing retracts into the main aircraft structure to reduce drag and low-altitude buffet for high-speed flight, and is extended only for takeoff, low-speed cruise and landing. The Gérin Varivol biplane, which flew in 1936, extended the leading and trailing edges to increase wing area.[27]



Variable sweep (swing-wing) | Variable-geometry oblique wing | Telescoping wing | Extending wing

- **Folding wing**: part of the wing extends for takeoff and landing, and folds away for high-speed flight. The outer sections of the XB-70 Valkyrie wing folded down during supersonic cruise. (Many aircraft have wings that may be folded for storage on the ground or on board ship. These are not folding wings in the sense used here).

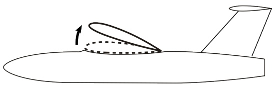


Folding wing

Variable chord

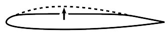
- **Variable incidence**: the wing plane can tilt upwards or downwards relative to the fuselage. The wing on the Vought F-8 Crusader was rotated, lifting the leading edge on takeoff to improve performance. If powered prop-rotors are fitted to the wing to allow vertical takeoff or STOVL performance, merges into the powered lift category.

- **Variable camber**: the leading and/or trailing edge sections of the whole wing pivot to increase the effective camber of the wing and sometimes also its area. This enhances manoeuvrability. An early example was flown on the Westland N.16 of 1917.[28]
- **Variable thickness**: the upper wing centre section can be raised to increase wing thickness and camber for landing and take-off, and reduced for high speed. Charles Rocheville and others flew some experimental aircraft.[29][30][31]



Variable incidence wing

Variable camber aerofoil

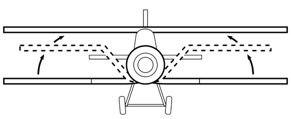


Variable thickness aerofoil

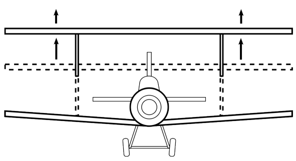
Polymorphism

A **polymorphic** wing is able to change the number of planes in flight. The Nikitin-Shevchenko IS "folding fighter" prototypes were able to morph between biplane and monoplane configurations after takeoff by folding the lower wing into a cavity in the upper wing.

The **slip wing** is a variation on the polymorphic idea, whereby a low-wing monoplane was fitted with a second detachable "slip" wing above it to assist takeoff, which was then jettisoned once aloft. The idea was first flown on the experimental Hillson Bi-mono.



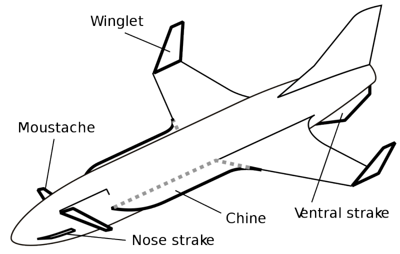
Polymorphic wing



Slip wing

Minor independent surfaces

Aircraft may have additional minor aerodynamic surfaces. Some of these are treated as part of the overall wing configuration:



Various minor surfaces

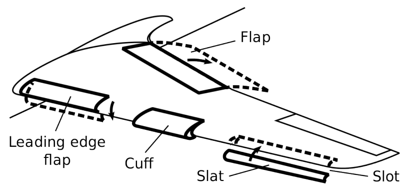
- **Winglet**: a small fin at the wingtip, usually turned upwards. Reduces the size of vortices shed by the wingtip, and hence also tip drag.
- **Strake**: a small surface, typically longer than it is wide and mounted on the fuselage. Strakes may be located at various positions in order to improve aerodynamic behaviour. Leading edge root extensions (LERX) are also sometimes referred to as wing strakes.
- **Chine**: sharp-edged profile running along the fuselage. When used aerodynamically it is extended outwards to form a lifting surface, typically blending into the main wing. As well as improving low speed (high angle of attack) handling, provides extra lift at high supersonic speeds for minimal increase in drag. Seen on the Lockheed SR-71 Blackbird.
- **Moustache**: small high-aspect-ratio canard surface having no movable control surface. Typically is retractable for high speed flight. Deflects air downward onto the wing root, to delay the stall. Seen on the Dassault Milan.

Additional minor features

Additional minor features may be applied to an existing aerodynamic surface such as the main wing:

High lift

High-lift devices maintain lift at low speeds and delay the stall to allow slower takeoff and landing speeds:



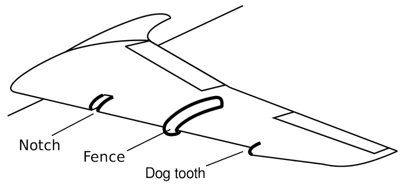
High-lift devices

- **Slat** and **slot**: a Leading edge slat is a small aerofoil extending in front of the main leading edge. The spanwise gap behind it forms a leading-edge slot. Air flowing up through the slot is deflected backwards by the slat to flow over the wing, allowing the aircraft to fly at lower air speeds without flow separation or stalling. A slat may be fixed or retractable.
- **Flap**: a hinged aerodynamic surface, usually on the trailing edge, which is rotated downwards to generate extra lift and drag. Types include plain, slotted, and split. Some, such as Fowler Flaps, also extend rearwards to increase wing area. The Krueger flap is a leading-edge device.
- **Cuff**: an extension to the leading edge which modifies the aerofoil section, typically to improve low-speed characteristics.

Spanwise flow control

On a swept wing, air tends to flow sideways as well as backwards and reducing this can improve the efficiency of the wing:

- **Wing fence**: a flat plate extending along the wing chord and for a short distance vertically. Used to control spanwise airflow over the wing.
- **Dogtooth leading edge**: creates a sharp discontinuity in the airflow over the wing, disrupting spanwise flow.[32]
- **Notched leading edge**: acts like a dogtooth.[32]

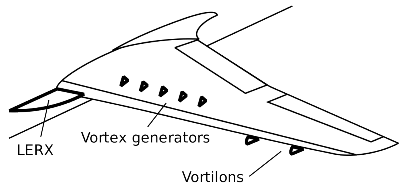


Spanwise flow control device

Vortex creation

Vortex devices maintain airflow at low speeds and delay the stall, by creating a vortex which re-energises the boundary layer close to the wing.

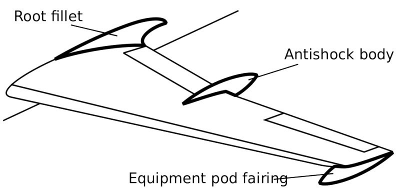
- **Vortex generator**: small triangular protrusion on the upper leading wing surface; usually, several are spaced along the span of the wing. Vortex generators create additional drag at all speeds.
- **Vortilon**: a flat plate attached to the underside of the wing near its outer leading edge, roughly parallel to normal airflow. At low speeds, tip effects cause a local spanwise flow which is deflected by the vortilon to form a vortex passing up and over the wing.
- **Leading-edge root extension (LERX)**: generates a strong vortex over the wing at high angles of attack, but unlike vortex generators it can also increase lift at such high angles, while creating minimal drag in level flight.



Vortex devices

Drag reduction

- **Anti-shock body**: a streamlined pod shape added to the leading or trailing edge of an aerodynamic surface, to delay the onset of shock stall and reduce transonic wave drag. Sometimes called a *Küchemann carrot*.
- **Fillet**: a small curved infill at the junction of two surfaces, such as a wing and fuselage, blending them smoothly together to reduce drag.
- **Fairings** of various kinds, such as blisters, pylons and wingtip pods, containing equipment which cannot fit inside the wing, and whose only aerodynamic purpose is to reduce the drag created by the equipment.



Drag-reduction devices

Notes

1. **^** Taylor, J. (Ed.), *Jayne's all the world's aircraft 1980–81, Jane's (1980)*
2. **^** Green, W.; *Warplanes of the second world war, Vol. 5, Flying boats*, Macdonald (1962), p.131
3. **^** Taylor, 1990. p. 76
4. **^** *Kroo, I. (2005), "Nonplanar Wing Concepts For Increased Aircraft Efficiency", VKI lecture series on Innovative Configurations and Advanced Concepts for Future Civil Aircraft June 6–10, 2005*
5. **^** *"Nonplanar Wings: Closed Systems". Aero.stanford.edu. Retrieved 2012-03-31.*
6. **^** Airliners.net, Lee Richards Annular, 2012, retrieved 31 March 2012

7. **^** Ligeti Stratos joined wing aircraft
8. **^** Angelucco, E. and Matrciardi, P.; *World Aircraft Origins-World War 1*, Sampson Low, 1977
9. **^** Kermode (1972), Chapter 3, p. 103.
0. **^** *Garrison, Peter (2003-01-01). "Rectangular Wings | Flying Magazine". Flyingmag.com. Retrieved 2012-03-31.*
1. **^** Tom Benson; *Wing Area*, NASA
2. **^** Ilan Kroo. AA241 *Aircraft Design: Synthesis and Analysis Wing Geometry Definitions*, Stanford University.
3. **^** G. Dimitriadis; *Aircraft Design* Lecture 2: Aerodynamics, Université de Liège.
4. **^** *"Alexander de Seversky". centennialofflight.net. Retrieved 2012-03-31.*
5. **^** Potts, J.R.; Disc-wing aerodynamics, University of Manchester, 2005.
6. **^** letter from Hall-Warren, N.; *Flight International*, 1962, p. 716.
7. **^** *"swept wing | avro vulcan | 1953 | 0030 | Flight Archive". Flightglobal.com. 1952-12-05. Retrieved 2012-05-29.*
8. ^ ***a b*** Diederich and Foss; *Static Aeroelastic Phenomena of M-, W- and Λ- wings*, NACA 1953.
9. **^** *"Aerodynamics at Teddington", Flight: 764, 5 June 1959*
0. ^ ***a b*** *Katz, Marley, Pepper, NACA RM L50G31 (PDF), NACA*
1. **^** P180 Avanti-Specification and Description. See page 55, Appendix A: "Notes about the 3-Lifting-Surface design".
2. **^** *Ernst-Heinrich Hirschel; Horst Prem; Gero Madelung (2004). Aeronautical research in Germany: from Lilienthal until today. Springer Science & Business Media. p. 167. ISBN 978-3-540-40645-7.*
3. **^** Benoliel, Alexander M., Aerodynamic Pitch-up of Cranked Arrow Wings: Estimation, Trim, and Configuration Design, Virginia Polytechnic Institute & State University, May 1994, retrieved 31 March 2012
4. **^** *"Boeing Sonic Cruiser ousts 747X". Flightglobal.com. 2001-04-03. Retrieved 2012-03-31.*
5. **^** *"WHAT IS IT? Aircraft Characteristics That Aid the Spotter Classified : A Simple Guide for Basic Features in Design the Beginner", Flight: 562, 4 June 1942*
6. **^** *"fs 29 - "TF" ". Uni-stuttgart.de. 2012-02-05. Retrieved 2012-03-31.*
7. **^** *"Plane With Expanding Wing, Flies In Tests". Popular Science. November 1932. p. 31.*
8. **^** Lukins, A.H.; *The book of Westland aircraft*, Aircraft (Technical) Publications Ltd, (1943 or 1944).
9. **^** *Hearst Magazines (January 1931). "Adjustable Airplane's Wings Are Changed In Flight". Popular Mechanics. Hearst Magazines. p. 55.*
0. **^** Flight, August 15, 1929
1. **^** Boyne, W.J.; *The best of Wings magazine*, Brassey's (2001)
2. ^ ***a b*** *Wing vortex devices*

References

- Kermode, A. C.; *Mechanics of Flight*, Eighth (metric) edition, Pitman, London, 1972. ISBN 0-273-31623-0
- Taylor, John W. R. *The Lore of Flight*, Universal Books, London, 1990. ISBN 0-9509620-1-5.
- *"What is it? Aircraft Characteristics That Aid the Spotter". Flight. June 4, 1942.*

See also

There is a Wikipedia Book on **Aircraft wing configurations**

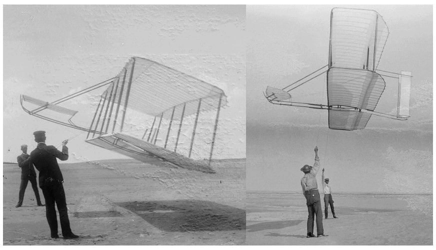
- Aircraft design process

External links

- High wing, low wing—*Flight* article on the merits of wing position

Lift-to-drag ratio

In aerodynamics, the **lift-to-drag ratio**, or **L/D ratio**, is the amount of lift generated by a wing or vehicle, divided by the aerodynamic drag it creates by moving through the air. A higher or more favorable L/D ratio is typically one of the major goals in aircraft design; since a particular aircraft's required lift is set by its weight, delivering that lift with lower drag leads directly to better fuel economy in aircraft, climb performance, and glide ratio.



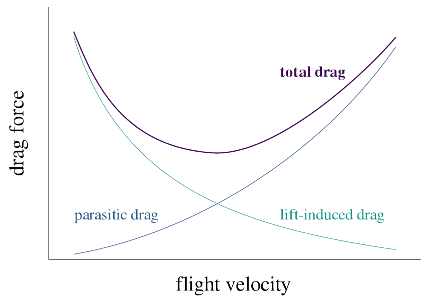
The Wright brothers testing their gliders in 1901 (left) and 1902 (right). The angle of the tether reflects the dramatic improvement in the lift-to-drag ratio

The term is calculated for any particular airspeed by measuring the lift generated, then dividing by the drag at that speed. These vary with speed, so the results are typically plotted on a 2D graph. In almost all cases the graph forms a U-shape, due to the two main components of drag.

Lift-to-drag ratios can be determined by flight test, by calculation or by testing in a wind tunnel.

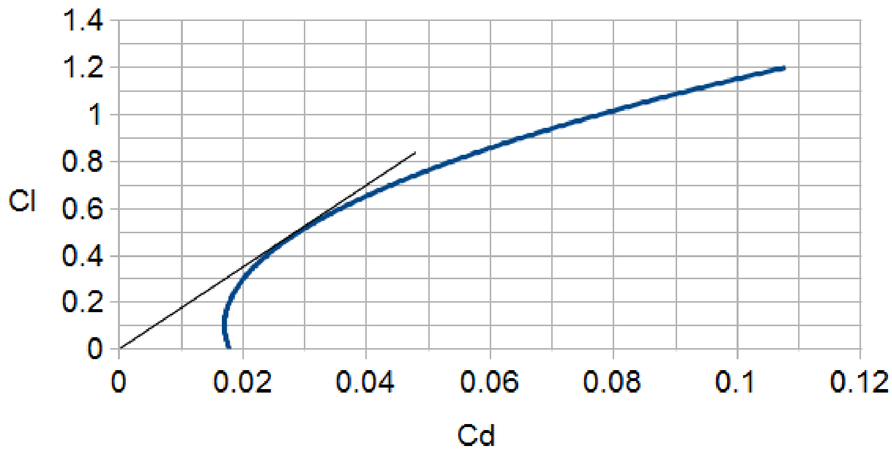
Drag

Lift-induced drag is a component of total drag that arises whenever a finite span wing generates lift. At low speeds an aircraft has to generate lift with a higher angle of attack, thereby leading to greater induced drag. This term dominates the low-speed side of the lift versus velocity graph.



The drag curve

Form drag is caused by movement of the aircraft through the air. This type of drag, also known as air resistance or profile drag varies with the square of speed (see drag equation). For this reason profile drag is more pronounced at higher speeds, forming the right side of the lift/velocity graph's U shape. Profile drag is lowered primarily by streamlining and reducing cross section.



Drag polar for light aircraft. The tangent gives the maximum L/D point.

Lift, like drag, increases as the square of the velocity and the ratio of lift to drag is often plotted in terms of the lift and drag coefficients C_L and C_D. Such graphs are referred to as drag polars. Speed increases from left to right. The lift/drag ratio is given by the slope from the origin to some point on this curve and so the peak L/D ratio does not occur at the point of least drag, the leftmost point. Instead it occurs at a slightly higher speed. Designers will typically select a wing design which produces an L/D peak at the chosen cruising speed for a powered fixed-wing aircraft, thereby maximizing economy. Like all things in aeronautical engineering, the lift-to-drag ratio is not the only consideration for wing design. Performance at high angle of attack and a gentle stall are also important.

Glide ratio

As the aircraft fuselage and control surfaces will also add drag and possibly some lift, it is fair to consider the L/D of the aircraft as a whole. As it turns out, the glide ratio, which is the ratio of an (unpowered) aircraft's forward motion to its descent, is (when flown at constant speed) numerically equal to the aircraft's L/D. This is especially of interest in the design and operation of high performance sailplanes, which can have glide ratios approaching 60 to 1 (60 units of distance forward for each unit of descent) in the best cases, but with 30:1 being considered good performance for general recreational use. Achieving a glider's best L/D in practice requires precise control of airspeed and smooth and restrained operation of the controls to reduce drag from deflected control surfaces. In zero wind conditions, L/D will equal distance traveled divided by altitude lost. Achieving the maximum distance for altitude lost in wind conditions requires further modification of the best airspeed, as does alternating cruising and thermaling. To achieve high speed across country, glider pilots anticipating strong thermals often load their gliders (sailplanes) with water ballast: the increased wing loading means optimum glide ratio at higher airspeed, but at the cost of climbing more slowly in thermals. As noted below, the maximum L/D is not dependent on weight or wing loading, but with higher wing loading the maximum L/D occurs at a faster airspeed. Also, the faster airspeed means the aircraft will fly at higher Reynolds number and this will usually bring about a lower zero-lift drag coefficient.

Theory

Mathematically, the maximum lift-to-drag ratio can be estimated as:

$$(L/D)_{max} = \frac{1}{2}\sqrt{\frac{\pi\epsilon AR}{C_{D,0}}},$$ [1]

where *AR* is the aspect ratio, ϵ the span efficiency factor, a number less than but close to unity for long, straight edged wings, and $C_{D,0}$ the zero-lift drag coefficient.

Most importantly, the maximum lift-to-drag ratio is independent of the weight of the aircraft, the area of the wing, or the wing loading.

It can be shown that two main drivers of maximum lift-to-drag ratio for a fixed wing aircraft are wingspan and total wetted area. One method for estimating the zero-lift drag coefficient of an aircraft is the equivalent skin-friction method. For a well designed aircraft, zero-lift drag (or parasite drag) is mostly made up of skin friction drag plus a small percentage of pressure drag caused by flow separation. The method uses the equation:

$$C_{D,0} = C_{fe}\frac{S_{wet}}{S_{ref}},$$ [2]

where C_{fe} is the equivalent skin friction coefficient, S_{wet} is the wetted area and S_{ref} is the wing reference area. The equivalent skin friction coefficient accounts for both separation drag and skin friction drag and is a fairly consistent value for aircraft types of the same class. Substituting this into the equation for maximum lift-to-drag ratio, along with the equation for aspect ratio (b^2/S_{ref}), yields the equation:

$$(L/D)_{max} = \frac{1}{2}\sqrt{\frac{\pi\epsilon}{C_{fe}}\frac{b^2}{S_{wet}}}$$

where *b* is wingspan. The term b^2/S_{wet} is known as the wetted aspect ratio. The equation demonstrates the importance of wetted aspect ratio in achieving an aerodynamically efficient design.

Supersonic/hypersonic lift to drag ratios

At very high speeds, lift to drag ratios tend to be lower. Concorde had a lift/drag ratio of around 7 at Mach 2, whereas a 747 is around 17 at about mach 0.85.

Dietrich Küchemann developed an empirical relationship for predicting L/D ratio for high Mach:[3]

$$L/D_{max} = \frac{4(M+3)}{M}$$

where M is the Mach number. Windtunnel tests have shown this to be roughly accurate.

Examples

A House sparrow has a 4:1 L/D ratio, a Herring gull a 10:1 one, a Common tern 12:1 and an Albatross 20:1, to be compared to 8.3:1 for the Wright Flyer to 17.7:1 for a Boeing 747 in cruise.[4] A cruising Airbus A380 reaches 20:1.[5] The Concorde at take-off and landing had a 4:1 L/D ratio, increasing to 12:1 at Mach 0.95 and 7.5:1 at Mach

2.[6] A Helicopter at 100 kn (190 km/h) has a 4.5:1 L/D ratio.[7] A Cessna 172 glides at a 10.9:1 ratio.[8] A cruising Lockheed U-2 has a 25.6 L/D ratio.[9] The Rutan Voyager had a 27:1 ratio and the Virgin Atlantic GlobalFlyer 37:1.[10]

Computed aerodynamic characteristics[11]

Jetliner	cruise L/D	First flight
L1011-100	14.5	Nov 16, 1970
DC-10-40	13.8	Aug 29, 1970
A300-600	15.2	Oct 28, 1972
MD-11	16.1	Jan 10, 1990
B767-200ER	16.1	Sep 26, 1981
A310-300	15.3	Apr 3, 1982
B747-200	15.3	Feb 9, 1969
B747-400	15.5	Apr 29, 1988
B757-200	15.0	Feb 19, 1982
A320-200	16.3	Feb 22, 1987
A330-300	18.1	Nov 2, 1992
A340-200	19.2	Apr 1, 1992
A340-300	19.1	Oct 25, 1991
B777-200	19.3	Jun 12, 1994

In gliding flight, the L/D ratios are equal to the glide ratio (when flown at constant speed).

Flight article	Scenario	L/D ratio/ glide ratio
Eta (glider)	Gliding	70[12]
Great frigatebird	Soaring over the ocean	15-22 at typical speeds[13]
Hang glider	Gliding	15
Air Canada Flight 143 (Gimli Glider)	a Boeing 767-200 with all engines failed caused by fuel exhaustion	~12
British Airways Flight 9	a Boeing 747-200B with all engines failed caused by volcanic ash	~15
US Airways Flight 1549	a Airbus A320-214 with all engines failed caused by bird strike	~17
Paraglider	High performance model	11
Helicopter	Autorotation	4
Powered parachute	Rectangular/elliptical parachute	3.6/5.6
Space Shuttle	Approach	4.5[14]
Hypersonic Technology Vehicle 2	Equilibrium hypersonic gliding estimate[15]	2.6
Wingsuit	Gliding	2.5
Northern flying squirrel	Gliding	1.98
Space Shuttle	Hypersonic	1[14]
Apollo CM	Reentry	0.368[16]

See also

- Gravity drag rockets can have an effective lift to drag ratio while maintaining altitude
- Inductrack maglev has a higher lift/drag ratio than aircraft at sufficient speeds
- Lift coefficient
- Range (aeronautics) range depends on the lift/drag ratio
- Thrust specific fuel consumption the lift to drag determines the required thrust to maintain altitude (given the aircraft weight), and the SFC permits calculation of the fuel burn rate
- Thrust-to-weight ratio

References

[8]

1. **^** *Loftin, LK, Jr. "Quest for performance: The evolution of modern aircraft. NASA SP-468". Retrieved 2006-04-22.*
2. **^** *Raymer, Daniel (2012). Aircraft Design: A Conceptual Approach (5th ed.). New York: AIAA.*
3. **^** Aerospaceweb.org Hypersonic Vehicle Design
4. **^** *Antonio Filippone. "Lift-to-Drag Ratios". Advanced topics in aerodynamics. Archived from the original on March 28, 2008.*
5. **^** *Cumpsty, Nicholas (2003). Jet Propulsion. Cambridge University Press. p. 4.*

6. **^** *Christopher Orlebar (1997). The Concorde Story. Osprey Publishing. p. 116. ISBN 9781855326675.*
7. **^** *Leishman, J. Gordon (24 April 2006). Principles of helicopter aerodynamics. Cambridge University Press. p. 230. ISBN 0521858607. "The maximum lift-to-drag ratio of the complete helicopter is about 4.5"*
8. ^ ***a b*** Cessna Skyhawk II Performance Assessment http://temporal.com.au/c172.pdf
9. **^** *"U2 Developments transcript". Central Intelligence Agency. 1960. Lay summary – transcript.*
0. **^** *David Noland (February 2005). "The Ultimate Solo". Popular Mechanics.*
1. **^** *Rodrigo Martínez-Val; et al. (January 2005). "Historical evolution of air transport productivity and efficiency". 43rd AIAA Aerospace Sciences Meeting and Exhibit. doi:10.2514/6.2005-121.*
2. **^** Eta aircraft Eta aircraft performances plots - accessed 2004-04-11
3. **^** Flight performance of the largest volant bird
4. ^ ***a b*** Space Shuttle Technical Conference pg 258
5. **^** http://scienceandglobalsecurity.org/archive/2015/09/hypersonic_boost-glide_weapons.html
6. **^** Hillje, Ernest R., "Entry Aerodynamics at Lunar Return Conditions Obtained from the Flight of Apollo 4 (AS-501)," NASA TN D-5399, (1969).

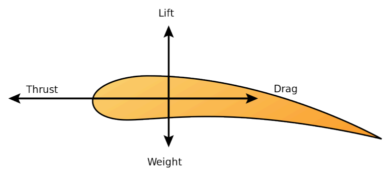
Thrust

Thrust is a reaction force described quantitatively by Newton's third law. When a system expels or accelerates mass in one direction, the accelerated mass will cause a force of equal magnitude but opposite direction on that system.[1] The force applied on a surface in a direction perpendicular or normal to the surface is also called thrust. Force, and thus thrust, is measured using the International System of Units (SI) in newtons (symbol: N), and represents the amount needed to accelerate 1 kilogram of mass at the rate of 1 meter per second per second. In mechanical engineering, force orthogonal to the main load (such as in parallel helical gears) is referred to as thrust.

A Pratt & Whitney F100 jet engine is being tested. This engine generates thrust for a jet to propel it forward.

Examples

A fixed-wing aircraft generates forward thrust when air is pushed in the direction opposite to flight. This can be done in several ways including by the spinning blades of a propeller, or a rotating fan pushing air out from the back of a jet engine, or by ejecting hot gases from a rocket engine.[2] The forward thrust is proportional to the mass of the airstream multiplied by the difference in velocity of the airstream. Reverse thrust can be generated to aid braking after landing by reversing the pitch of variable-pitch propeller blades, or using a thrust reverser on a jet engine. Rotary wing aircraft and thrust vectoring V/STOL aircraft use engine thrust to support the weight of the aircraft, and vector sum of this thrust fore and aft to control forward speed.



Forces on an aerofoil cross section

A motorboat generates thrust (or reverse thrust) when the propellers are turned to accelerate water backwards (or forwards). The resulting thrust pushes the boat in the opposite direction to the sum of the momentum change in the water flowing through the propeller.

A rocket is propelled forward by a thrust force equal in magnitude, but opposite in direction, to the time-rate of momentum change of the exhaust gas accelerated from the combustion chamber through the rocket engine nozzle. This is the exhaust velocity with respect to the rocket, times the time-rate at which the mass is expelled, or in mathematical terms:

$$\mathbf{T} = \mathbf{v}\frac{\mathrm{d}m}{\mathrm{d}t}$$

Where **T** is the thrust generated (force), $\frac{\mathrm{d}m}{\mathrm{d}t}$ is the rate of change of mass with respect to time (mass flow rate of exhaust), and **v** is the speed of the exhaust gases measured relative to the rocket.

For vertical launch of a rocket the initial thrust at liftoff must be more than the weight.

Each of the three Space Shuttle Main Engines could produce a thrust of 1.8 MN, and each of the Space Shuttle's two Solid Rocket Boosters 14.7 MN, together 29.4 MN.[3]

By contrast, the simplified Aid For EVA Rescue (SAFER) has 24 thrusters of 3.56 N each.

In the air-breathing category, the AMT-USA AT-180 jet engine developed for radio-controlled aircraft produce 90 N (20 lbf) of thrust.[4] The GE90-115B engine fitted on the Boeing 777-300ER, recognized by the Guinness Book of World Records as the "World's Most Powerful Commercial Jet Engine," has a thrust of 569 kN (127,900 lbf).

Concepts

Thrust to power

The power needed to generate thrust and the force of the thrust can be related in a non-linear way. In general, $\mathbf{P}^2 \propto \mathbf{T}^3$. The proportionality constant varies, and can be solved for a uniform flow:

$$\frac{\mathrm{d}m}{\mathrm{d}t} = \rho A v$$

$$\mathbf{T} = \frac{\mathrm{d}m}{\mathrm{d}t} v, \mathbf{P} = \frac{1}{2}\frac{\mathrm{d}m}{\mathrm{d}t} v^2$$

$$\mathbf{T} = \rho A v^2, \mathbf{P} = \frac{1}{2}\rho A v^3$$

$$\mathbf{P}^2 = \frac{\mathbf{T}^3}{4\rho A}$$

Note that these calculations are only valid for when the incoming air is accelerated from a standstill - for example when hovering.

The inverse of the proportionality constant, the "efficiency" of an otherwise-perfect thruster, is proportional to the area of the cross section of the propelled volume of fluid (A) and the density of the fluid (ρ). This helps to explain why moving through water is easier and why aircraft have much larger propellers than watercraft.

Thrust to propulsive power

A very common question is how to contrast the thrust rating of a jet engine with the power rating of a piston engine. Such comparison is difficult, as these quantities are not equivalent. A piston engine does not move the aircraft by itself (the propeller does that), so piston engines are usually rated by how much power they deliver to the propeller. Except for changes in temperature and air pressure, this quantity depends basically on the throttle setting.

A jet engine has no propeller, so the propulsive power of a jet engine is determined from its thrust as follows. Power is the force (F) it takes to move something over some distance (d) divided by the time (t) it takes to move that distance:[5]

$$\mathbf{P} = \mathbf{F}\frac{d}{t}$$

In case of a rocket or a jet aircraft, the force is exactly the thrust (T) produced by the engine. If the rocket or aircraft is moving at about a constant speed, then distance divided by time is just speed, so power is thrust times speed:[6]

P = **T***v*

This formula looks very surprising, but it is correct: the *propulsive power* (or *power available* [7]) of a jet engine increases with its speed. If the speed is zero, then the propulsive power is zero. If a jet aircraft is at full throttle but attached to a static test stand, then the jet engine produces no propulsive power, however thrust is still produced. Compare that to a piston engine. The combination piston engine–propeller also has a propulsive power with exactly the same formula, and it will also be zero at zero speed –- but that is for the engine–propeller set. The engine alone will continue to produce its rated power at a constant rate, whether the aircraft is moving or not.

Now, imagine the strong chain is broken, and the jet and the piston aircraft start to move. At low speeds:

The piston engine will have constant 100% power, and the propeller's thrust will vary with speed

The jet engine will have constant 100% thrust, and the engine's power will vary with speed

Excess thrust

If a powered aircraft is generating thrust T and experiencing drag D, the difference between the two, T − D, is termed the excess thrust. The instantaneous performance of the aircraft is mostly dependent on the excess thrust.

Excess thrust is a vector and is determined as the vector difference between the thrust vector and the drag vector.

Centre of thrust

The centre of thrust for an object is an average point at which the total thrust may be considered to apply. It may differ from the centre of gravity.

See also

- Aerodynamic force
- Astern propulsion
- Gimballed thrust, the most common thrust system in modern rockets
- Stream thrust averaging
- Thrust-to-weight ratio
- Thrust vectoring
- Tractive effort

References

1. **^** *"What is Thrust?". www.grc.nasa.gov. Retrieved 16 February 2018.*
2. **^** *"Newton's Third Law of Motion". www.grc.nasa.gov. Retrieved 16 February 2018.*
3. **^** *"Space Launchers - Space Shuttle". www.braeunig.us. Retrieved 16 February 2018.*
4. **^** *"AMT-USA jet engine product information". Archived from the original on 2006-11-10. Retrieved 2006-12-13.*

5. **^** *"Convert Thrust to Horsepower By Joe Yoon". Retrieved 2009-05-01.*
6. **^** "Introduction to Aircraft Flight Mechanics", Yechout & Morris
7. **^** "Understanding Flight", Anderson & Eberbaht

Selected Amphibious Aircrafts

Grumman J2F Duck

The **Grumman J2F Duck** (company designation **G-15**) was an American single-engine amphibious biplane. It was used by each major branch of the U.S. armed forces from the mid-1930s until just after World War II, primarily for utility and air-sea rescue duties. It was also used by the Argentine Navy, who took delivery of their first Duck in 1937. After the war, J2F Ducks saw service with independent civilian operators, as well as the armed forces of Colombia and Mexico.

The J2F was an improved version of the earlier JF Duck, with its main difference being a longer float.[1]

J2F Duck

Grumman J2F-4 Duck in flight

Role	Utility amphibian
National origin	United States
Manufacturer	Grumman Columbia Aircraft Corp
First flight	1936

Development

The J2F-1 Duck first flew on 2 April 1936, powered by a 750 hp (559 kW) Wright R-1820 Cyclone, and was delivered to the U.S. Navy on the same day. The J2F-2 had a Wright Cyclone engine which was boosted to 790 hp (589 kW). Twenty J2F-3 variants were built in 1939 for use by the Navy as executive transports with plush interiors. Due to pressure of work following the United States entry into the war in 1941, production of the J2F Duck was transferred to the Columbia Aircraft Corp of New York. They produced 330 aircraft for the Navy and U.S. Coast Guard.[2] If standard Navy nomenclature practice had been followed, these would have been designated JL-1s, but it was not, and all Columbia-produced airframes were delivered as J2F-6s.[3]

Several surplus Navy Ducks were converted for use by the United States Air Force in the air-sea rescue role as the **OA-12** in 1948.

Design

The J2F was an equal-span single-bay biplane with a large monocoque central float which also housed the retractable main landing gear, a similar design to the Leroy Grumman-designed landing gear first used for Grover Loening's early amphibious biplane designs, and later adopted for the Grumman FF fighter biplane. The aircraft had strut-mounted stabilizer floats beneath each lower wing. A crew of two or three were carried in tandem cockpits, forward for the pilot and rear for an observer with room for a radio operator if required. It had a cabin in the fuselage for two passengers or a stretcher.

The Duck's main pontoon was blended into the fuselage, making it almost a flying boat despite its similarity to a conventional landplane which has been float-equipped. This configuration was shared with the earlier Loening OL, Grumman having acquired the rights to Loening's hull, float and undercarriage designs.[4] Like the F4F Wildcat, its narrow-tracked landing gear was hand-cranked.

J2F Duck	
Introduction	1936
Primary users	United States Navy United States Army Air Forces United States Coast Guard United States Marine Corps
Number built	584
Developed from	Grumman JF Duck

Operational history

The J2F was used by the U.S. Navy, Marines, Army Air Forces and Coast Guard. Apart from general utility and light transport duties, its missions included mapping, scouting/observation, anti-submarine patrol, air-sea rescue work, photographic surveys and reconnaissance, and target tug.

J2Fs of the utility squadron of US Patrol Wing 10 were destroyed at Mariveles Bay, Philippines, by a Japanese air raid on 5 January 1942.[5] The only Duck to survive the attack had a dead engine but had been concealed at Cabcaben airfield during the Battle of Bataan, to be repaired afterwards with a cylinder removed from a destroyed J2F-4 submerged in Manila Bay. Following repairs the J2F-4 departed after midnight on 9 April 1942, overloaded with five passengers and the pilot, becoming the last aircraft to depart Bataan before the surrender of the Bataan to the Japanese only hours later. Among its passengers was Carlos P. Romulo (diplomat, politician, soldier, journalist and author), who recounted the flight in his 1942 best-selling book *I Saw the Fall of the Philippines* (Doubleday, Doran & Company, Inc., Garden City, New York 1943, pp. 288–303), for which he received the Pulitzer Prize for Correspondence.

Variants

J2F-3 at NAS Jacksonville in 1940

OA-12 in USAF markings (this aircraft was a J2F-6 painted to resemble an OA-12A, at the USAF Museum in Dayton, Ohio).

J2F-1

Initial production version with 750 hp R-1820-20 engines, 29 built.

J2F-2

United States Marine Corps version with nose and dorsal guns and underwing bomb racks, 21 built.

J2F-2A

As J2F-2 with minor changes for use in the United States Virgin Islands, nine built.

J2F-3

J2F-2 but powered by an 850 hp R-1820-26 engine, 20 built.

J2F-4

J2F-2 but powered by an 850 hp R-1820-30 engine and fitted with target towing equipment, 32 built.

J2F-5

J2F-2 but powered by a 1,050 hp R-1820-54 engine, 144 built.

J2F-6

Columbia Aircraft built version of the J2F-5 with a 1,050 hp R-1820-64 engine in a long-chord cowling, fitted with underwing bomb racks and provision for target towing gear; 330 built.

OA-12

Air-sea rescue conversion for the United States Army Air Forces (and later United States Air Force, OA-12A).

Operators

Argentina

- Argentine Naval Aviation[6] received four new-build Grumman G-15s (equivalent to J2F-4s) in 1939, to supplement the eight Grumman G-20s (export version of the Grumman JF-2) received in 1937.[7] In 1946–1947, 32 ex-US Navy Ducks (consisting of one J2F-4, 24 J2F-5s and 7 J2F-6s) were acquired,[8] with the last examples remaining in use until 1958.[9]

Colombia

- Colombian Navy[10] (operated three examples from 1948).

Mexico

- Mexican Navy (operated three ex-U.S. Navy J2F-6s from 1950-1951).[11]

Peru

- Peruvian Navy (operated one ex-USN example from 1961-1964).

United States

- United States Army Air Forces
- United States Coast Guard
- United States Marine Corps
- United States Navy

Columbia-built J2F-6 Duck in U.S. Marine Corps markings displayed at Planes of Fame Museum in Valle, Arizona, October 2005.

Surviving aircraft

The United States Coast Guard worked with North South Polar, Inc. to recover a J2F-4 Duck, serial number V-1640, downed in a storm on a Greenland glacier on 29 November 1942.[12] Two Coast Guard airmen were lost along with a rescued U.S. Army Air Forces passenger from a downed B-17 searching for a downed C-53 with five on board.[13] The three men of the Duck are presumed to still be entombed at the site. North South Polar, under the auspices of the Coast Guard team, located the aircraft in August 2012 resting 38 feet beneath the surface of the ice sheet. As per the mandate of Title 10 of the U.S. Code, North South Polar, the Coast Guard and the Joint POW/MIA Accounting Command plan to recover the men's remains for proper interment. The Coast Guard and North South Polar are also developing plans to recover the aircraft and restore it to flying condition as a memorial to the aircrew.[14]

Grumman J2F-6 Duck owned and operated by Kermit Weeks at Fantasy of Flight in Polk City, Florida.

Noted aviation entrepreneur and aircraft collector Jack Erickson maintains a flying J2F-6 Grumman Duck in Madras, Oregon, based at the Erickson Aircraft Collection. The museum's J2F-6 Duck was accepted by the United States Navy on 26 May 1945 and served as a pool aircraft at New York, Weymouth, Quonset Point and Chincoteage Naval bases. In 1948 it was declared surplus and acquired by the United States Air Force as an A-12A. The American Automotive Company bought it from the Air Force the following year for $727.00. Thereafter, it operated out of Puerto Rico, the Virgin Islands and the United States before becoming part of the museum's collection in 1993 where it received an "in-house" restoration.[15]

Aircraft collector Kermit Weeks has been the top Duck owner since World War II, owning as many as four. A J2F-6 model known as "Candy Clipper," was purchased in 1983 by Weeks and is still regularly flown by him at Fantasy of Flight. When Fantasy of Flight opens again in January 2015, they plan to include the Duck as part of a limited display collection. The second Weeks Duck was acquired in Lake Wales, Florida, from Sam Poole and is currently under a slow rebuild in Wichita, Kansas. A third was included in the Tallmantz Collection that Weeks purchased in 1985, and was traded to the National Museum of the United States Air Force where it is currently on display. A fourth was purchased from the San Diego Air & Space Museum in 2001 and traded for the Grumman F3F that is now in the Fantasy of Flight collection.[16]

Specifications (J2F-6)

Data from Jane's Fighting Aircraft of World War II[17]

General characteristics

- **Crew:** two (pilot and observer)
- **Capacity:** two rescued airmen
- **Length:** 34 ft 0 in (10.37 m)
- **Wingspan:** 39 ft 0 in (11.9 m)
- **Height:** 13 ft 11 in (4.25 m)
- **Wing area:** 409 ft^2 (38 m^2)
- **Empty weight:** 5,480 lb (2,485 kg)
- **Loaded weight:** 7,700 lb (3,496 kg)
- **Powerplant:** 1 × Wright R-1820-54 nine-cylinder radial engine, 900 hp (670 kW)

Performance

- **Maximum speed:** 190 mph (304 km/h)
- **Cruise speed:** 155 mph (248 km/h)
- **Stall speed:** 70 mph (112 km/h)
- **Range:** 780 mi (1,255 km)
- **Service ceiling:** 20,000 ft (6,100 m)
- **Rate of climb:** ft/min (m/s)

Armament

- 1 × Browning .30 cal machine gun (7.62 mm) on flexible mount in rear cockpit
- 650 lb (295 kg) of bombs or depth charges

Popular culture

- A J2F Duck was used in the 1971 film *Murphy's War*, which includes a spectacular three-minute rough water takeoff scene along with numerous flying and aerobatic sequences. The actual airplane used in this film is on display at the National Museum of the United States Air Force near Dayton, Ohio; although it has been restored and painted to represent a rescue OA-12.
- A Grumman Duck was also seen in several episodes of the 1970s TV series *Baa Baa Black Sheep*, (aka Black Sheep Squadron) based on the legendary exploits of Marine fighter squadron VMF-214.

See also

Related development

- Grumman JF Duck

Aircraft of comparable role, configuration and era

- Loening OL

Related lists

- List of aircraft of World War II

References

Notes

1. **^** Allen 1983, p. 49.
2. **^** Jordan, Corey C. "Grumman's Ascendency: Chapter Two." Archived 2012-03-25 at the Wayback Machine. *Planes and Pilots Of World War Two*, 2000. Retrieved: 22 July 2011.
3. **^** Swanborough, Gordon, and Bowers, Peter M., "United States Navy Aircraft since 1911", Naval Institute Press, Annapolis, Maryland, 1976, Library of Congress card number 90-60097, ISBN 0-87021-792-5, page 221.
4. **^** Allen 1983, p. 47.
5. **^** Alsleben, Allan. "US Patrol Wing 10 in the Dutch East Indies, 1942." *Forgotten Campaign: The Dutch East Indies Campaign 1941-1942*, 2000. Retrieved: 22 July 2011.
6. **^** Nuñez Padin, 2002
7. **^** Lezon and Stitt 2003, pp. 41–42, 44–45
8. **^** Lezon and Stitt 2004, pp. 48–49.
9. **^** Lezon and Stitt 2004, p. 59.
0. **^** Allen 1983, p.77
1. **^** Allen 1983, p. 52.
2. **^** Zuckoff, pp 40-47
3. **^** Coast Guard announces WWII Coast Guard Grumman Duck crash site located after 70 years Archived 2013-07-06 at the Wayback Machine.
4. **^** Mungier, Monique. "Race to Find Aviators Entombed in Greenland Glacier." *The New York Times*, 20 September 2010. Retrieved: 24 September 2010.
5. **^** http://www.ericksoncollection.com/aircraft/#/grumman-j2f-6-duck/
6. **^** "Fantasy of Flight's Facebook Page" Retrieved: 8 December 2014.
7. **^** Bridgeman 1946, pp. 235–236.

Bibliography

- Allen, Francis J. "A Duck Without Feathers". *Air Enthusiast*. Issue 23, December 1983—March 1984, pp. 46–55, 77–78. Bromley, Kent UK: Pilot Press, 1983.
- Bridgeman, Leonard. " The Grumman Duck ." *Jane's Fighting Aircraft of World War II*. London: Studio, 1946. ISBN 1-85170-493-0.
- Hosek, Timothy. *Grumman JF Duck - Mini in Action 7*. Carrollton, Texas: Squadron/Signal Publications Inc., 1996. ISBN 0-89747-366-3.
- Jarski, Adam. *Grumman JF/J2F Duck (Monografie Lotnicze 98)* (in Polish with English captions). Gdańsk, Poland: AJ-Press, 2007. ISBN 978-83-7237-169-0.
- Lezon, Ricardo Martin and Robert M. Stitt. "Eyes of the Fleet:Seaplanes in Argentine Navy Service: Part one". *Air Enthusiast*. Issue 108, November/December 2003. pp. 34–45.
- Lezon, Ricardo Martin and Robert M. Stitt. "Eyes of the Fleet:Seaplanes in Argentine Navy Service: Part two". *Air Enthusiast*. Issue 10, January/February 2004. pp. 46–59.
- Nuñez Padin, Jorge Félix. *Grumman G.15, G.20 & J2F Duck (Serie Aeronaval Nro. 15)* (in Spanish). Buenos Aires, Argentina: Museo de Aviación Naval, Instituto Naval, 2002.

- *Zuckoff, Mitchell (2013). Frozen in Time. New York, New York: HarperCollins. ISBN 978-0-06-213343-4.*

Further reading

- *Ginter, Steve (2009). Grumman JF/J2F Duck. Naval Fighters.* ***N°84*** *(First ed.). California, United States: Ginter Books. ISBN 0-942612-84-1. Retrieved 31 January 2015.*

External links

Wikimedia Commons has media related to ***Grumman J2F Duck***.

- (1945) NAVAER 01-220QA-1 Pilot's Handbook of Flight Operating Instructions Navy Model J2F-6 Airplane
- Histarmar website, Grumman J2F5/6 page (retrieved 2015-01-31)
- Histarmar website, Grumman G-15/20 page (retrieved 2015-01-31)

Shin Meiwa US-1A

The **Shin Meiwa PS-1** and **US-1A** (Japanese: 新明和 **PS-1**, **US-1A**) are large STOL aircraft designed for anti-submarine warfare (ASW) and air-sea rescue (SAR) work respectively by Japanese aircraft manufacturer Shin Meiwa. The PS-1 was a flying boat which carried its own beaching gear on board, while the US-1A is a true amphibian. The aircraft has been replaced by the ShinMaywa US-2.

PS-1 / US-1A	
	
A US-1A in flight	
Role	Air-sea rescue amphibian
Manufacturer	Shin Meiwa
First flight	5 October 1967 (PX-S)[1]
Introduction	1971 (PS-1)
Retired	2017
Primary user	Japan Maritime Self Defense Force
Produced	PS-1: 23 US-1: 6 US-1A: 14
Variants	ShinMaywa US-2

Design and development

In 1962, Shin Meiwa flew a flying boat testbed, the UF-XS, converted from a Grumman HU-16 Albatross to build upon its wartime experience (as Kawanishi) and demonstrate its ideas on building flying boats that could land and take-off from the open ocean. It was fitted with a novel boundary layer control system to provide enhanced STOL performance, while the Albatross's two 1,425 hp (1,063 kW) Wright R-1820 radial engines were supplemented by two 600 hp (450 kW) Pratt & Whitney R-1340 radial engines on the aircraft's wings, with an additional 1,250 shp (930 kW) General Electric T58 turboshaft inside the aircraft's hull to drive the boundary layer control system.[2] In 1966, the Japan Maritime Self-Defense Force (JMSDF) awarded the company a contract to further develop these ideas into an anti-submarine warfare (ASW) patrol aircraft. Two prototypes were built under the designation **PS-X** and flight tests began on October 5, 1967, leading to an order for production under the designation **PS-1** in 1969.

The aircraft was able to land in seas up to 3 metres (9.8 ft) in height. Water distance for takeoff or landing with 79,400 pounds (36,000 kg) aircraft weight was 720 feet (220 m) with no wind or 500 feet (150 m) into a 15-knot wind.[1] Apart from the boundary layer control system (powered by an independent gas turbine carried in the fuselage), the aircraft had a number of other innovative features, including a system to suppress spray during water handling,[1] and directing the propwash from the aircraft's four turboprop engines over its wings to create yet more lift. Between 1971 and 1978, the JMSDF ordered 21 of these aircraft, and operated them as Fleet Air Wing 31 from 1973[1] until 1989 when they were phased out and replaced by Lockheed P-3 Orions. The small production run resulted in an extremely high unit-cost for these aircraft, and the programme was politically controversial.

The PS-1 ASW variant carried homing torpedoes, depth charges and 127mm Zuni rockets as offensive armament but had no defensive weapons. It was equipped with dipping sonar, which had limited use as it required the aircraft to land on water to deploy. It could also carry up to 20 sonobuoys. It had a crew of ten: pilot, co-pilot, flight engineer, navigator and six sensor/weapons operators.[3]

The PS-1 had not been in service long before the JMSDF requested the development of a search-and-rescue variant. The deletion of the PS-1's military equipment allowed for greater fuel capacity, workable landing gear, and rescue equipment. The new variant, the **US-1A**, could also quickly be converted for troop-carrying duties. First flown on October 15, 1974, it was accepted into service the following year, and eventually 19 aircraft were purchased. From the seventh aircraft on, an uprated version of the original engine was used, but all aircraft were eventually modified to this **US-1A** standard. The US-1A's first rescue was from a Greek vessel in 1976. Between that time and 1999, US-1As had been used in over 500 rescues, saving 550 lives.[4]

In 1976, one PS-1 was experimentally modified for aerial firefighting, with an internal capacity of 7,350 litres (1,940 US gal) of water.[5]

With the US-1A fleet beginning to show its age, the JMSDF attempted to obtain funding for a replacement in the 1990s, but could not obtain enough to develop an entirely new aircraft. Therefore, in 1995, ShinMaywa (as Shin Meiwa was by then renamed) began plans for an upgraded version of the US-1A, the **US-1A *kai*** (**US-1A 改** - "improved US-1A"). This aircraft features numerous aerodynamic refinements, a pressurised hull, and more powerful Rolls-Royce AE 2100 engines. Flight tests began on December 18, 2003. The JMSDF purchased up to 14 of these aircraft, which entered service as the ShinMaywa US-2.

The US-1A was retired on December 13, 2017 when the last example in JMSDF service made its final flight. A total of 827 people have been recued by US-1s since the type entered service in 1976.[6]

Concept aircraft not built

In 1977 Shin Meiwa had several ideas for its STOL flying boat concept on the drawing board but none were ever built. They were the **Shin Meiwa LA** (Light Amphibian), a 40-passenger light amphibian for inter-island feeder service; the 400-passenger **Shin Meiwa MA** (Medium Amphibian); the **Shin Meiwa MS** (Medium Seaplane) a 300-passenger long-range flying boat with its own beaching gear; and the gargantuan **Shin Meiwa GS** (Giant Seaplane) with a capacity of an astonishing 1200 passengers seated on three decks. Unlike the Shin Meiwa LA and MA which were like the US-1 in design, the Shin Meiwa MS and GS had their engines located in front of and above the wing to take advantage of the Coandă effect. In the end, none of the four designs got beyond the drawing boards.[7]

Operators

- **Japan**

- Japan Maritime Self Defense Force

Specifications (US-1A)

Data from Jane's All The World's Aircraft 1988-89[8]

General characteristics

- **Crew:** nine (pilot, co-pilot, flight engineer, navigator, radio operator, radar operator, two observers)
- **Capacity:** 20 survivors or 12 stretchers (US-1 only)[1]
- **Length:** 33.46 m (109 ft 9¼ in)
- **Wingspan:** 33.15 m (108 ft 9 in)
- **Height:** 9.95 m (32 ft 7¾ in)
- **Wing area:** 135.8 m² (1,462 ft²)
- **Empty weight:** 23,300 kg (51,367 lb)
- **Max. takeoff weight:** 45,000 kg[9] (99,200 lb)
- *plus* 1× General Electric T58 gas turbine, 1,104 kW (1,360 shp) driving boundary layer control system
- **Powerplant:** 4 × Ishikawajima-Harima/General Electric T64-IHI-10J turboprops, 2,605 kW (3,493 ehp) each

Performance

- **Maximum speed:** 511 km/h (276 knots, 318 mph)
- **Cruise speed:** 426 km/h (230 knots, 265 mph)
- **Range:** 3,817 km (2,060 nmi, 2,372 mi)
- **Service ceiling:** 7,195 m (23,600 ft)
- **Rate of climb:** 8.1 m/s (1,600 ft/min)

Armament

- 4 x 150 kilograms (330 lb) depth charges, 2 x Mark 44 torpedo, 6 x 127mm Zuni rockets (PS-1 only)[1]

Avionics

[1]

- APS-80J Ocean search radar
- AQS-10A Magnetic anomaly detector
- HQS-101 dipping sonar
- 20 x Sonobuoys
- AQA-5N Sonobuoy signal processors
- ASA-16 ASW display system

See also

Related development

- ShinMaywa US-2

Aircraft of comparable role, configuration and era

- Harbin SH-5
- Beriev Be-12
- Martin P5M Marlin
- Canadair CL-215

Related lists

- List of military aircraft of Japan
- List of flying boats

References

Notes

1. ^ ***a b c d e f g*** *Dean, Ralph J. (1984). "Japan's Stalwart Seaplanes". Proceedings. United States Naval Institute.* ***110*** *(3): 182&183.*
2. **^** Lake *Air International* November 2005, p. 27.
3. **^** *Bernard Fitzsimons (1978). The Illustrated encyclopedia of 20th century weapons and warfare.* ***20****. Columbia House. p. 2149.*
4. **^** *"Rescue Operations". ShinMaywa Industries, Ltd. Retrieved 22 October 2014.*
5. **^** *Jane's All the World's Aircraft 2003-2004. Jane's Information Group. 2003. p. 313. ISBN 0-7106-2537-5.*
6. **^** *Fischer, Bob (February 2018). "US-1A amphibian retired". Air International. Vol. 94 no. 2. p. 17. ISSN 0306-5634.*
7. **^** Paul Wahl "1200 Passengers on three decks...a come back for flying boats" *Popular Mechanics* November 1977, pp. 84-85
8. **^** Taylor 1988, pp.172-173.
9. **^** Operating from land - Maximum takeoff weight from water 43,000 kg (94,800 lb)

Bibliography

- *Lake, Jon (November 2005). "ShinMaywa's Innovative Amphibian". Air International. Vol. 69 no. 5. pp. 26–30. ISSN 0306-5634.*
- *Taylor, John W. R., ed. (1988). Jane's All The World's Aircraft 1988-89. Coulsdon, UK: Jane's Defence Data. ISBN 0-7106-0867-5.*

External links

Wikimedia Commons has media related to ***ShinMaywa US-1***.

- ShinMaywa aircraft page
- Giant Amphibian - Japan has one godzilla of a seaplane - Air & Space/Smithsonian magazine
- The Shin Meiwa PS-1 / US-1 & Harbin SH-5 Flying Boats www.airvectors.net

Lake Aircraft

Lake Aircraft	
Type	Private
Industry	Aerospace
Founded	1959
Headquarters	Kissimmee, Florida New Hampshire
Key people	Armand Rivard
Products	parts for LA-4 aircraft
Number of employees	6
Website	lakeamphib.com

Lake LA-4-200 Buccaneer

Lake LA-4-200 Buccaneer

Lake Model 250 Seawolf

Lake Aircraft was a manufacturer of amphibious aircraft. Its factory was in Sanford, Maine, USA, and its sales offices were located at Laconia / Gilford, New Hampshire and Kissimmee, Florida.

The assets of the company were sold in 2004 to an investor which incorporated as "Sun Lake Aircraft" in Vero Beach, Florida.

The assets are now owned by Revo Inc, owned by Armand Rivard.

History

The first design in the series produced was the Colonial Skimmer. It was derived from an original design produced by David Thurston in 1946 when he was with Grumman Aircraft. Grumman never produced the design, but Thurston formed Colonial Aircraft Corporation as a side business to continue development.

Colonial's first amphibious aircraft, designated the "Colonial Aircraft C-1 Skimmer" and based on the original Grumman G-65 Tadpole design, first flew in 1948. Colonial grew to produce almost 50 of the C-1 and larger C-2 design before being sold in 1959.

The new owner, M.L. (Al) Alson, renamed the company Lake Aircraft and enlarged the basic design again into the LA-4, a 180-horsepower, 4-seat aircraft, which was the basis for the entire line of aircraft that continues today.

Lake aircraft produced in the 1960 - 1980 range are listed by the Federal Aviation Administration as having been built by "Consolidated Aeronautics."

For many years the Lake LA-4-200 was advertised as "The world's only single-engine production amphibian."

In January 2009 company owner Armand Rivard indicated that he intended to sell the company and retire. The company had previously been offered for sale in 2001, 2002, via auction in 2005 and in 2007. Lake Aircraft produced one aircraft in 2007 and none in 2008, but continues to make parts for existing aircraft. In 2009 the company employed six people, down from the 200 employees that it had in the 1980s.[1]

Evolution of Lake Amphibious Aircraft

Years Produced	Model	seats	Horsepower	Max Cruise Speed	Payload with Main Full Fuel
1948–1959	C1 and C2	2	150-180	90 mph	340 lb payload
1960–1969	Lake LA-4	4	180	110 mph	440 lb
1970–1982	Lake LA4-200	4	200	105 knots	500 lb
1982–1985	Lake LA4-200 EP	4	200	110 knots	550 lb
1984–1995	Lake Model 250	6	250	132 knots	800 lb
1987–2005	Lake Model 250 Turbocharged	6	270	155 knots	720 lb
2006	Seafury		250 & 270		

References

1. ^ *Pew, Glenn (January 2009). "Lake Aircraft Again Puts Assets Up For Sale". Retrieved 2009-01-12.*

External links

Wikimedia Commons has media related to ***Lake Aircraft***.

Official website

Consolidated PBY Catalina

The **Consolidated PBY Catalina**, also known as the **Canso** in Canadian service, is an American flying boat, and later an amphibious aircraft of the 1930s and 1940s produced by Consolidated Aircraft. It was one of the most widely used seaplanes of World War II. Catalinas served with every branch of the United States Armed Forces and in the air forces and navies of many other nations.

During World War II, PBYs were used in anti-submarine warfare, patrol bombing, convoy escort, search and rescue missions (especially air-sea rescue), and cargo transport. The PBY was the most numerous aircraft of its kind and the last active military PBYs were not retired from service until the 1980s. In 2014, nearly 80 years after its first flight, the aircraft continues to fly as a waterbomber (or airtanker) in aerial firefighting operations all over the world.

PBY Catalina	
	
A PBY-5A on patrol, 1942-43	
Role	Maritime patrol bomb search and rescue sea
Manufacturer	Consolidated Aircraft
First flight	28 March 1935
Introduction	October 1936, Unite States Navy
Retired	January 1957 (United Navy Reserve) 1979 (Brazilian Air Fo
Primary users	United States Navy United States Army A Forces Royal Air Force Royal Canadian Air Fo
Produced	1936–1945
Number built	3,305 (2,661 U.S.-bu 620 Canadian-built, 2 viet-built[2])
Unit cost	US$90,000 (as of 19 Adjusted for inflation: US$1606456
Variants	Bird Innovator

Naming

The designation "PBY" was determined in accordance with the U.S. Navy aircraft designation system of 1922; *PB* representing "Patrol Bomber" and *Y* being the code assigned to Consolidated Aircraft as its manufacturer. Catalinas built by other manufacturers for the U.S. Navy were designated according to different manufacturer codes, thus Canadian Vickers-built examples were designated **PBV**, Boeing Canada examples **PB2B** (there already being a Boeing PBB) and Naval Aircraft Factory examples were designated **PBN**. In accordance with contemporary British naming practice of naming seaplanes after coastal port towns, Royal Canadian Air Force examples were named **Canso**, for the town of that name in Nova Scotia. The Royal Air Force used the name **Catalina** and the U.S. Navy adopted this name in 1942.[3] The United States Army Air Forces and later the United States Air Force used the designation **OA-10**. U.S. Navy Catalinas used in the Pacific against the Japanese for night operations were painted black overall; as a result these aircraft were sometimes referred to locally as "*Black Cats*".

Design

Background

The PBY was originally designed to be a patrol bomber, an aircraft with a long operational range intended to locate and attack enemy transport ships at sea in order to disrupt enemy supply lines. With a mind to a potential conflict in the Pacific Ocean, where troops would require resupply over great distances, the U.S. Navy in the 1930s invested millions of dollars in developing long-range flying boats for this purpose. Flying boats had the advantage of not requiring runways, in effect having the entire ocean available. Several different flying boats were adopted by the Navy, but the PBY was the most widely used and produced.

Although slow and ungainly, Catalinas distinguished themselves in World War II. Allied forces used them successfully in a wide variety of roles for which the aircraft was never intended. PBYs are remembered for their rescue role, in which they saved the lives of thousands of aircrew downed over water. Catalina airmen called their aircraft the "Cat" on combat missions and **"Dumbo"** in air-sea rescue service.[4]

PBY riding at sea anchor.

Development

As American dominance in the Pacific Ocean began to face competition from Japan in the 1930s, the U.S. Navy contracted Consolidated, Martin and Douglas in October 1933 to build competing prototypes for a patrol flying boat.[5] Naval doctrine of the 1930s and 1940s used flying boats in a wide variety of roles that today are handled by multiple special-purpose aircraft. The U.S. Navy had adopted the Consolidated P2Y and Martin P3M models for this role in 1931, but both aircraft were underpowered and hampered by inadequate range and limited payloads.

Consolidated and Douglas both delivered single prototypes of their new designs, the XP3Y-1 and XP3D-1, respectively. Consolidated's XP3Y-1 was an evolution of the XPY-1 design that had originally competed unsuccessfully for the P3M contract two years earlier and of the XP2Y design that the Navy had authorized for a limited production run. Although the Douglas aircraft was a good design, the Navy opted for Consolidated's because the projected cost was only $90,000 per aircraft.

PBY waist gunner mounting port side gun blister.

Consolidated's XP3Y-1 design (company *Model 28*) had a parasol wing with external bracing struts, mounted on a pylon over the fuselage. Wingtip stabilizing floats were retractable in flight to form streamlined wingtips and had been licensed from the Saunders-Roe company. The two-step hull design was similar to that of the P2Y, but the Model 28 had a cantilever cruciform tail unit instead of a strut-braced twin tail. Cleaner aerodynamics gave the Model 28 better performance than earlier designs. Construction is all-metal, stressed-skin, of aluminum sheet, except the ailerons and wing trailing edge, which are fabric covered.[6]

The prototype was powered by two 825 hp (615 kW) Pratt & Whitney R-1830-54 Twin Wasp radial engines mounted on the wing's leading edges. Armament comprised four .30 in (7.6 mm) Browning AN/M2 machine guns and up to 2,000 lb (910 kg) of bombs.

The XP3Y-1 had its maiden flight on 28 March 1935, after which it was transferred to the U.S. Navy for service trials. The XP3Y-1 was a significant performance improvement over previous patrol flying boats. The Navy requested further development in order to bring the aircraft into the category of *patrol bomber*, and in October 1935, the prototype was returned to Consolidated for further work, including installation of 900 hp (670 kW) R-1830-64 engines. For the redesignated XPBY-1, Consolidated introduced redesigned vertical tail surfaces which resolved a problem with the tail becoming submerged on takeoff, which had made lift-off impossible under some conditions. The XPBY-1 had its maiden flight on 19 May 1936, during which a record non-stop distance flight of 3,443 mi (2,992 nmi; 5,541 km) was achieved.

The XPBY-1 was delivered to VP-11F in October 1936. The second squadron to be equipped was VP-12, which received the first of its aircraft in early 1937. The second production order was placed on 25 July 1936. Over the next three years, the design was gradually developed further and successive models introduced.

The aircraft eventually bore the name Catalina after Catalina Island; the name was coined in November 1941, as Great Britain ordered their first 30 aircraft.[7]

Mass-produced U.S. Navy variants

Model	Production period and distinguishing features	Quantity
PBY-1	September 1936 – June 1937 Original production model.	60
PBY-2	May 1937 – February 1938 Minor alterations to tail structure, hull reinforcements.	50
PBY-3	November 1936 – August 1938 Higher power engines.	66
PBY-4	May 1938 – June 1939 Higher power engines, propeller spinners, acrylic glass blisters over waist guns (some later units).	32
PBY-5	September 1940 – July 1943 Higher power engines (using higher octane fuel), discontinued use of propeller spinners, standardized waist gun blisters. Self-sealing fuel tanks introduced during production run.	684
PBY-5A	October 1941 – January 1945 Hydraulically actuated, retractable tricycle landing gear, with main gear design based on one from the 1920s designed by Leroy Grumman, for amphibious operation. Introduced tail gun position, replaced bow single gun position with bow "eyeball" turret equipped with twin .30 machine guns (some later units), improved armor, self-sealing fuel tanks.[8]	802
PBY-6A	January 1945 – May 1945 Incorporated changes from PBN-1,[8] including a taller vertical tail, increased wing strength for greater carrying capacity, new electrical system, standardized "eyeball" turret, and a radome over cockpit for radar.	175

An estimated 4,051 Catalinas, Cansos, and GSTs of all versions were produced between June 1937 and May 1945 for the U.S. Navy, the United States Army Air Forces, the United States Coast Guard, Allied nations, and civilian customers.

PBN Nomad

The Naval Aircraft Factory made significant modifications to the PBY design, many of which would have significantly interrupted deliveries had they been incorporated on the Consolidated production lines.[9] The new aircraft, officially known as the **PBN-1 Nomad**, had several differences from the basic PBY. The most obvious upgrades were to the bow, which was sharpened and extended by two feet, and to the tail, which was enlarged and featured a new shape. Other improvements included larger fuel tanks, increasing range by 50%, and stronger wings permitting a 2,000 lb (908 kg) increase in gross takeoff weight. An auxiliary power unit was installed, along with an improved electrical system, and the weapons were upgraded with continuous-feed mechanisms.[9]

138 of the 156 PBN-1s produced served with the Soviet Navy. The remaining 18 were assigned to training units at NAS Whidbey Island and the Naval Air Facility in Newport, Rhode Island.[10] Later, improvements found in the PBN such as the larger tail were incorporated into the amphibious PBY-6A.

Operational history

A radar-equipped PBY-5A from VP-6(CG) over Greenland, in 1945.

Roles in World War II

Around 3,300 aircraft were built, and these operated in nearly all operational theatres of World War II. The Catalina served with distinction and played a prominent and invaluable role against the Japanese. This was especially true during the first year of the war in the Pacific, because the PBY and the Boeing B-17 Flying Fortress were the only aircraft available with the range to be effective in the Pacific.

Anti-submarine warfare

Catalinas were the most extensively used anti-submarine warfare (ASW) aircraft in both the Atlantic and Pacific theaters of World War II, and were also used in the Indian Ocean, flying from the Seychelles and from Ceylon. Their duties included escorting convoys to Murmansk. By 1943, U-boats were well-armed with anti-aircraft guns and two Victoria Crosses were won by Catalina pilots pressing home their attacks on U-boats in the face of heavy fire: Flying Officer John Cruickshank of the RAF, in 1944, for sinking *U-347* (although the submarine is now known to have been *U-361*[11]) and in the same year Flight Lieutenant David Hornell of the Royal Canadian Air Force (posthumously) against *U-1225*. Catalinas destroyed 40 U-boats, but not without losses of their own. A Brazilian Catalina attacked and sank *U-199* in Brazilian waters on 31 July 1943. Later, the aircraft was baptized as “Arará”, in memory of the merchant ship of that name which was sunk by another U-boat.[12]

Maritime patrol


A PBY-5A of VP-61 over the Aleutian Islands in 1943

In their role as patrol aircraft, Catalinas participated in some of the most notable naval engagements of World War II. The aircraft's parasol wing and large waist blisters provided excellent visibility and combined with its long range and endurance, made it well suited for the task.

A RAF Coastal Command Catalina, piloted by Ensign Leonard B. Smith of the U.S. Navy and flying out of Castle Archdale Flying boat base, Lower Lough Erne, Northern Ireland, located on 26 May 1941, some 690 nmi (1,280 km; 790 mi) northwest of Brest, the German battleship *Bismarck*, which was attempting to evade Royal Navy forces as she sought to join other Kriegsmarine forces in Brest.[N 1][13][14][15][16][17] This sighting eventually led to the destruction of the German battleship.

On 7 December 1941, before the Japanese amphibious landings on Kota Bharu, Malaya, their invasion force was approached by a Catalina flying boat of No. 205 Squadron RAF. The aircraft was shot down by five Nakajima Ki-27 fighters before it could radio its report to air headquarters in Singapore.[18] Flying Officer Patrick Bedell, commanding the Catalina, and his seven crew members became the first Allied casualties in the war with Japan.[19]

A flight of Catalinas spotted the Japanese fleet approaching Midway Island, beginning the Battle of Midway.[20]

A Royal Canadian Air Force (RCAF) Canso flown by Squadron Leader L.J. Birchall foiled Japanese plans to destroy the Royal Navy's Indian Ocean fleet on 4 April 1942 when it detected the Japanese carrier fleet approaching Ceylon (Sri Lanka).[21]

Night attack and naval interdiction


Squadron Leader Leonard Birchall aboard a Consolidated Catalina before being shot down and captured near Ceylon by the Japanese

During the Battle of Midway four USN PBYs of Patrol Squadrons 24 and 51 made an attack on the occupation force of the Japanese fleet on the night of June 3–4, 1942.[22]

The Royal Australian Air Force (RAAF) also operated Catalinas as night raiders, with four squadrons Nos. 11, 20, 42, and 43 laying mines from 23 April 1943 until July 1945 in the southwest Pacific deep in Japanese-held waters, bottling up ports and shipping routes and forcing ships into deeper waters to become targets for U.S. submarines; they tied up the major strategic ports such as Balikpapan which shipped 80% of Japanese oil supplies. In late 1944, their mining missions sometimes exceeded 20 hours in duration and were carried out from as low as 200 ft (61 m) in the dark. Operations included trapping the Japanese fleet in Manila Bay in assistance of General Douglas MacArthur's landing at Mindoro in the Philippines. Australian Catalinas also operated out of Jinamoc in the Leyte Gulf, and mined ports on the Chinese coast from Hong Kong to as far north as Wenchow. Both USN and RAAF Catalinas regularly mounted nuisance night bombing raids on Japanese bases, with the RAAF claiming the slogan "The First and the Furthest". Targets of these raids included a major base at Rabaul. RAAF aircrews, like their U.S. Navy counterparts, employed "terror bombs", ranging from scrap metal and rocks to empty beer bottles with razor blades inserted into the necks, to produce high pitched screams as they fell, keeping Japanese soldiers awake and scrambling for cover.[23]

Search and rescue

Catalinas were employed by every branch of the U.S. military as rescue aircraft. A PBY piloted by LCDR Adrian Marks (USN) rescued 56 sailors in high seas from the heavy cruiser *Indianapolis* after the ship was sunk during World War II. When there was no more room inside, the crew tied sailors to the wings. The aircraft could not fly in this state; instead it acted as a lifeboat, protecting the sailors from exposure and the risk of shark attack, until rescue ships arrived. Catalinas continued to function in the search-and-rescue role for decades after the end of the war.

Search and Rescue OA-10 at USAF Museum

Early commercial use

Catalinas were also used for commercial air travel. For example, Qantas Empire Airways flew commercial passengers from Suva to Sydney, a journey of 2,060 miles (3,320 km), which in 1949 took two days.[24] The longest commercial flights (in terms of time aloft) ever made in aviation history were the Qantas flights flown weekly from 29 June 1943 through July 1945 over the Indian Ocean, dubbed the Double Sunrise. Qantas offered non-stop service between Perth and Colombo, a distance of 3,592 nmi (4,134 mi; 6,652 km). As the Catalina typically cruised at 110 kn (130 mph; 200 km/h), this took from 28 to 32 hours and was called the "flight of the double sunrise", since the passengers saw two sunrises during their non-stop journey. The flight was made in radio silence because of the possibility of Japanese attack and had a maximum payload of 1,000 lb (450 kg) or three passengers plus 143 lb (65 kg) of military and diplomatic mail.[25]


Flight steward Max White at work on board a Qantas Empire Airways Catalina aircraft en route from Suva to Sydney in January 1949 with young passenger Jennifer Grey

Post-World War II employment

An Australian PBY [named "Frigate Bird II" - an ex RAAF aircraft, registered VH-ASA] made the first trans-Pacific flight across the South Pacific between Australia and Chile in 1951 by (Sir) Gordon Taylor,[26] making numerous stops at islands along the way for refueling, meals, and overnight sleep of its crew, flown from Sydney to Quintero in Chile after making initial landfall at Valparaiso via Tahiti and Easter Island.[27]

With the end of the war, all of the flying boat versions of the Catalina were quickly retired from the U.S. Navy, but the amphibious versions remained in service for some years. The last Catalina in U.S. service was a PBY-6A operating with a Naval Reserve squadron, which was retired from use on 3 January 1957.[5] The Catalina subsequently equipped the world's smaller armed services into the late 1960s in fairly substantial numbers.


Civilian Catalina, modified for aerial firefighting, arrives at the Seaplane Base, NAS Whidbey Island, Oak Harbor, Washington, 18 September 2009

The U.S. Air Force's Strategic Air Command used Catalinas (designated OA-10s) in service as scout aircraft from 1946 through 1947.

The Brazilian Air Force flew Catalinas in naval air patrol missions against German submarines starting in 1943. The flying boats also carried out air mail deliveries. In 1948, a transport squadron was formed and equipped with PBY-5As converted to the role of amphibious transports. The 1st Air Transport Squadron (ETA-1) was based in the port city of Belem and flew Catalinas and C-47s until 1982. Catalinas were convenient for supplying military detachments scattered along the Amazon. They reached places that were otherwise accessible only by helicopters. The ETA-1 insignia was a winged turtle with the motto "Though slowly, I always get there". Today, the last Brazilian Catalina (a former RCAF one) is displayed at the Airspace Museum (MUSAL) in Rio de Janeiro.[28]

A PBY-6A Catalina drops a load of water from its bomb-bay doors

Jacques-Yves Cousteau used a PBY-6A (N101CS) to support his diving expeditions. His second son, Philippe, was killed in an accident in this aircraft that occurred on the Tagus River near Lisbon. The Catalina nosed over during a high-speed taxi run undertaken to check the hull for leakage following a water landing. The aircraft turned upside down, causing the fuselage to break behind the cockpit. The wing separated from the fuselage and the left engine broke off, penetrating the captain's side of the cockpit.[29]

Paul Mantz converted an unknown number of surplus Catalinas to flying yachts at his Orange County California hangar in the late 1940s and early 1950s.

An OA-10A converted by Steward-Davis Inc to their Super Cat standard. It is additionally fitted out for survey work for Geoterrex Inc

Steward-Davis converted several Catalinas to their **Super Catalina** standard (later known as **Super Cat**), which replaced the usual 1,200 hp (890 kW) Pratt & Whitney R-1830 Twin Wasp engines with Wright R-2600 Cyclone 14 engines of 1,700 hp (1,300 kW). A larger, squared-off rudder was installed to compensate for the increased yaw which the more powerful engines could generate. The Super Catalina also had extra cabin windows and other alterations.[30]

Chilean Air Force (FACH) Captain Roberto Parragué, in his PBY Catalina FACH No. 405 called "Manu-Tara", which means Lucky Bird in the Rapanui language, undertook the first flight between Easter Island and the continent of South America (from Chile), as well as the first flight to Tahiti, making him a national hero of France as well as of Chile. The flight was authorized by the Chilean President in 1951, but a second flight he made in 1957 was not authorized, and he was dismissed from the Chilean Air Force.

Of the few dozen remaining airworthy Catalinas, the majority are in use as aerial firefighting aircraft. China Airlines, the official airline of the Republic of China (Taiwan) was founded with two Catalina amphibians.

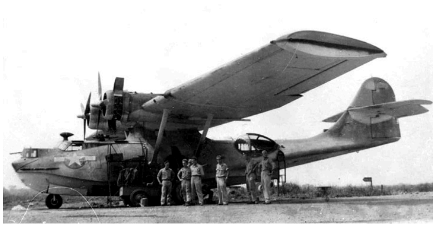
Platforms are folded out and deployed from Catalinas for use in open ocean fishing and Mahi Mahi tracking in the Pacific Ocean.

Catalina affair

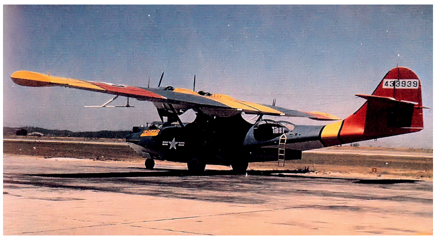
The Catalina Affair is the name given to a Cold War incident in which a Swedish Air Force Catalina was shot down by Soviet fighters over the Baltic Sea in June 1952 while investigating the disappearance of a Swedish Douglas DC-3 (later found to have been shot down by a Soviet fighter while on a signals intelligence mission; it was found in 2003 and raised 2004–2005).

Variants

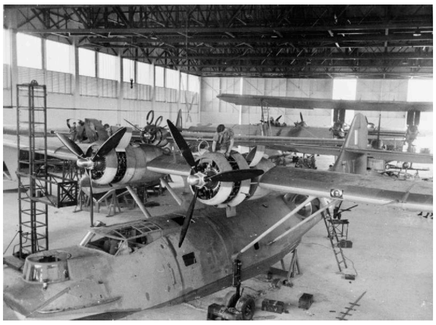
Prototype Model 28 flying boat, later re-designated XP-BY-1.



A U.S. Army Air Forces OA-10 and crew.



Canadian Vickers SA-10A Catalina 44-33939 (USN BuNo 67903), USAF 4th Rescue Group, Hamilton AFB, California, 1952. Sold in 1958 to Cuban Air Force as 191



Catalina Is of 205 Sqn. RAF undergoing service in their hangar at Seletar, Singapore.

US Navy

A United States Coast Guard PBY-5A at Tern Island in 1953

XP3Y-1

Prototype Model 28 flying boat later re-designated XPBY-1, one built (USN Bureau No. 9459). Later fitted with a 48-foot-diameter (15 m) ring to sweep magnetic sea mines. A 550 hp Ranger engine drove a generator to produce a magnetic field.[31]

XPBY-1

Prototype version of the Model 28 for the United States Navy, a re-engined XP3Y-1 with two 900 hp R-1830-64 engines, one built.

PBY-1 (Model 28-1)

Initial production variant with two 900 hp R-1830-64 engines, 60 built.

PBY-2 (Model 28-2)

Equipment changes and improved performance, 50 built.

PBY-3 (Model 28-3)

Powered by two 1,000 hp R-1830-66 engines, 66 built.

PBY-4 (Model 28-4)

Powered by two 1,050 hp R-1830-72 engines, 33 built (including one initial as a XP-BY-4 which later became the XPBY-5A).

PBY-5 (Model 28-5)

Either two 1,200 hp R-1830-82 or −92 engines and provision for extra fuel tanks (with partial self-sealing protection). 683 built (plus one built at New Orleans), some aircraft to the RAF as the Catalina IVA and one to the United States Coast Guard. The PBY-5 was also built in the Soviet Union as the GST.

XPBY-5A

One PBY-4 converted into an amphibian and first flown in November 1939.

PBY-5A (Model 28-5A)

Amphibious version of the PBY-5 with two 1,200 hp R-1830-92 engines, first batch (of 124) had one 0.3in bow gun, the remainder had two bow guns; 803 built including diversions to the United States Army Air Forces, the RAF (as the Catalina IIIA) and one to the United States Coast Guard.

PBY-6A

Amphibious version with two 1,200 hp R-1830-92 engines and a taller fin and rudder. Radar scanner fitted above cockpit and two 0.5 in nose guns; 175 built including 21 transferred to the Soviet Navy.

PBY-6AG

One PBY-6A used by the United States Coast Guard as a staff transport.

PB2B-1

Boeing Canada built PBY-5 for the RAF and RCAF from 1942. 240 built.

PB2B-2

Boeing Canada built version of the PBY-5 but with the taller fin of the PBN-1. 67 built. Most supplied to the RAF as the Catalina VI.

PBN-1 Nomad

Naval Aircraft Factory built version of the PBY-5 with major modification including a 2ft bow extension, modified hull lines with a modified step, re-designed wingtip floats and tail surfaces and a revised electrical system. A total of 155 were built for delivery to the RAF as the Catalina V although 138 were Lend-Leased to the Soviet Navy as the KM-1

PBV-1A

Canadian Vickers built version of the PBY-5A, 380 built including 150 to the Royal Canadian Air Force as the Canso-A and the rest to the USAAF as the OA-10A.

USAAF

OA-10

United States Army Air Forces designation for PBY-5A, 105 built; 58 aircraft survivors re-designated A-10 in 1948.

OA-10A

USAAF designation of Canadian Vickers-built version of the PBV-1A, 230 built. Survivors re-designated A-10A in 1948. Three additional aircraft from Navy in 1949 as A-10As.

OA-10B

USAAF designation of PBY-6A, 75 built. Re-designated A-10B in 1948.

RAF

Catalina I

Direct purchase aircraft for the Royal Air Force, same as the PBY-5 with six 0.303 in guns (one in bow, four in waist blisters and one aft of the hull step) and powered by two 1,200 hp R-1830-S1C3-G engines, 109 built.

Catalina IA

Operated by the Royal Canadian Air Force as the Canso, 14 built.

Catalina IB

Lend-lease PBY-5Bs for the RAF, 225 aircraft built.

Catalina II

Equipment changes, six built.

Catalina IIA

Vickers-Canada built Catalina II for the RAF, 50 built.

Catalina IIIA

Former U.S. Navy PBY-5As used by the RAF on the North Atlantic Ferry Service, 12 aircraft. These were the only amphibians that saw RAF service.

Catalina IVA

Lend-lease PBY-5s for the RAF, 93 aircraft.

Catalina IVB

Lend-lease PB2B-1s for the RAF, some to the Royal Australian Air Force.

Catalina VI

Lend-lease PB2B-2s for the RAF, some to the RAAF.

Canadian Vickers PBV-1A Canso A at RIAT, England in 2009. A version of the PBY-5A Catalina, this aircraft was built in 1944 for the Royal Canadian Air Force

Restored Catalina, displayed in IWM Duxford

Swedish Air Force Consolidated PBY Catalina on display at the Swedish Air Force museum in Linköping, Sweden

Japan Maritime Self-Defense Force PBY-6A

RCAF

Canso-A

RCAF designation for PBV-1A

Other Users

GST

Soviet built version of the PBY-5 ("Gydro Samoliot Transportnyi").

Steward-Davis Super Catalina ("Super Cat")

Catalina converted to use 1,700 hp Wright R-2600 Cyclone 14 engines, with enlarged rudder and other changes.

Avalon Turbo Canso

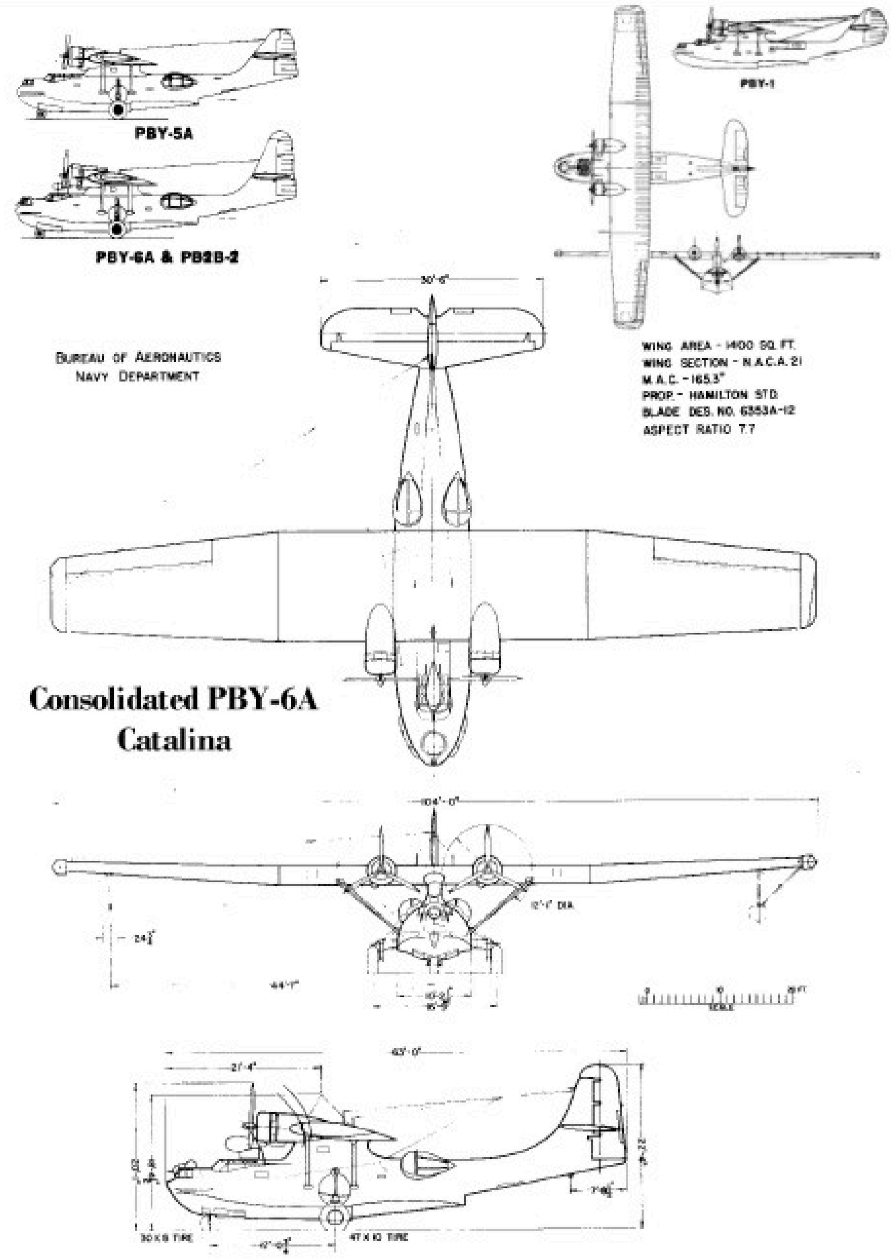
Proposed turboprop conversion of Canso water bombers, powered by two Rolls-Royce Dart engines.

Operators

Surviving aircraft

Specifications (PBY-5A)

Data from Encyclopedia of World Air Power[32] *Jane's Fighting Aircraft of World War II*[8] *Handbook of Erection and Maintenance Instructions for Navy Model PBY-5 and PBY-5A Airplanes.*[33] *and* Quest for Performance[34]



Orthographically projected diagram of the PBY Catalina.

General characteristics

- **Crew:** 10 – pilot, co-pilot, bow turret gunner, flight engineer, radio operator, navigator, radar operator, two waist gunners, ventral gunner
- **Length:** 63 ft 10 7/16 in (19.46 m)
- **Wingspan:** 104 ft 0 in (31.70 m)
- **Height:** 21 ft 1 in (6.15 m)
- **Wing area:** 1,400 ft² (130 m²)
- **Empty weight:** 20,910 lb (9,485 kg)
- **Max. takeoff weight:** 35,420 lb (16,066 kg)
- **Zero-lift drag coefficient:** 0.0309
- **Drag area:** 43.26 ft² (4.02 m²)
- **Aspect ratio:** 7.73
- **Powerplant:** 2 × Pratt & Whitney R-1830-92 Twin Wasp radial engines, 1,200 hp (895 kW) each

Performance

- **Maximum speed:** 196 mph (314 km/h)
- **Cruise speed:** 125 mph (201 km/h)
- **Range:** 2,520 mi (4,030 km)
- **Service ceiling:** 15,800 ft (4,000 m)
- **Rate of climb:** 1,000 ft/min (5.1 m/s)
- **Wing loading:** 25.3 lb/ft² (123.6 kg/m²)
- **Power/mass:** 0.034 hp/lb (0.056 kW/kg)
- **Lift-to-drag ratio:** 11.9

Armament

- 3 .30 cal (7.62 mm) machine guns (two in nose turret, one in ventral hatch at tail)

- 2 .50 cal (12.7 mm) machine guns (one in each waist blister)
- 4,000 lb (1,814 kg) of bombs or depth charges; torpedo racks were also available

See also

Related development

- Consolidated P2Y
- Consolidated PB2Y Coronado

Aircraft of comparable role, configuration and era

- Aichi H9A
- Blackburn Sydney
- Dornier Do 24
- Douglas XP3D
- Kawanishi H6K
- Latécoère 300
- Martin PBM Mariner

Related lists

- List of aircraft of World War II
- List of Consolidated PBY Catalina survivors
- List of flying boats
- List of PBY Catalina operators

References

Notes

1. **^** Smith was one of nine American officers assigned to the RAF as special observers.

Citations

1. **^** Legg 2002, p. 285.
2. **^** Legg, David. "PBY: A retrospective on PBY bows." *Yahoo groups: PBY Catalina / Canso*. Retrieved: 30 March 2013.
3. **^** Gunston 1986, p. 63.
4. **^** Weathered, William W. "Comment and Discussion". *United States Naval Institute Proceedings*, October 1968.
5. ^ ***a b*** Cacutt 1989, pp. 187–194.
6. **^** *"Catalina Aircraft - Description - Specifications". catalinaflying.org.au. Retrieved 31 January 2018.*
7. **^** Creed 1985, p. 48.
8. ^ ***a b c*** Bridgeman 1946, p. 218.
9. ^ ***a b*** Bridgeman 1946, p. 247.
0. **^** "Naval Aircraft Factory PBN-1 Nomad." *Aviation Enthusiast Corner*. Retrieved: 14 November 2017.
1. **^** *Hofmann, Markus. "U 347". Deutsche U-Boote 1935–1945 – u-boot-archiv.de (in German). Retrieved 26 December 2014.*
2. **^** "O Brasil na WWII: 'Arará', o Catalina que destruiu o U-199" (in Portuguese). *naval.com*, 8 November 2008. Retrieved: 15 February 2011.

3. **^** Miller 1997, p. 162.
4. **^** Smith, Leonard B. Bismarck: The Report of the Scouting and Search for Bismarck by Ensign Smith." Archived December 5, 2010, at the Library of Congress Web Archives *Naval History & Heritage (Frequently asked questions)*, 9 June 1941. Retrieved: 18 June 2010.
5. **^** "Bismarck: British/American Cooperation and the Destruction of the German Battleship." *Naval History & Heritage (Frequently asked questions)*, 4 November 2009. Retrieved: 18 June 2010.
6. **^** "Flying-boats in Fermanagh." Archived 2012-07-20 at the Wayback Machine. *Inland Waterways News*, *Inland Waterways Association of Ireland*, Spring 2002. Retrieved: 20 May 2012.
7. **^** "Castle Archdale Country Park." Archived 2009-05-01 at the Wayback Machine. *Northern Ireland Environment Agency*. Retrieved: 19 July 2009.
8. **^** Alan Warren (2007), page 86
9. **^** *L, Klemen; Kossen, Bert; Bernaudin, Pierre-Emmanuel; Niehorster, Dr. Leo; Takizawa, Akira; Carr, Sean; Broshot, Jim; Leulliot, Nowfel (1999–2000). "Seventy minutes before Pearl Harbor – The landing at Kota Bharu, Malaya, on December 7, 1941". Forgotten Campaign: The Dutch East Indies Campaign 1941–1942.*
0. **^** . "Scouting and Early Attacks from Midway, 3–4 June 1942". Archived April 13, 2010, at the Library of Congress Web Archives *United States Naval Historical Center*, 1999. Retrieved: 18 June 2010.
1. **^** Greenhous et al. 1994, p. 386.
2. **^** *"Online Library of Selected Images: World War II in the Pacific: Battle of Midway". Hyperwar. Naval History and Heritage Command. Retrieved 21 April 2017.*
3. **^** Gaunt and Cleeworth 2000.
4. **^** *"Jennifer Grey Goes by Air". Qantas Empire Airways. **15** (3): 11. March 1949.*
5. **^** "The Catalinas." *Qantas history*. Retrieved: 26 October 2011
6. **^** THE SKY BEYOND, Sir Gordon Taylor
7. **^** *"SHORT SANDRINGHAM F-OBIP". qam.com.au. Retrieved 23 November 2015.*
8. **^** "Consolidated Vultee 28 (PBY-5A/C-10A) Catalina." *MUSAL*. Retrieved: 18 June 2010.
9. **^** "ASN Aircraft accident Consolidated PBY-6A Catalina N101CS Alverca." *Aviation Safety Network*. Retrieved: 30 October 2011.
0. **^** Legg 2002, p. 31.
1. **^** Hayward, John T., VADM USN. "Comment and Discussion" *United States Naval Institute Proceedings*, August 1978, p. 24.
2. **^** Gunston, Bill, ed. *Encyclopedia of World Air Power.* London: Aerospace Publishing Ltd, 1981. ISBN 0-517-53754-0.
3. **^** *Handbook of Erection and Maintenance Instructions for Navy Model PBY-5 and PBY-5A Airplanes*.
4. **^** Loftin, L.K. Jr. "Quest for Performance: The Evolution of Modern Aircraft." *NASA SP-468*. Retrieved: 18 June 2010.

Bibliography

- Bridgeman, Leonard. "The Consolidated Vultee Model 28 Catalina." *Jane's Fighting Aircraft of World War II*. London: Studio, 1946. ISBN 1-85170-493-0.
- Cacutt, Len, ed. "PBY Catalina: Ocean Patroller." *Great Aircraft of the World*. London: Marshall Cavendish, 1989. ISBN 1-85435-250-4.
- Creed, Roscoe. *PBY: The Catalina Flying Boat*. Annapolis, Maryland: US Naval Institute Press, 1986. ISBN 0-87021-526-4.
- Crocker, Mel. *Black Cats and Dumbos: WW II's Fighting PBYs*. Huntington Beach, California: Crocker Media Expressions, 2002. ISBN 0-9712901-0-5.
- Dorny, Louis B. *US Navy PBY Catalina Units of the Pacific War*. Botley, Oxford, UK: Osprey Publishing, 2007. ISBN 1-84176-911-8.
- Gaunt, Coral and Robert Cleworth. *Cats at War: Story of RAAF Catalinas in the Asia Pacific Theatre of War.* Roseville, NSW Australia: J.R. Cleworth, 2000. ISBN 978-1-86408-586-0.
- Greenhous, Brereton et al. *The Crucible of War 1939–1945: The Official History of the Royal Canadian Air Force, Vol. III.* Toronto:

University of Toronto Press, 1994. ISBN 978-0-8020-0574-8.

- *Gunston, Bill (1986). American Warplanes. New York: Crown Publishers Inc. ISBN 0-517-61351-4.*
- Hendrie, Andrew. *Flying Cats: The Catalina Aircraft in World War II*. Annapolis, Maryland: US Naval Institute Press, 1988. ISBN 0-87021-213-3.
- Kinzey, Bert. *PBY Catalina in Detail & Scale*. Carrollton, Texas: Squadron/Signal Publications, Inc., 2000. ISBN 1-888974-19-2.
- Knott, Richard C. *Black Cat Raiders of World War II*. Annapolis, Maryland: US Naval Institute Press, 2000. ISBN 1-55750-471-7.
- Legg, David. *Consolidated PBY Catalina: The Peacetime Record*. Annapolis, Maryland: US Naval Institute Press, 2002. ISBN 1-55750-245-5.
- *Miller, Nathan (1997). War at Sea: A Naval History of World War II. New York: Oxford University Press. ISBN 978-0-19-511038-8.*
- Petrescu, FLorian Ion and Reilly Victoria Petrescu. *The Aviation History*. Stoughton, Wisconsin: Books on Demand, 2012. ISBN 978-3-84823-077-8.
- Ragnarsson, Ragnar. *US Navy PBY Catalina Units of the Atlantic War*. Botley, Oxford, UK: Osprey Publishing, 2006. ISBN 1-84176-910-X.
- Scarborough, William E. *PBY Catalina in Action (Aircraft number 62)*. Carrollton, Texas: Squadron/Signal Publications, Inc., 1983. ISBN 0-89747-149-0.
- Scarborough, William E. *PBY Catalina: Walk Around*. Carrollton, Texas: Squadron/Signal Publications, Inc., 1996. ISBN 0-89747-357-4.
- Wagner, Ray. *The Story of the PBY Catalina* (Aero Biographies Volume 1). San Diego, California: Flight Classics, 1972. ISBN 978-0-911721-30-0.

Further reading

- *Núñez Padin, Jorge Felix (2009). Núñez Padin, Jorge Felix, ed. JRF Goose, PBY Catalina, PBM Mariner & HU-16 Albatros. Serie Aeronaval (in Spanish).* ***25***. *Bahía Blanca, Argentina: Fuerzas Aeronavales. ISBN 9789872055745. Archived from the original on 2016-03-03. Retrieved 2015-01-26.*

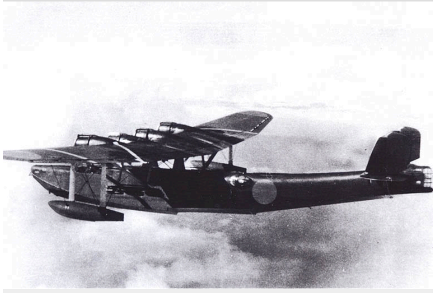
External links

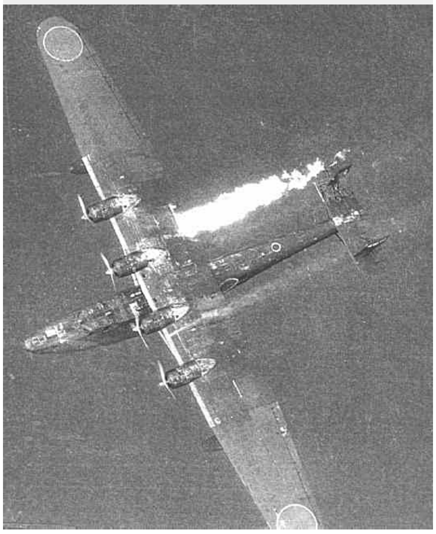
Wikimedia Commons has media related to ***Consolidated PBY Catalina***.

- PBY Catalina Foundation
- (1945) AN 01-5M-3 Handbook of Structural Repair for Navy Models PBY-5, PBY-5A , PBY-6A Army Model OA-10 Airplanes
- Catalina Aircraft Trust
- *Popular Mechanics*, February 1943, *"Here Comes The Cats"* very large and detailed article

Kawanishi H6K

The **Kawanishi H6K** was an Imperial Japanese Navy flying boat produced by the Kawanishi Aircraft Company and used during World War II for maritime patrol duties. The Allied reporting name for the type was **Mavis**; the Navy designation was "Type 97 Large Flying Boat" (九七式大型飛行艇).

H6K	
	
Role	Patrol flying boat
Manufacturer	Kawanishi
First flight	14 July 1936
Introduction	January 1938
Retired	1945 (Japan)
Primary user	IJN Air Service
Number built	215[1]
Developed from	Kawanishi H3K



An H6K suffering from a wing tank fire descending.

Design and development

The aircraft was designed in response to a Navy requirement of 1934 for a long range flying boat and incorporated knowledge gleaned by a Kawanishi team that visited the Short Brothers factory in the UK, at that time one of the world's leading producers of flying boats, and from building the Kawanishi H3K, a license-built, enlarged version of the Short Rangoon.[2] The **Type S**, as Kawanishi called it, was a large, four-engine monoplane with twin tails, and a hull suspended beneath the parasol wing by a network of struts. Three prototypes were constructed, each one making gradual refinements to the machine's handling both in the water and in the air, and finally fitting more powerful engines. The first of these flew on 14 July 1936 and was originally designated **Navy Type 97 Flying Boat**, later **H6K**. Eventually, 217 would be built.[3]

Operational history

H6Ks were deployed from 1938 onwards, first seeing service in the Sino-Japanese War and were in widespread use by the time the full-scale Pacific War erupted, in 1942. At that time of the war, four *Kōkūtai* (Air Groups) operated a total of 66 H6K4s.[4]

The type had some success over South East Asia and the South West Pacific. H6Ks had excellent endurance, being able to undertake 24-hour patrols, and were often used for long-range reconnaissance and bombing missions. From bases in the Dutch East Indies, they were able to undertake missions over a large portion of Australia.

However, the H6K became vulnerable to a newer generation of heavier armed and faster fighters.[4] It continued in service throughout the war, in areas where the risk of interception was low. In front-line service, it was replaced by the Kawanishi H8K.

Variants

An H6K2-L Navy Transport Flying Boat Type 97

H6K1

Evaluation prototypes with four Nakajima Hikari 2 engines, 4 built.

H6K1 (Navy Flying Boat Type 97 Model 1)

Prototypes with 746 kW 1,000 hp Mitsubishi Kinsei 43 Engines, 3 converted from the original H6K1 prototypes.

H6K2 Model 11

First production model. Includes two H6K2-L officer transport modification, 10 built.

H6K2-L (Navy Transport Flying Boat Type 97)

Unarmed transport version of H6K2 powered by Mitsubishi Kinsei 43 engines, 16 built.

H6K3 Model 21

Modified transport version of H6K2 for VIPs and high-ranking officers, 2 built.

H6K4 Model 22

Major production version, modified H6K2 with revised weapons, some with 694 kW (930 hp) Mitsubishi Kinsei 46 engines. Fuel capacity increased from 7,764 L (1,708 Imp gal) to 13,410 L (2,950 Imp gal). Includes two H6K4-L transport versions, 100 to 127 (if other numbers are all correct) built.

H6K4-L

Transport version of H6K4, similar to H6K2-L, but with Mitsubishi Kinsei 46 engines, 20 built and another two converted from the H6K4.

H6K5 Model 23

Fitted with 969 kW (1,300 hp) Mitsubishi Kinsei 51 or 53 engines and new upper turret replacing the open position, 36 built.

Operators

Royal Air Force mechanics inspecting an H6K at Soerabaja, Java, prior to a test flight in January 1946. Note the Indonesia flag added by nationalists and the additional blue band added to the fuselage marking by the Dutch

Indonesia

- Air Service Volunteer Corps - A single H6K5 flying boat was restored to flight by Indonesian forces during the Indonesian War of Independence.[5]

Japan

- Imperial Japanese Navy Air Service
- Imperial Japanese Airways

Used on the routes Yokohama-Saipan-Koror (Palau)-Timor, Saigon-Bangkok and Saipan-Truk-Ponape-Jaluit.[6]

Specifications (H6K4)

Data from Warplanes of the Second World War, Volume Five: Flying Boats;[3] *Japanese Aircraft of the Pacific War*[7]

General characteristics

- **Crew:** 9
- **Length:** 25.63 m (84 ft 3 in)
- **Wingspan:** 40.00 m (131 ft 2 in)

- **Height:** 6.27 m (20 ft 6 in)
- **Wing area:** 170 m^2 (1,830 ft^2)
- **Empty weight:** 11,707 kg (25,755 lb)
- **Loaded weight:** 17,000 kg (37,400 lb)
- **Max. takeoff weight:** 21,500 kg (47,300 lb)
- **Powerplant:** 4 × Mitsubishi Kinsei 43 or 46 14-cylinder, air-cooled, radial engines, 746 kW (1,000 hp) each

Performance

- **Maximum speed:** 331 km/h (211 mph)
- **Cruise speed:** 216 km/h (138 mph)
- **Range:** 6,580 km (4,112 mi)
- **Service ceiling:** 9,610 m (31,520 ft)
- **Rate of climb:** 370 m/min (1,213 ft/min)
- **Wing loading:** 100 kg/m^2 (20 lb/ft^2)
- **Power/mass:** 0.17 kW/kg (0.11 hp/lb)

Armament

- 1× 7.7 mm (0.30 in) Type 92 machine gun in nose
- 1× Type 92 machine gun in spine
- 2× Type 92 machine guns in waist blisters
- 1× 20 mm Type 99 cannon in tail turret
- 2× 800 kg (1,764 lb) torpedoes **or** 1,000 kg (2,205 lb) of bombs

See also

Related development

- Short Rangoon
- Kawanishi H3K

Aircraft of comparable role, configuration and era

- Aichi H9A
- Blackburn Sydney
- Consolidated PBY Catalina
- Dornier Do 24
- Latécoère 300
- Martin M-130
- Potez-CAMS 141

Related lists

- List of aircraft of World War II
- List of military aircraft of Japan
- List of seaplanes and flying boats

References

Notes

1. **^** Francillon 1979, p. 307.
2. **^** Air International & December 1985, p. 294.
3. ^ ***a*** ***b*** Green 1972, p. 129.
4. ^ ***a*** ***b*** Green 1972, p. 128.
5. **^** *Air Enthusiast Quarterley* 1976, p. 156.
6. **^** Francillon 1979, p. 306.
7. **^** Francillon 1979, pp. 306–307.

Bibliography

- Doubilet, David. "The Flying Boat". *Sport Diver Magazine*. Volume 15, Number 8, September 2007.
- Francillon, Ph.D., René J. *Japanese Aircraft of the Pacific War*. Annapolis, Maryland, MD: Naval Institute Press, 1995.
- Green, William. *Warplanes of the Second World War, Volume Five: Flying Boats*. London: Macdonald & Co.(Publishers) Ltd., 1962. ISBN 0-356-01449-5.
- "Kawanishi's Parasol Patroller". *Air International*, December 1985, Volume 29, No. 6. Bromley, UK: Fine Scroll. pp. 293–298, 304-305.
- "Pentagon Over The Islands...The Thirty Year History of Indonesian Military Aviation". *Air Enthusiast Quarterly*. No. 2, 1976. pp. 154–162.
- Richards, M.C. "Kawanishi 4-Motor Flying-Boats (H6K 'Mavis' and H8K 'Emily')". *Aircraft in Profile Volume 11*. Windsor, Berkshire, UK: Profile Publications Ltd., 1972.
- Van der Klaauw, Bart. *Water- en Transportvliegtuigen Wereldoorlog II* (in Dutch). Alkmaar, the Netherlands: Uitgeverij de Alk. ISBN 90-6013-677-2.

External links

Wikimedia Commons has media related to ***Kawanishi H6K***.

- Kawanishi H6K (Mavis) on www.militaryfactory.com
- Duel between an HK6 and 2 B-17s

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