Amphibious Aircrafts

...a short overview

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Contents

Introduction

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Canadair CL-415 operating on "Fire watch" out of Red Lake, Ontario, c. 2007

An **amphibious** or **amphibian aircraft** is an aircraft that can take off and land on either land or water. All Amphibian aircraft are thus classified both as seaplanes and make up the rarest subclass of seaplanes. Like all seaplanes, Amphibious aircraft are typically flying boats and floatplanes — but while their major physical attributes are those placing them within those broad classes, amphibians are also engineered with retractable wheels making them amphibious — at the expense of extra weight and complexity, plus diminished range and fuel economy factors comparative to planes specialized for land or water only.

Design

While floatplanes sometimes have floats that are interchangeable with wheeled landing gear (thereby producing a conventional land-based aircraft), it is rare for a floatplane to successfully incorporate retractable wheels whilst retaining its floats; the Grumman J2F Duck would be a notable example of one exception

Figure 1: *Drawing of an amphibious aircraft from the Tissandier collection, 1880s*

which does. Some amphibian floatplanes, such as the amphibian version of the Cessna Caravan, incorporate retractable wheels within their floats.

The majority of 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 J2F Duck), require small outrigger floats to be fitted underneath the wings: while these impose additional drag and weight on all seaplanes of this type, amphibious aircraft also face the possibility that these floats would hit the runway during wheeled landings. A solution would be to have the aircraft fitted with wing-mounted retractable floats such as those found on the Grumman Mallard, a flying boat type of seaplane designed and built in the mid 1940s with dozens still employed today in regular small volume commercial (ferry service) air taxi roles. The class which has retractable floats which also act as extra fuel tanks since fuel liquids weigh less than water of equal volume; these floats are removable for extended land/snow operations if and when use of extra fuel tanks is undesired but the plane type and class serves as an example of a true amphibious aircraft since they also retract up off the ground.

Usage

Amphibious aircraft are heavier and slower, more complex and more expensive to purchase and operate than comparable landplanes but are also more versatile. They do compete favorably, however, with helicopters that compete for the same types of jobs, if not quite as versatile. Amphibious aircraft have longer range than comparable helicopters, and can indeed achieve nearly the range of land-only airplanes,[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 ShinMaywa US-1, ideal for long-range air-sea rescue tasks. In addition, amphibious aircraft are particularly useful as "bush" aircraft engaging in light transport in remote areas, where they are required to operate not only from airstrips, but also from lakes and rivers.

History

Amphibious aircraft have been built in various nations since the early 1920s, but it was not until World War II that saw their widespread service. The Grumman Corporation, a United States-based pioneer of amphibious aircraft, introduced a family of light utility amphibious aircraft - the Goose, the Widgeon and the Mallard - during the 1930s and the 1940s, originally intended for civilian market. However, the military potential of these very capable aircraft could not be ignored, and large numbers of these versatile aircraft were ordered by the Military of the United States and their allies during World War II, for service in air-sea rescue, anti-submarine patrol, and a host of other tasks. The concept of military amphibious aircraft was so successful that the PBY Catalina, which began life as a pure flying boat, introduced an amphibian variant during the war. After World War II, the United States military ordered hundreds of the Hu-16 Albatross and its variants for use in open ocean rescue, for the United States Air Force, Coast Guard and Navy.

The capabilities of these amphibious aircraft were found to be particularly useful in the unforgiving terrains of Alaska and northern Canada, where some remained in civilian service long after the war, providing remote communities in these regions with vital links to the outside world. Nonetheless, with the increased availability of airstrips and amenities in remote communities, fewer amphibious aircraft are manufactured today than in the past, although a handful of manufacturers around the world still produce amphibious aircraft (flying boats or floatplanes with retractable landing gear), such as the Bombardier 415, the Grumman Albatross and the amphibian version of the Cessna Caravan.

See also

- Amphibious helicopter
- Beriev
- List of seaplanes and flying boats
- Seaplane
- Floatplane
- Flying boat
- RAPT system

Technical Aspects

Propeller

A **propeller** is a type of fan which 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 air or water is accelerated behind the blade. Propeller dynamics can be modeled by both Bernoulli's principle and Newton's third law.

History

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 "j-stroke" involves a related but not identical 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 actual 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.

Figure 2: *Rotating the Hamilton Standard 54H60 propeller on a US Navy EP-3E Orion's number four engine as part of pre-flight checks*

In 1784, J. P. Paucton proposed a gyrocopter-like aircraft using similar screws for both lift and propulsion. At about the same time, James Watt proposed using screws to propel boats, although he did not use them for his steam engines. This was not his own invention, though; Toogood and Hays had patented it a century earlier, and it had become an uncommon use as a means of propelling boats since that time.

By 1827, Austrian-Czech constructor Josef Ressel had invented a screw propeller which had multiple blades fastened around a conical base; this new method of propulsion allowed steam ships to travel at much greater speeds without using sails thereby making ocean travel faster (first tests with the Austro-Hungarian Navy). Propellers remained extremely inefficient and little-utilized until 1835, when Francis Pettit Smith discovered a new way of building propellers. Up to that time, propellers were literally screws, of considerable length. But during the testing of a boat propelled by one, the screw snapped off, leaving a fragment shaped much like a modern boat propeller. The boat moved faster with the broken propeller.[2] At about the same time, Frédéric Sauvage and John Ericsson applied for patents on vaguely similar, although less efficient shortened-screw propellers, leading to an apparently permanent controversy as to who the official inventor is among those three men. Ericsson became

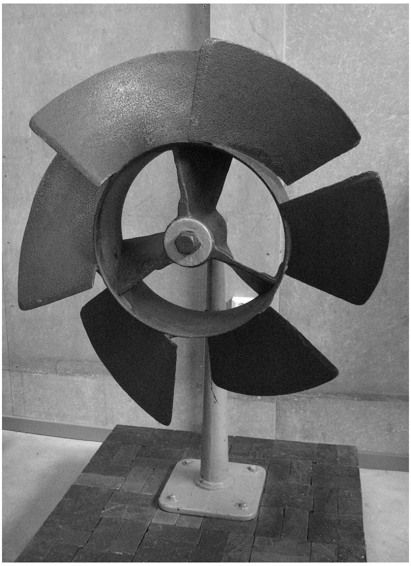


Figure 3: *Ship propeller from 1843. Designed by C F Wahlgren based on one of John Ericsson propellers. It was fitted to the steam ship s/s Flygfisken built at the Motala dockyard.*

widely famous when he built the *Monitor*, an armoured battleship that in 1862 fought the Confederate States' *Virginia* in an American Civil War sea battle.

The first screw propeller to be powered by a gasoline engine, fitted to a small boat (now known as a powerboat) was installed by Frederick Lanchester, also from Birmingham. This was tested in Oxford. The first 'real-world' use of a propeller was by David Bushnell, who used hand-powered screw propellers to navigate his submarine "Turtle" in 1776.

The superiority of screw against paddles was taken up by navies. Trials with Smith's SS *Archimedes*, the first steam driven screw, 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.

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 modeled 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

Figure 4: *A World War I wooden aircraft propeller on a workbench.*

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 behavior 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.

The twisted airfoil (aerofoil) shape of modern aircraft propellers was pioneered by the Wright brothers. While both the blade element theory and the momentum theory had their supporters, the Wright brothers were able to combine both theories. They found that a propeller is essentially the same as a wing and so were able to use data collated from their earlier wind tunnel experiments on wings. They also found that the relative angle of attack from the forward movement of the aircraft was different for all points along the length of the blade, thus it was necessary to introduce a twist along its length. Their original propeller blades are only about 5% less efficient than the modern equivalent, some 100 years later.[3]

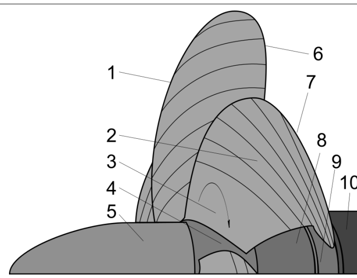
Alberto Santos Dumont was another early pioneer, having designed propellers before the Wright Brothers (albeit not as efficient) for his airships. He applied the knowledge he gained from experiences with airships to make a propeller with a steel shaft and aluminium blades for his 14 bis biplane. Some of his designs used a bent aluminium sheet for blades, thus creating an airfoil shape. These are heavily undercambered because of this and combined with the lack of a 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.

Aviation

Aircraft propellers convert rotary motion from piston engines or turboprops to provide propulsive force. They may be fixed or variable pitch. Early aircraft propellers were carved by hand from solid or laminated wood with later propellers being constructed from metal. The most modern propeller designs use high-technology composite materials.

Marine

Naming



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

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 size propeller (free-tip) is that of an actuator disc in an ideal fluid. An actual marine propeller is made up of sections of helicoidal surfaces which act together 'screwing' through the water (hence the common reference to marine propellers as "screws"). Three, four, or five blades are most common in marine propellers, although designs which are intended to operate at reduced noise will have more 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 normal 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, a change which could cause conventional propellers to lock up as insufficient torque is generated. 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. One example of the latter is the CRP Azipod[4] by the ABB Group. 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.

Additional designs

An Azimuthing propeller is a vertical axis propeller.

The blade outline is defined either by a projection on a plane normal to the propeller shaft (*projected outline*) or by setting the circumferential chord across the blade at a given radius against radius (*developed outline*). The outline is usually symmetrical about a given radial line termed the *median*. If the median is curved back relative to the direction of rotation the propeller is said to have *skew back*. The skew is expressed in terms of circumferential displacement at the blade tips. If the blade face in profile is not normal to the axis it is termed *raked*, expressed as a percentage of total diameter.

Each blade's pitch and thickness varies with radius, early blades had a flat face and an arced back (sometimes called a circular back as the arc was part of a circle), modern propeller blades have aerofoil sections. The *camber line* is the line through the mid-thickness of a single blade. The *camber* is the maximum difference between the camber line and the *chord* joining the trailing and leading edges. The camber is expressed as a percentage of the chord.

The radius of maximum thickness is usually forward of the mid-chord point with the blades thinning to a minimum at the tips. The thickness is set by the demands of strength and the ratio of thickness to total diameter is called *blade thickness fraction.*

The ratio of pitch to diameter is called *pitch ratio*. Due to the complexities of modern propellers a nominal pitch is given, usually a radius of 70% of the total is used.

Blade area is given as a ratio of the total area of the propeller disc, either as *developed blade area ratio* or *projected blade area ratio*.

Transverse axis propellers

Most propellers have their axis of rotation parallel to the fluid flow. There have however been some attempts to power vehicles with the same principles behind vertical axis wind turbines, where the rotation is perpendicular to fluid flow. Most attempts have been unsuccessful[5]. Blades that can vary their angle of attack during rotation have aerodynamics similar to flapping flight[6]. Flapping flight is still poorly understood and almost never seriously used in engineering because of the strong coupling of lift, thrust and control forces.

The fanwing is one of the few types that has actually flown. It takes advantage of the trailing edge of an airfoil to help encourage the circulation necessary for lift.

The Voith-Schneider propeller pictured below is another successful example, operating in water.

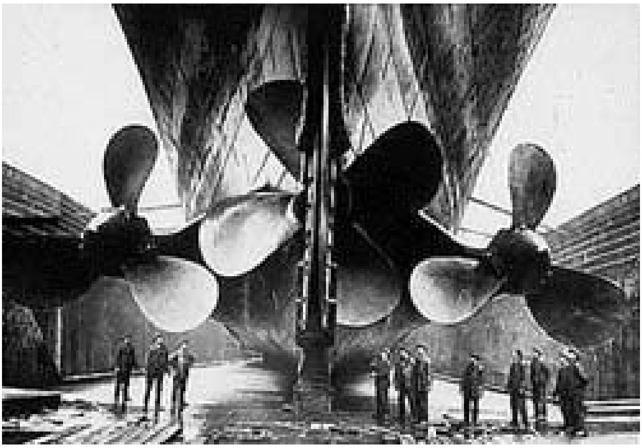


Figure 5: *Propellers of the Titanic: 2 triple-blade and 1 quadruple-blade at center*

Figure 6: *A propeller from the Lusitania*

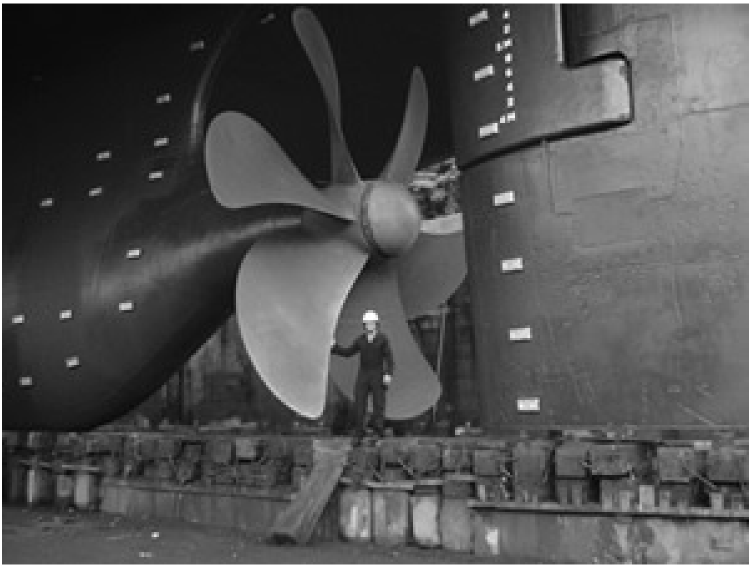


Figure 7: *Propeller on a modern mid-sized merchant vessel*

History of ship and submarine screw propellers

James Watt of Scotland is generally credited with applying the first screw propeller to an engine, an early steam engine, beginning the use of an hydrodynamic screw for propulsion.

Mechanical ship propulsion began with the steam ship. The first successful ship of this type is a matter of debate; candidate inventors of the 18th century include William Symington, the Marquis de Jouffroy, John Fitch and Robert Fulton, however William Symington's ship the *Charlotte Dundas* is regarded as the world's "first practical steamboat". Paddlewheels as the main motive source became standard on these early vessels (see Paddle steamer). Robert Fulton had tested, and rejected, the screw propeller.

The screw (as opposed to paddlewheels) was introduced in the latter half of the 18th century. David Bushnell's invention of the submarine (Turtle) in 1775 used hand-powered screws for vertical and horizontal propulsion. The Bohemian engineer Josef Ressel designed and patented the first practicable screw propeller in 1827. Francis Pettit Smith tested a similar one in 1836. In 1839, John Ericsson introduced practical screw propulsion into the United States. Mixed paddle and propeller designs were still being used at this time (*vide* the 1858 *SS Great Eastern*).

Figure 8: *Sketch of hand-cranked vertical and horizontal screws used in Bushnell's Turtle, 1775*

In 1848 the British Admiralty held a tug of war contest between a propeller driven ship, *Rattler*, and a paddle wheel ship, *Alecto*. *Rattler* won, towing *Alecto* astern at 2.5 knots (4.6 km/h), but it was not until the early 20th century paddle propelled vessels were entirely superseded. The screw propeller replaced the paddles owing to its greater efficiency, compactness, less complex power transmission system, and reduced susceptibility to damage (especially in battle)

Initial designs owed much to the ordinary screw from which their name derived - early propellers consisted of only two blades and matched in profile the length of a single screw rotation. This design was common, but inventors endlessly experimented with different profiles and greater numbers of blades. The propeller screw design stabilized by the 1880s.

In the early days of steam power for ships, when both paddle wheels and screws were in use, ships were often characterized by their type of propellers, leading to terms like screw steamer or screw sloop.

Propellers are referred to as "lift" devices, while paddles are "drag" devices.

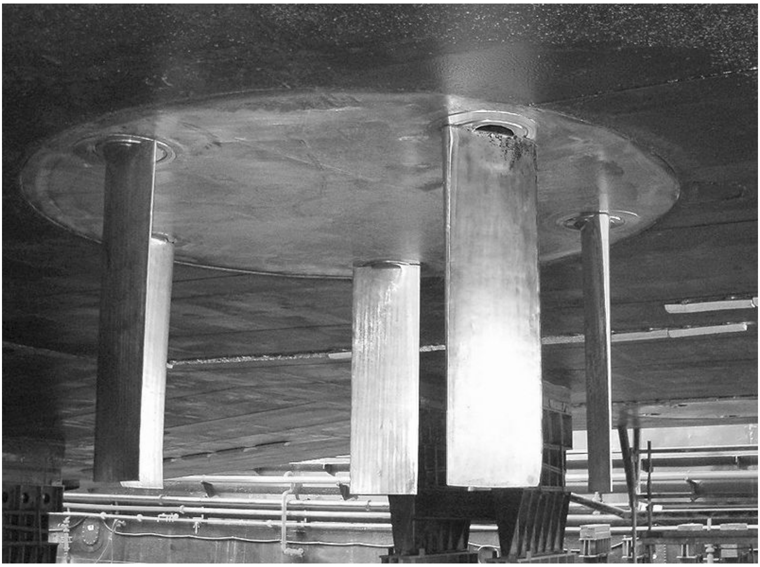


Figure 9: *Voith-Schneider propeller*

Figure 10: *Cavitation damage evident on the propeller of a personal watercraft.*

Marine propeller cavitation

Cavitation 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 occur in many ways on a propeller. The two most common types of propeller cavitation are suction side surface cavitation and tip vortex cavitation.

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 vapour pressure of the water, resulting in the formation of a pocket of vapour. 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, and thrust produced by the propeller drops. This condition is called ”thrust breakdown”. This effect wastes energy, makes the propeller ”noisy” as the vapour bubbles collapse, and most seriously, 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[7] demonstrates tip vortex cavitation well. 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.

Figure 11: *14-ton propeller from Voroshilov a Kirov class cruiser on display in Sevastopol*

Forces acting on an aerofoil

The force (F) experienced by an aerofoil blade is determined by its area (A), chord (c), velocity (V) and the angle of the aerofoil to the 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 are expressed non-dimensionally as:

$$C_L = \frac{L}{\frac{1}{2}\rho A V^2} \text{ and } C_D = \frac{D}{\frac{1}{2}\rho A V^2}$$

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 (τ), Lift $= L = \rho V \tau$. The effect of the flow over and the circulation around the aerofoil 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

Single blade

Taking an arbitrary radial section of a blade at *r*, if revolutions are *N* then the rotational velocity is $2\pi Nr$. 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, V_a , the difference, or *slip ratio*, is:

$$\text{Slip} = \frac{NP - V_a}{NP} = 1 - \frac{J}{p}$$

where $J = \frac{V_a}{ND}$ is the *advance coefficient*, and $p = \frac{P}{D}$ is the *pitch ratio*.

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

$$\mathrm{d}L = \tfrac{1}{2}\rho V_1^2 C_L dA = \tfrac{1}{2}\rho C_L [V_a^2(1+a)^2 + 4\pi^2 r^2 (1-a')^2] b\mathrm{d}r$$

where:

$$V_1^2 = V_a^2(1+a)^2 + 4\pi^2 r^2 (1-a')^2$$

$$\mathrm{d}D = \frac{1}{2}\rho V_1^2 C_D \mathrm{d}A = \frac{1}{2}\rho C_D [V_a^2(1+a)^2 + 4\pi^2 r^2 (1-a')^2] b\mathrm{d}r$$

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

$$\mathrm{d}T = \mathrm{d}L\cos\varphi - \mathrm{d}D\sin\varphi = \mathrm{d}L(\cos\varphi - \frac{\mathrm{d}D}{\mathrm{d}L}\sin\varphi)$$

where:

$$\begin{aligned} tan\beta &= \frac{\mathrm{d}D}{\mathrm{d}L} = \frac{C_D}{C_L} \\ &= \frac{1}{2}\rho V_1^2 C_L \frac{\cos(\varphi+\beta)}{\cos\beta} b\mathrm{d}r \end{aligned}$$

As $V_1 = \frac{V_a(1+a)}{\sin\varphi}$,

$$\mathrm{d}T = \frac{1}{2}\rho C_L \frac{V_a^2(1+a)^2\cos(\varphi+\beta)}{\sin^2\varphi\cos\beta} b\mathrm{d}r$$

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

$$\begin{aligned} \mathrm{d}M &= \mathrm{d}L \sin\varphi + \mathrm{d}D \cos\varphi \\ &= \mathrm{d}L(\sin\varphi + \frac{\mathrm{d}D}{\mathrm{d}L}\cos\varphi) \\ &= \frac{1}{2}\rho V_1^2 C_L \frac{\sin(\varphi+\beta)}{\cos\varphi} b\mathrm{d}r \end{aligned}$$

Substituting for V_1 and multiplying by r, gives torque as:

$$\mathrm{d}Q = r\mathrm{d}M = \frac{1}{2}\rho C_L \frac{V_a^2(1+a)^2\sin(\varphi+\beta)}{\sin^2\varphi\cos\beta} br\mathrm{d}r$$

which can be integrated as before.

The total thrust power of the propeller is proportional to TV_a and the shaft power to $2\pi NQ$. So efficiency is $\frac{TV_a}{2\pi NQ}$. The blade efficiency is in the ratio between thrust and torque:

$$\text{blade element efficiency} = \frac{V_a}{2\pi Nr} \cdot \frac{1}{\tan(\varphi+\beta)}$$

showing that the blade efficiency is determined by its momentum and its qualities in the form of angles φ and β , where β 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, V_a , together with the character of the fluid in which the propeller is operating and gravity. These factors create the following non-dimensional relationship:

$$T = \rho V^2 D^2 [f_1(\frac{ND}{V_a}), f_2(\frac{v}{V_a D}), f_3(\frac{gD}{V_a^2})]$$

where f_1 is a function of the advance coefficient, f_2 is a function of the Reynolds' number, and f_3 is a function of the Froude number. Both f_2 and f_3 are likely to be small in comparison to f_1 under normal operating conditions, so the expression can be reduced to:

$$T = \rho V_a^2 D^2 \times f_r(\frac{ND}{V_a})$$

For two identical propellers the expression for both will be the same. So with the propellers T_1, T_2 , and using the same subscripts to indicate each propeller:

$$\frac{T_1}{T_2} = \frac{\rho_1}{\rho_2} \times \frac{V_{a1}^2}{V_{a2}^2} \times \frac{D_1^2}{D_2^2}$$

For both Froude number and advance coefficient:

$$\frac{T_1}{T_2} = \frac{\rho_1}{\rho_2} \times \frac{D_1^3}{D_2^3} = \frac{\rho_1}{\rho_2}\lambda^3$$

where λ is the ratio of the linear dimensions.

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

$$\frac{P_{T1}}{P_{T2}} = \frac{\rho_1}{\rho_2}\lambda^{3.5}$$

For torque:

$$Q = \rho V_a^2 D^3 \times f_q\left(\frac{ND}{V_a}\right)$$

...

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 (P_D) and in open water (P'_D) is termed *relative rotative efficiency.*

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

P'_E/ P_T = hull efficiency = η_H

P_T/ P'_D = propeller efficiency = η_O

P'_D/ P_D = relative rotative efficiency = η_R

P_D/ P_S = shaft transmission efficiency

Producing the following:

$$PC = \left(\frac{\eta_H \cdot \eta_O \cdot \eta_R}{\text{appendage coefficient}}\right) \cdot \text{transmission efficiency}$$

The terms contained within the brackets are commonly grouped as the *quasi-propulsive coefficient* (QPC , η_D). The QPC 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.

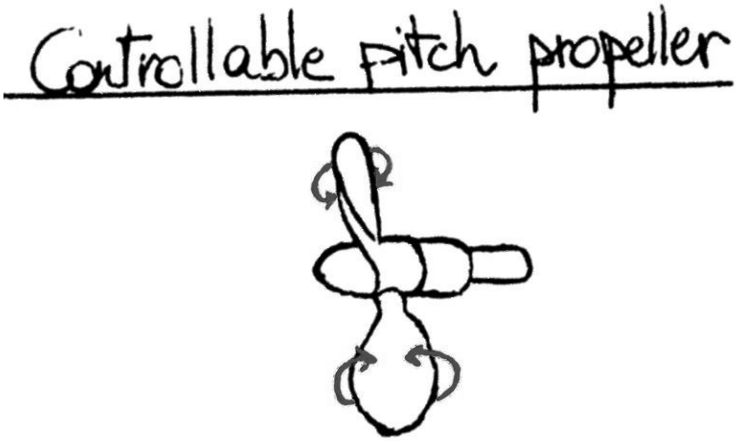


Figure 12: *A controllable pitch propeller*

Types of marine propellers

Controllable pitch propeller

At present, one of the newest and best type of 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 (eg when the sails are used instead).

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.[8]

Modular propeller

A modular propeller provides more control over the boats 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.[9]

Figure 13: *A failed rubber bush in an outboard's propeller*

Protection of small engines

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 which is designed to fail when over loaded; 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/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 an undamaged shear pin is fitted.[10]

In larger and more modern engines, a rubber bush transmits the torque of the drive shaft to the propeller's hub. Under a damaging load the friction of the bush in the hub is overcome and the rotating propeller slips on the shaft preventing overloading of the engine's components.[11] After such an event the rubber bush itself 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 bush may perish over time leading to its failure under loads below its designed failure load.

Whether a rubber bush can be replaced or repaired depends upon the propeller; some cannot. Some can but need special equipment to insert the oversized bush for an interference fit. Others can be replaced easily.

In some modern propellers, a hard polymer insert called a *drive sleeve* replaces the rubber bush. 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.[12] This fails completely under excessive load but can easily be replaced.

See also

- Screw-propelled vehicle

Propeller phenomena

- Propeller walk
- Cavitation

Propeller variations

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

Materials and Manufacture

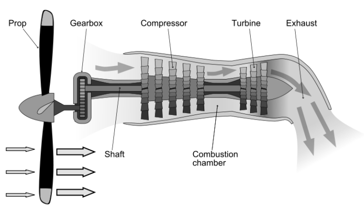
- Balancing machine
- Composite materials

External links

- Titanic's Propellers[13]
- Experimental Aircraft Propellers[14]

Turboprop

Turboprop



Schematic diagram showing the operation of a turboprop engine

Part of a series on
Aircraft propulsion

Shaft engines (to drive propellers, rotors, ducted fans, or propfans):

- Internal combustion engines:
  - Piston engine
  - Wankel engine
  - Turbines:
    - Turboprop
    - Turboshaft
- External combustion engines:
  - Steam-powered
- Others:
  - Human-powered
  - Electric

Reaction engines:

- Turbines:
  - Turbojet
  - Turbofan
- Rocket-powered
- Motorjet
- Pulsejet
- Ramjet
  - Scramjet

Turboprop engines are a type of aircraft powerplant that use a gas turbine to drive a propeller. The gas turbine is designed specifically for this application, with almost all of its output being used to drive the propeller. The engine's exhaust gases contain little energy compared to a jet engine and play a minor role in the propulsion of the aircraft.

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.

Turboprop engines are generally used on small subsonic aircraft, but some aircraft outfitted with turboprops have cruising speeds in excess of 500 kt (926 km/h, 575 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 Kuznetsov NK-12 and Progress D-27.

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.

Turboprops are very efficient at modest flight speeds (below 450 mph) because the jet velocity of the propeller (and exhaust) is relatively low. 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. The most common application of turboprop engines in civilian aviation is in small commuter aircraft, where their greater reliability than reciprocating engines offsets their higher initial cost.

Technological aspects

Much of the jet thrust in a turboprop is sacrificed in favor of shaft power, which is obtained by extracting additional power (up to that necessary to drive the compressor) from turbine expansion. 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. Owing to the additional expansion in the turbine system, the residual energy in the exhaust jet is low. Consequently, the exhaust jet produces (typically) less than 10% of the total thrust.

Propellers are not efficient when the tips reach or exceed supersonic speeds. For this reason, a reduction gearbox is placed in the drive line between the power turbine and the propeller to allow the turbine to operate at its most efficient speed while the propeller operates at its most efficient speed. The gearbox is part of the engine and contains the parts necessary to operate a constant speed propeller. This differs from the turboshaft engines used in helicopters, where the gearbox is remote from the engine.

Residual thrust on a turboshaft is avoided by further expansion in the turbine system and/or truncating and turning the exhaust through 180 degrees, to produce two opposing jets. Apart from the above, there is very little difference between a turboprop and a turboshaft.

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.

Propellers lose efficiency as aircraft speed increases, so turboprops are normally not used on high-speed aircraft. However, propfan engines, which are very similar to turboprop engines, can cruise at flight speeds approaching Mach 0.75. To increase the efficiency of the propellers, a mechanism can be used to alter the pitch, thus adjusting the pitch 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.

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

History

The world's first turboprop was the Jendrassik Cs-1, designed by the Hungarian mechanical engineer György Jendrassik. It was produced and tested in the Ganz factory in Budapest between 1939 and 1942. It was planned to fit to the Varga RMI-1 X/H twin-engined reconnaissance bomber designed by László Varga in 1940, but the program was cancelled. Jendrassik had also designed a

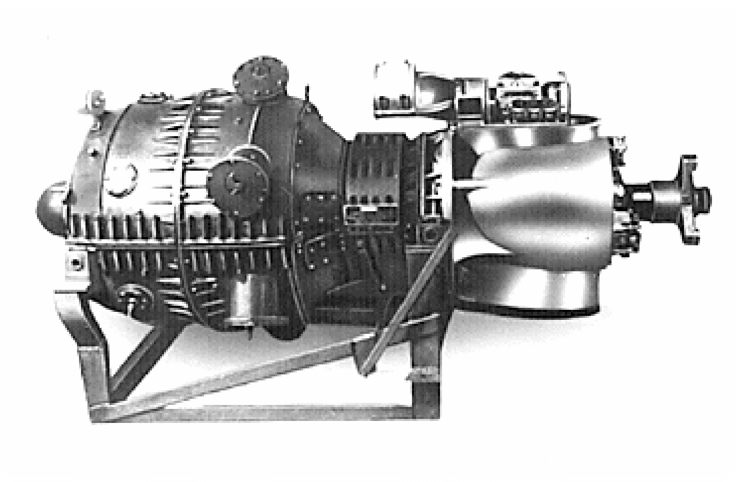


Figure 14: *Jendrassik Cs-1, built in Budapest, Hungary in 1938*

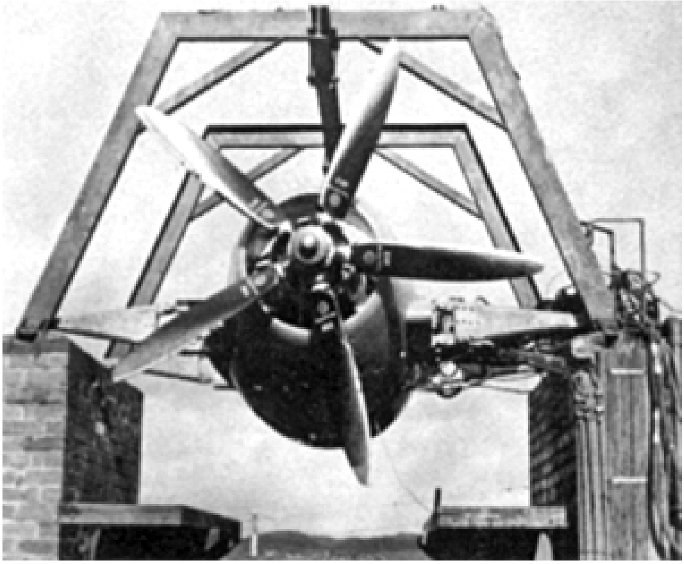


Figure 15: *A Rolls-Royce RB.50 Trent on a test rig at Hucknall, in March 1945*

Figure 16: *Kuznetsov NK-12M Turboprop, on a Tu-95*

small-scale 75 kW turboprop in 1937. However, Jendrassik's achievement was not unnoticed. After WW2, György Jendrassik moved to London. Building off a similar principle the first British turboprop engine was the Rolls Royce RB.50 Trent

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 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[15][16]. It first flew on 20th September 1945. From their experience with the Trent, Rolls-Royce developed 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[17]. It was also the first four-engined turboprop. Its first flight was on 16th July 1948. The world's first single engined turboprop aircraft was the Armstrong Siddeley Mamba-powered Boulton Paul Balliol, which first flew on 24th March 1948[18].

The Soviet Union built on German World War II development by Junkers (BMW and Hirth/Daimler-Benz also developed and partially tested designs). While the Soviet Union had the technology to create a jet-powered strategic bomber comparable to Boeing's B-52 Stratofortress, they instead produced the Tupolev Tu-95, 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 Allison T40, into a series of experimental aircraft during the 1950s, but none would be adopted into service.

The first American turboprop engine was the General Electric XT31, first used in the experimental Consolidated Vultee XP-81[19]. The XP-81 first flew in December 1945, the first aircraft to use a combination of turboprop and turbojet power. America skipped over turboprop airliners in favor of the Boeing 707, but the technology of the unsuccessful Lockheed Electra was used in both the long-lived P-3 Orion as well as the classic C-130 Hercules, one of the most successful military aircraft ever in terms of length of production. One of the most popular turboprop engines is the Pratt & Whitney Canada PT6 engine.

The first turbine powered, shaft driven helicopter was the Bell XH-13F, a version of the Bell 47 powered by Continental XT-51-T-3 (Turbomeca Artouste) engine[20].

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- Green, W. and Cross, R.*The Jet Aircraft of the World* (1955). London: MacDonald
- James, D.N. *Gloster Aircraft since 1917* (1971). London: Putnam & Co. ISBN 0 370 00084 6

See also

- Gas turbine
- Jet engine
- Jet engine performance
- Jet aircraft
- Jetboat
- Propfan
- Ramjet
- Supercharger
- Turbocharger
- Turbofan
- Turbojet
- Turboshaft

External links

- Wikibooks: Jet propulsion

Wing configuration

This article summarises the **wing configuration**s of fixed-wing aircraft, popularly called aeroplanes, airplanes or just planes.

For aircraft configurations in general, including fuselage, tail and powerplant configuration, see the main Aircraft article.

For rotary-winged aircraft types, see the main Rotorcraft article.

For direct-lift and compound or hybrid types, see the main Powered lift article.

This page provides a breakdown of types, allowing a full description of any aircraft's wing configuration. For example the Spitfire wing may be classified as a *conventional low wing cantilever monoplane with straight elliptical wings of moderate aspect ratio and slight dihedral*.

Sometimes the distinction between types 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 Extension” (or LERX).

All the configurations described have flown (if only very briefly) on full-size aircraft, except as noted.

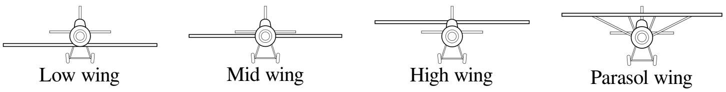
Some variants may be duplicated under more than one heading, due to their complex nature. This is particularly so for variable geometry and combined (closed) wing types.

Number and position of main-planes

Aircraft can have different numbers of wings:

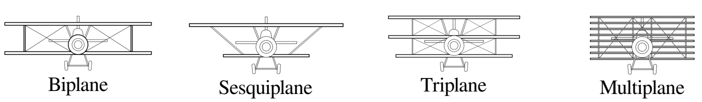
- No wings at all. See the main article on Aircraft for more about:
  - **Lifting body** - relies on air flow over the fuselage to provide lift. See Wings vs. bodies below.
  - **Powered lift** - relies on downward thrust from the engines to stay airborne.
- **Monoplane** - one wing. Most aeroplanes have been monoplanes since before the Second World War. The wing may be mounted at various heights relative to the fuselage:

- **Low wing** - fixed to the lower fuselage.
- **Mid wing** - fixed approximately half way up the fuselage.
- **High** or **Shoulder wing** - fixed to the upper fuselage.
- **Parasol wing** - mounted on struts above the fuselage.



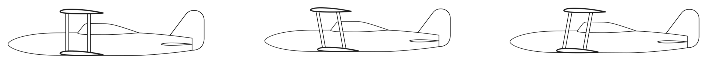
A fixed wing aircraft may have more than one wing plane, stacked one above another:

- **Biplane** - two planes of approximately equal size, stacked one above the other. The most common type until the 1930s, when the cantilever monoplane took over.
  - **Sesquiplane** - literally "one-and-a-half planes" is a variant on the biplane in which the lower wing is significantly smaller than the upper wing.
- **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 small size and high manoeuvrability as fighters, 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 it never saw operational military 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. No example with more than four wings has ever flown successfully: the nine-wing Caproni Ca.60 flying boat was only airborne briefly before crashing.



A **Tandem wing** design has two similar-sized wings, one behind the other. See Horizontal stabiliser below.

A **staggered** design has the upper wing slightly forward of the lower. This helps give stability to stacked wings, and is usual on successful designs. Backwards stagger is also seen in a few examples such as the Beechcraft Staggerwing.



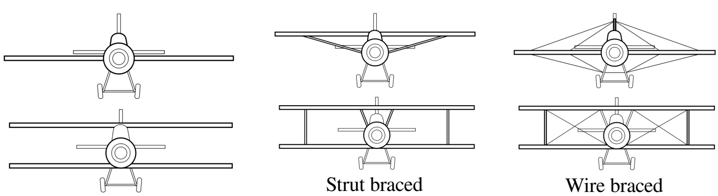
Unstaggered biplane Forwards stagger Backwards stagger

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. A strut may act in compression or tension at different points in the flight regime.
  - **Wire braced** - in addition to struts, some tension wires also help to support the wing. Nominally, the struts act only in compression.

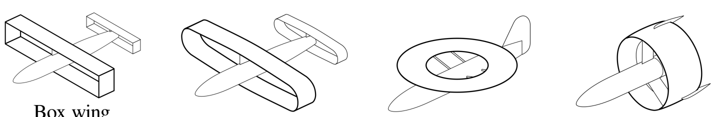


Cantilever Strut braced Wire braced

A braced multiplane may have one or more ”bays”, which are the compartments created by adding interplane struts; this relates to only one side of the aircraft’s wing panels. For example, the de Havilland Tiger Moth is a single-bay biplane where the Bristol F.2 Fighter is a two-bay biplane.[21]

Single-bay biplane Two-bay biplane

- **Combined** or **closed wing** - two wings are joined structurally at or near the tips in some way. 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. Some Dunne biplanes were of this type. Tandem box wings have also been studied (see *Joined wing* description below).
  - **Rhomboidal wing** - a tandem layout in which the front wing sweeps back and the rear wing sweeps forwards such that they join at or near the tips to form a continuous surface in a hollow diamond shape. The Edwards Rhomboidal biplane of 1909 failed to fly[22]. The design has recently seen a revival of interest where it is referred to as a **joined wing** .
  - **Annular** or **ring wing** - may refer to various types:
    - **Flat** - the wing is shaped like a circular disc with a hole in it. A Lee-Richards type was one of the first stable aircraft to fly, shortly before the First World War.[23]
    - **Cylindrical** - the wing is shaped like a cylinder. The Coléoptère took off and landed vertically, but never achieved transition to horizontal flight.
    - 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.



Box wing Annular box wing Flat annular wing Cylindrical wing

Wings can also be characterised as:

- **Rigid** - stiff enough to maintain the aerofoil profile in varying conditions of airflow.
- **Flexible** - usually a thin membrane. Requires external bracing or wind pressure to maintain the aerofoil shape. Common types include Rogallo wings and kites.

Wing planform

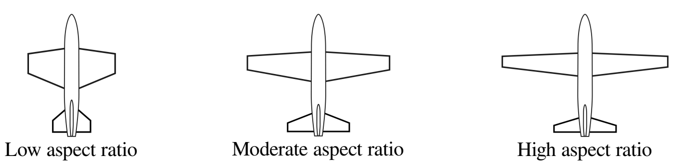
The wing planform is the silhouette of the wing when viewed from above or below.

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.[24] 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, more maneuverable and with less drag at high speeds. They tend to be used by fighter aircraft, such as the Lockheed F-104 Starfighter, and by very high-speed aircraft (e.g. North American X-15).
- **Moderate aspect ratio** - general-purpose wing (e.g. the Lockheed P-80 Shooting Star).
- **High aspect ratio** - long and slender wing. More efficient aerodynamically, having less drag, at low speeds. They tend to be used by high-altitude subsonic aircraft (e.g. the Lockheed U-2), subsonic airliners (e.g. the Bombardier Dash 8) and by high-performance sailplanes (e.g. Glaser-Dirks DG-500).



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

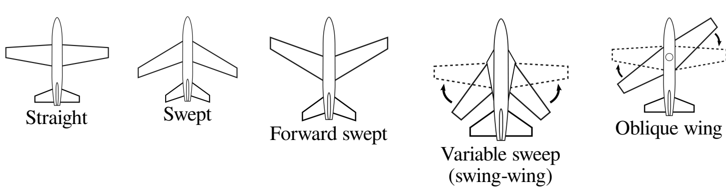
Wing sweep

Wings may be swept forwards or back 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. Other uses are described below.

- **Straight** - extends at right angles to the line of flight. The most efficient structurally, and common for low-speed designs, such as the P-80 Shooting Star.
- **Swept back** - (references to ”swept” often assume swept back). From the root, the wing angles backwards towards the tip. In early tailless examples, such as the Dunne aircraft, this allowed the outer wing section to act as a conventional tail empennage 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 supersonic designs e.g. the English Electric Lightning.
- **Forward swept** - the wing angles forwards from the root. Benefits are similar to backwards sweep, also at significant angles of sweep it avoids the stall problems and has reduced tip losses allowing a smaller wing, but requires even greater stiffness and for this reason is not often used. A civil example is the HFB-320 Hansa Jet.

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

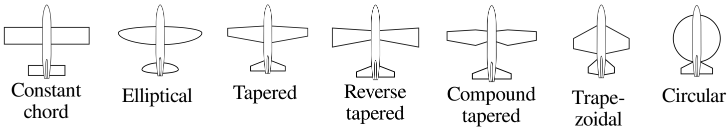
- **Swing-wing** - also called ”variable sweep wing”. The left and right hand wings vary their sweep together, usually backwards. Seen in a few types of combat aircraft, the first being the General Dynamics F-111.
- **Oblique wing** - a single full-span wing pivots about its mid point, so that one side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



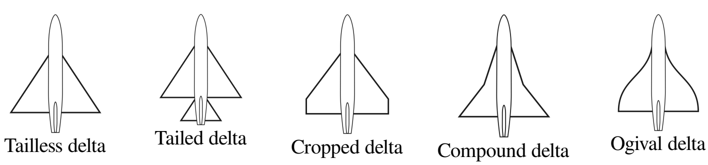
Planform variation along span

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

- **Constant chord** - leading and trailing edges are parallel. Simple to make, and common where low cost is important, e.g. in the Short Skyvan.[25]
- **Elliptical** - wing edges are parallel at the root, and curve smoothly inwards to a rounded tip, with no division between the edges and the tip. Aerodynamically the most efficient, but difficult to make. Famously used on the Supermarine Spitfire.
- **Tapered** - wing narrows towards the tip, with straight edges. Structurally and aerodynamically more efficient than a constant chord wing, and easier to make than the elliptical type. One of the commonest types of all, as on the Hawker Sea Hawk.
  - **Reverse tapered** - wing widens towards the tip. Structurally very 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, to increase visibility for the pilot. Typically needs to be braced to maintain stiffness. The Westland Lysander was an observation aircraft.
  - **Trapezoidal** - a low aspect ratio tapered wing, having little or no sweep such that the leading edge sweeps back and the trailing edge sweeps forwards. Used for example on the Lockheed F-22 Raptor.
- **Bird like** - a curved shape appearing similar to a bird's outstretched wing. Popular during the pioneer years, and achieved some success on the Etrich Taube.
- **Circular** - approximately circular planform. The Vought XF5U attempted to counteract the large tip vortices by using large propellers rotating in the opposite sense to the vortices.
  - **Flying saucer** - tailless circular flying wing. The Avrocar demonstrated the inherent instability of the design, while the Moller M200G uses computer control to achieve artificial stability in hover mode.
  - **Flat annular wing** - the circle has a hole in, forming a closed wing (see above). A Lee-Richards type was one of the first stable aircraft to fly, shortly before the First World War[26].

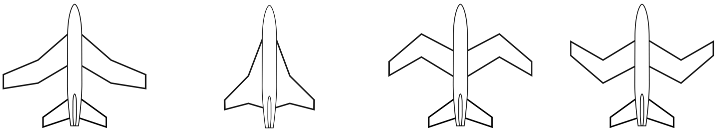


- **Delta** - triangular planform with swept leading edge and straight trailing edge. Offers the advantages of a swept wing, with good structural efficiency. Variants are:
  - **Tailless delta** - a classic high-speed design, used for example in the widely built Dassault Mirage III series.
  - **Tailed delta** - adds a conventional tailplane, to improve handling. Popular on Soviet types such as the Mikoyan-Gurevich MiG-21.
  - **Cropped delta** - tip is cut off. This helps avoid tip drag at high angles of attack. At the extreme, merges into the ”tapered swept” configuration.
  - **Compound delta** or **double delta** - inner section has a (usually) steeper leading edge sweep e.g. Saab Draken. This improves the lift at high angles of attack and delays or prevents stalling. The HAL Tejas has an inner section of reduced sweep.
  - **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 and Tupolev Tu-144 supersonic transports.



The angle of sweep may also be varied, or cranked, along the span:

- **Crescent** - wing outer section is swept less sharply than the inner section. Used for the Handley Page Victor.
- **Cranked arrow** - similar to a compound delta, but with the trailing edge also kinked inwards. Trialled experimentally on the General Dynamics F-16XL. (See also **Cranked** wing below.)
- **M-wing** - the inner wing section sweeps forward, and the outer section sweeps backwards. The idea has been studied from time to time, but no example has ever been built.[27][28]
- **W-wing** - the inner wing section sweeps back, and the outer section sweeps forwards. The reverse of the M-wing. The idea has been studied even less than the M-wing and no example has ever been built.[28]



Horizontal stabiliser

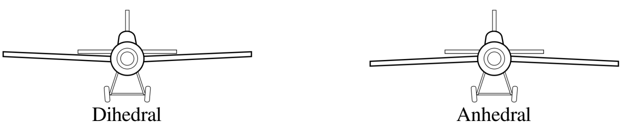
The classic aerofoil section wing is unstable in pitch, and requires some form of horizontal stabilising surface. Also it cannot provide any significant pitch control, requiring a separate control surface (elevator) elsewhere. The elevator may be hinged to a fixed horizontal stabiliser, or the whole stabiliser may pivot to double as the elevator.

- **Conventional** - ”tailplane” stabiliser at the rear of the aircraft, forming part of the tail or empennage.
- **Canard** - ”foreplane” stabiliser at the front of the aircraft. A fairly common feature of the 4.5th generation jet fighters as supersonic aerodynamics grew more mature and because the forward surface can contribute lift during level flight. But due to poor stealth characteristics these are not found on true fifth generation jet fighters. A good example is the Saab Viggen.
- **Tandem** - two main wings, one behind the other. The two act together to provide stability and both provide lift. An example is the Rutan Quickie.
- **Tandem triple or triplet** - having both conventional and canard stabiliser surfaces. This may be for manoeuvrability, or the canard surfaces may be used for active vibration damping, to smooth out air turbulence giving the crew a more comfortable ride and reducing fatigue on the airframe. Popularly (but incorrectly) referred to as a **tandem triplane**.
- **Tailless** - no separate stabilising surface, at front or rear. Either the lifting and horizontal stabilising surfaces are combined in a single plane, or the aerofoil profile is modified to provide inherent stability. The Short Sherpa used wingtips which could be rotated about the wing’s major axis to act as either ailerons and/or elevators. Recently, aircraft having a tailplane but no vertical tail fin have also been described as ”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 Boeing 737, giving a shallow 'V' shape when seen from the front. Adds lateral stability.
- **Anhedral** - the tips are lower than the root, as on the Ilyushin Il-76; the opposite of dihedral. Used to reduce stability where some other feature results in too much stability thus making manoeuvering difficult. A popular choice in modern fighters since the configuration makes them more agile in battle. In level flight, computers assist the pilot in preventing the plane from teetering about.

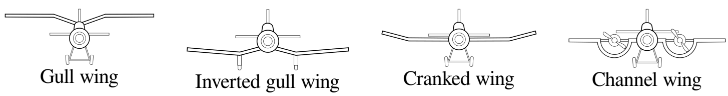


Some biplanes had different angles of dihedral/anhedral on different wings; e.g. the first Short Sporting Type, known as the *Shrimp*, had a flat upper wing and a slight dihedral on the lower wing.

The dihedral angle may vary along the span.

- **Gull wing** - sharp dihedral on the wing root section, little or none on the main section, as on the Göppingen Gö 3 glider. Typically done to raise wing-mounted engines higher above the ground or water.
- **Inverted gull** - anhedral on the root section, dihedral on the main section. The opposite of a gull wing. Typically done to reduce the length and weight of wing-mounted undercarriage legs. An example of the inverted gull wing is the F4U Corsair.
- **Cranked** - tip section dihedral differs from the main section, as in the F-4 Phantom II. (Note that the term "cranked" varies in usage[29][30][31][32]. Here, it is used to help clarify the relationship between changes of dihedral nearer the wing tip vs. nearer the wing root. See also **Cranked arrow** planform.)

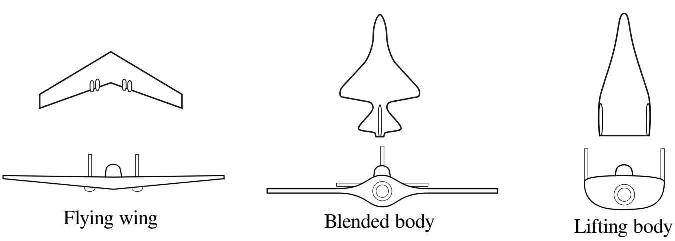
- The **channel wing** is an unusual variation where the frontal profile follows the arc of a propeller down, around and back up, before continuing outwards in a conventional manner. Since 1942 several examples have flown, notably the Custer Channel Wing aircraft, but none has entered production.
- **Ruptured duck** - main wing section has slight dihedral, with a large tip section having pronounced anhedral and reduced or negative angle of attack. Typically done to improve stability of tailless aircraft. Examples include the Dunne monoplane and Northrop XP-56 Black Bullet.



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 tail empennage (although fins and small pods, blisters, etc. may be present).
- **Blended body** or **blended wing-body** - smooth transition between wing and fuselage, with no hard dividing line. Reduces wetted area and hence, if done correctly, aerodynamic drag. The McDonnell XP-67 Bat was also designed to maintain the aerofoil section across the entire aircraft profile.
- **Lifting body** - the aircraft has no significant wings, and relies on the fuselage to provide aerodynamic lift.



Some proposed designs, typically a sharply-swept delta planform having a deep centre section tapering to a thin outer section, fall across these categories and may be interpreted in different ways, for example as a lifting body with a broad fuselage, or as a low-aspect-ratio flying wing with a deep center chord.

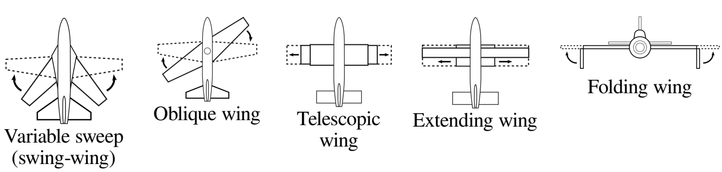
Variable geometry

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.

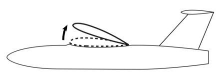
Variable planform

- **Swing-wing** - also called ”variable sweep 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 1950’s.
- **Oblique wing** - a single full-span wing pivots about its mid point, as used on the NASA AD-1, so that one side sweeps back and the other side sweeps forward.
- **Telescopic wing** - the outer section of wing telescopes over the inner section of wing, varying span, aspect ratio and wing area, as used on the FS-29 TF glider[33]. Another variant was used on the Pfitzner Flyer (1910): The telescopic extensions were used to create a lift differential, thus avoiding infringement of the Wright Brothers’ wing-warping patents. Both extensions were moved left or right simultaneously, lengthening one wing while shortening the other.
- **Extending 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.
- **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, to increase lift and reduce drag through generation of ’compression lift’ during supersonic flight. (Many aircraft have folding wings that can only be folded for storage on the ground).



Variable chord

- **Variable incidence** - the wing plane can tilt upwards or downwards relative to the fuselage. Used on the Vought F-8 Crusader to tilt the leading edge up by a small amount for takeoff, to give STOL performance. If powered proprotors are fitted to the wing to allow vertical takeoff or STOVL performance, merges into the powered lift category.
- **Variable camber** - the leading and trailing edge sections of the wing pivot and/or extend to increase the effective camber and/or area of the wing. This increases lift at low angles of attack, delays stalling at high angles of attack, and enhances manoeuverability.



Variable incidence wing

Variable camber aerofoil

Polymoprphism

A **polymorphic** wing is able to change the number of planes in flight. The Nikitin-Shevchenko IS ”folding fighter” protoypes were able to morph between biplane and monoplane configurations.

Minor aerodynamic surfaces

Additional minor aerodynamic surfaces may form part of the overall wing configuration:

- **Winglet** - a small vertical fin at the wingtip, usually turned upwards. Reduces the size of vortices shed by the wingtip, and hence also tip drag.
- **Chine** - narrow extension to the leading edge wing root, extending far along the forward fuselage. As well as improving low speed (high angle of attack) handling, provides extra lift at 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 and Tupolev Tu-144.

Minor surface features

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

- **Leading edge extensions** of various kinds.
- **Slot** - a spanwise gap behind the leading edge section, which forms a small aerofoil or *slat* extending along the leading edge of the wing. Air flowing through the slot is deflected by the slat to flow over the wing, allowing the aircraft to fly at lower air speeds. Leading edge slats are moveable extensions which open and close the slot.
- **Flap** - trailing-edge (or leading-edge) wing section which may be angled downwards for low-speed flight, especially when landing. Some types also extend backwards to increase wing area.
- **Wing fence** - a thin surface extending along the wing chord and for a short distance vertically. Used to control spanwise airflow over the wing.
- **Vortex generator** - small triangular protrusion on the upper leading wing surface; usually, several are spaced along the span of the wing. The vortices are used to re-energise the boundary layer and reduce drag.
- **Anti-shock body** - a streamlined ”pod” shaped body added to the leading or trailing edge of an aerodynamic surface, to delay the onset of shock stall and reduce transonic wave drag. Examples include the *Küchemann carrots* on the wing trailing edge of the Handley Page Victor B.2, and the tail fairing on the Hawker Sea Hawk.
- **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.

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Lift-to-drag ratio

In aerodynamics, the **lift-to-drag ratio**, or **L/D ratio** ("ell-over-dee"), is the amount of lift generated by a wing or vehicle, divided by the 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, climb performance, and glide 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.

Drag

Induced drag is caused by the generation of lift by the wing. Lift generated by a wing is perpendicular to the wing, but since wings typically fly at some small angle of attack, this means that a component of the force is directed to the rear. The rearward component of this force is seen as drag. 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 L/D graph, the left side of the U.

Profile drag is caused by air hitting the wing, and other parts of the aircraft. This form of drag, also known as wind resistance, 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 L/D graph's U shape. Profile drag is lowered primarily by reducing cross section and streamlining.

It is the lowest point of the graph, the point where the combined drag is at its lowest, that the wing or aircraft is performing at its best L/D. For this reason 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.

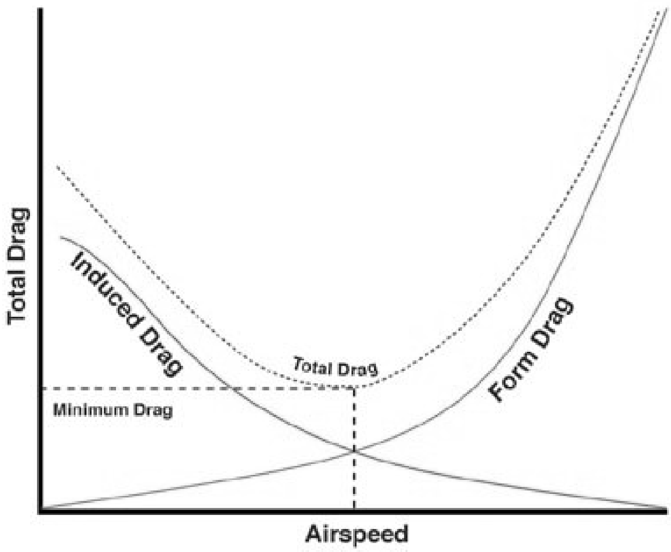


Figure 17: *The drag curve*

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 altitude lost divided by distance traveled. 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, gliders are often loaded with water ballast to increase the airspeed (allowing better penetration against a headwind). As noted below, to first order the L/D is not dependent on speed, although the faster speed means the airplane will fly at higher Reynold's number.

Theory

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

$$(L/D)_{max} = \frac{1}{2}\sqrt{\frac{\pi A \epsilon}{C_{D,0}}}^{34},$$

where A is the aspect ratio, ϵ is the aircraft's efficiency factor, and $C_{D,0}$ is the zero-lift drag coefficient.

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:[35]

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

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

Examples

The following table includes some representative L/D ratios.

Flight article	Scenario	L/D ratio
Virgin Atlantic GlobalFlyer	Cruise	37[36]
Lockheed U-2	Cruise	~28
Rutan Voyager	Cruise[37]	27
Albatross		20[38]
Boeing 747	Cruise	17
Common tern		12[38]
Herring gull		10[38]
Concorde	M2 Cruise	7.14
Cessna 150	Cruise	7
Concorde	Approach	4.35
House sparrow		4[38]

In gliding flight, the L/D ratios are equal to the glide ratio.

Flight article	Scenario	L/D ratio / Glide ratio
Modern Sailplane	gliding	~70
Hang glider		15
Gimli glider	Boeing 767-200 with fuel exhaustion	~12
Paraglider	high performance model	11
Powered parachute	Rectangular/elliptical parachute	3.6/5.6
Space Shuttle	Approach	4.5[39]
Wingsuit	Gliding	2.5
Northern flying squirrel	Gliding	1.98
Space Shuttle	Hypersonic	1[39]
Apollo CM	Reentry	0.368[40]

See also

- 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
- Range (aircraft) range depends on the lift/drag ratio
- Inductrack maglev has a higher lift/drag ratio than aircraft at sufficient speeds
- Gravity drag rockets can have an effective lift to drag ratio while maintaining altitude

Thrust

Thrust is a reaction force described quantitatively by Newton's second and third laws. When a system expels or accelerates mass in one direction the accelerated mass will cause a proportional but opposite force on that system.

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 turbine pushing air from the back of a jet engine, or by ejecting hot gases from a rocket engine. The forward thrust is proportional to the mass of the airstream multiplied by the velocity of the airstream. Reverse thrust can be generated to aid braking after landing by

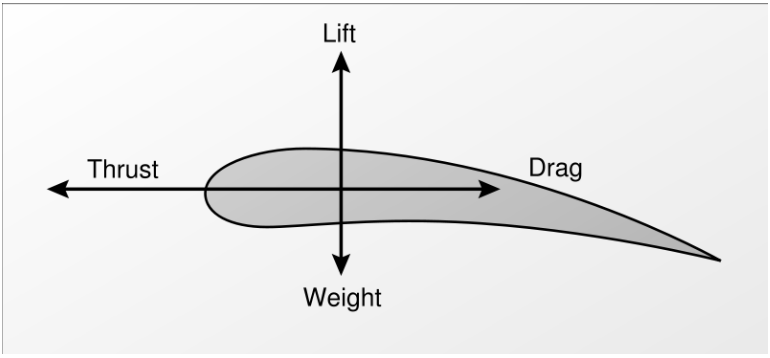


Figure 18: *Forces on an aerofoil cross section*

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 some of this thrust fore and aft to control forward speed.

Birds normally achieve thrust during flight by flapping their wings.

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:

$$\mathbf{T} = \frac{dm}{dt}\mathbf{v}$$

where:

- $\mathbf{T}$ is the thrust generated (force)
- $\frac{dm}{dt}$ is the rate of change of mass with respect to time (mass flow rate of exhaust);
- $\mathbf{v}$ is the speed of the exhaust gases measured relative to the rocket.

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

Each of the three Space shuttle main engines can produce a thrust of 1.8 MN, and each of its two Solid Rocket Boosters 14.7 MN, together 29.4 MN. Compare with the mass at lift-off of 2,040,000 kg, hence a weight of 20 MN.

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.[41] 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).

Thrust to power

Thrust at zero speed is zero power. Power requires work to be done, so zero velocity indicates zero work and zero power. Therefore the power of a rocket or aircraft engine is thrust times forward speed.

power (watts) = thrust (newtons) x speed (metres/second)

power (horsepower) = thrust (lbf) x speed (feet/second) / 550

power (horsepower) = thrust (lbf) x speed (feet/minute) / 33000.

For example: the Messerschmitt Me 262 with 3,960 pounds of thrust at 559 mph equates to 5,903 horsepower.

Thrust to power

A very common question is how to compare 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.

Now, a jet engine has no propeller – it pushes the aircraft by moving hot air behind it. One could imagine that a jet engine could be rated by how much power it transmits to the hot air on the exhaust (this depends basically on the throttle setting), but that quantity is not useful for anything (other than finding out how hot and fast the air is). The useful measurement is how much power the jet engine transmits to the aircraft through its thrust force. This is the propulsive power of the jet engine (do not confuse that with all the other power transfers the engine has – to create sound, to vibrate, to push hot air, etc.).

So let’s find out the propulsive power of a jet engine from its thrust. 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[42]:

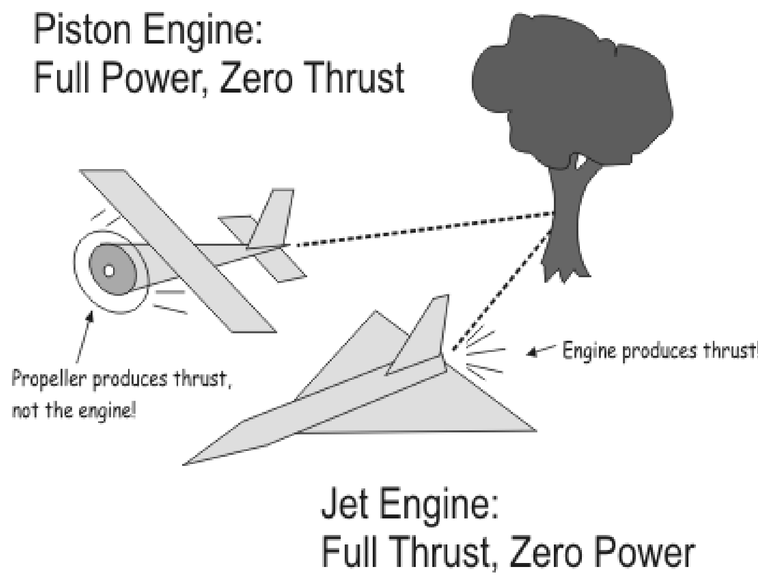


Figure 19: *Two aircraft tied to a tree*

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

In case of a rocket or a jet aircraft, the force is exactly the thrust 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:[43]

$$\mathbf{P} = \mathbf{T}v$$

This formula looks very surprising, but it is correct: the *propulsive power* (or *power available*[44]) 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 is tied to a very strong chain to a tree, then the jet engine produces no propulsive power. It certainly transfers a lot of power around, but all that is wasted. 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

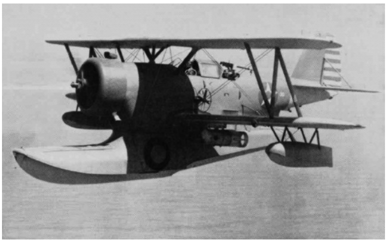
This shows why one cannot compare the rated power of a piston engine with the propulsive power of a jet engine – these are different quantities (even if the name ”power” is the same). There isn't any useful power measurement in a jet engine that compares directly to a piston engine rated power.

See also

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

Aircrafts

J2F Duck

J2F Duck	
	
Grumman J2F-5 Duck in early 1942	
Role	Utility amphibian
Manufacturer	Grumman
First flight	1936
Introduced	1936
Primary users	United States Navy United States Coast Guard
Number built	632
Developed from	JF Duck

The **Grumman J2F Duck** was an American single-engine amphibious biplane.

Development

The **G-15** was an improved version of the earlier JF Duck, differing by having a longer float.[45] It was ordered by the United States Navy as the **J2F Duck**.

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 US Navy on the same day. The J2F-2 had a Wright Cyclone engine but boosted to 790 hp (589 kW). 20 J2F-3 variants were built in 1939 for use as executive transports for the Navy with plush interiors. 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 US Coast Guard.

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. It had strut-mounted stabiliser 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.[46] Like the F4F Wildcat, its narrow-tracked landing gear was hand-cranked.

Operational service

The aircraft was used by both the United States Navy and United States Coast Guard, with the latter using them as utility aircraft for missions including mapping, rescue work, photography, and a target training.

Variants

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.

Figure 20: *J2F-3 at NAS Jacksonville in 1940*

Figure 21: *OA-12 of the USAAF*

J2F-2A
As J2F-2 with minor changes for use in the United States Virgin Island, 9 built.

J2F-3
J2F-2 but powered by a 850 hp R-1802-26 engine, 20 built.

J2F-4
J2F-2 but powered by a 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 1,050 hp R-1820-64 engines in a long-chord cowl, fitted with underwing bomb-racks and provision for towing-gear, 330 built.

OA-12
Air/Sea Rescue conversion for the United States Army Air Force.

Operators

Argentina[47]

Colombia[48]

Mexico

- Mexican Navy operated a small number of ex-US Navy J2F-6 post World War II.[49]

United States

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

Figure 22: *Columbia-built J2F-6 Duck in U.S. Marine Corps markings displayed at Valle, Arizona, in October 2005*

Specifications (J2F-6)

Data from Jane's Fighting Aircraft of World War II[50]

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 ft² (38 m²)
- **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 for observer
- 650 lb (295 kg) bombs or depth charges

Popular culture

A J2F Duck was used in the 1971 film Murphy's War which includes a spectacular 3 minute rough water take-off sequence and numerous flying and acrobatic sequences.

See also

Related development

- JF Duck

Comparable aircraft

- Loening OL

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Notes

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ShinMaywa US-1A

PS-1 / US-1A	
	
A US-1A at Kanoya Museum, Japan	
Role	Air-sea rescue amphibian
Manufacturer	Shin Meiwa
First flight	5 October 1967 (PX-S)
Introduction	1971 (PS-1)
Primary user	Japan Maritime Self Defence Force
Produced	19
Variants	ShinMaywa US-2

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. The PS-1 was a flying boat which carried its own beaching gear on board, while the US-1A is a true amphibian.

Design and development

In 1960, Shin Meiwa demonstrated a prototype flying boat, the UF-XS, that featured a novel boundary layer control system to provide enhanced STOL performance. The company also built upon its wartime experience (as Kawanishi) to refine the Grumman Albatross hull that the aircraft was based on. In 1966, the JMSDF awarded the company a contract to further develop these ideas into an 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.

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, and directing the exhaust 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 until 1989 when they were phased out and replaced with 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 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.

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 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, around 2007 and entered service as the ShinMaywa US-2.

Operators

- **Japan**
  Japan Maritime Self Defence Force

Specifications (US-1A)

Data from Jane's All The World's Aircraft 1988-89[51]

General characteristics

- **Crew:** nine (pilot, co-pilot, flight engineer, navigator, radio operator, radar operator, two observers)
- **Capacity:** 20 survivors or 12 stretchers
- **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 m^2 (1,462 ft^2)
- **Empty weight:** 23,300 kg (51,367 lb)
- **Max takeoff weight:** 45,000 kg[52] (99,200 lb)

- **Powerplant:** 4× Ishikawajima-Harima/General Electric T64-IHI-10J turboprops, 2,605 kW (3,493 ehp) each
- *plus* 1× General Electric T58 gas tubine, 1,104 kW (1,360 shp) driving boundary layer contol system

Performance

- **Maximum speed:** 511 km/h (276 knots, 318 mph)
- **Cruise speed:** 426 km/hr (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)

Avionics

- Ocean search radar

See also

Related development

- ShinMaywa US-2

Comparable aircraft

- Harbin SH-5
- Beriev Be-12
- Lockheed P5M Marlin

Related lists

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

References

- Taylor, John W.R. (editor). *Jane's All The World's Aircraft 1988-89.* Coulsdon, UK: Jane's Defence Data, 1988. ISBN 0 7106-0867-5.

External links

- ShinMaywa aircraft page[53]
- Giant Amphibian - Japan has one godzilla of a seaplane -[54] Air & Space/ Smithsonian magazine
- The Shin Meiwa PS-1 / US-1 & Harbin SH-5 Flying Boats[55] www.vectorsite.net

Lake Aircraft

Type	Private
Industry	Aerospace
Founded	1959
Headquarters	Kissimmee, Florida New Hampshire
Key people	Armand Rivard
Products	parts for LA-4 aircraft
Employees	6
Website	lakeamphib.com[56]

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

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

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

History

The first plane produced was the Colonial Skimmer. It was derived from an original design produced by Dave Thurston in 1946 when he was with Grumman Aircraft. Grumman never produced the design, but Thurston formed Colonial Aircraft 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 FAA 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 intends to sell the company and retire. The company had previously been offered for

Figure 23: *Lake LA-4-200 Buccaneer*

Figure 24: *Lake LA-4-200 Buccaneer*

Figure 25: *Lake LA-4-250 Seawolf*

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.[57]

EVOLUTION OF LAKE AMPHIBIAN Aircraft

YEARS PRODUCED	MODEL	seats	HORSE-POWER	MAX CRUISE Speed	PAYLOAD W/MAIN FUEL FULL
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 LA-250	6	250	132 knots	800 lb
1987-2005	LAKE LA-270T	6	270	155 knots	720 lb
2006	SEAFURY		250 & 270		

External links

Official website[56]

PBY Catalina

PBY Catalina	
	
PBY-5 landing at Naval Air Station Jacksonville.	
Role	Flying boat
Manufacturer	Consolidated Aircraft
Designed by	Isaac M. Laddon
First flight	March 28, 1935
Introduced	October 1936, United States Navy
Retired	January 1957, United States Navy Reserve
Primary users	United States Navy United States Army Air Forces Royal Air Force Royal Canadian Air Force
Produced	1936-1945
Number built	4,051 (estimated)
Unit cost	US$90,000 (as of 1935)
Variants	Bird Innovator

The **Consolidated PBY Catalina** was an American flying boat of the 1930s and 1940s produced by Consolidated Aircraft. It was one of the most widely used multi-role aircraft of World War II. PBYs served with every branch of the US military and in the air forces and navies of many other nations. In the United States Army Air Forces and later in the USAF their designation was the **OA-10**, while Canadian-built PBYs were known as the **Canso**.

During World War II, PBYs were used in anti-submarine warfare, patrol bombing, convoy escorts, search and rescue missions (especially air-sea rescue), and cargo transport. The PBY was the most successful aircraft of its kind; no other flying boat was produced in greater numbers. The last active military PBYs were not retired from service until the 1980s. Even today, over seventy years after its first flight, the aircraft continues to fly as an airtanker in aerial firefighting operations all over the world.

The initialism of ”PBY” was determined in accordance with the U.S. Navy aircraft designation system of 1922; *PB* representing ”Patrol Bomber” and *Y* being the code used for the aircraft's manufacturer, Consolidated Aircraft.

Development

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 compromise 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, PBYs distinguished themselves in World War II as exceptionally reliable. Allied armed forces used them successfully in a wide variety of roles that the aircraft was never intended for. They are remembered by many veterans of the war for their role in rescuing downed airmen, in which they saved the lives of thousands of aircrew downed over water. PBY airmen called their aircraft the ”cat” on combat missions and ”Dumbo” in air-sea rescue service.[58]

Prototyping

As American dominance in the Pacific Ocean began to face competition from Japan in the 1930s, the U.S. Navy contracted Consolidated Aircraft and Douglas Aircraft Corporation in October 1933 to build competing prototypes for a patrol flying boat.[59] 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 US Navy had adopted the Consolidated P2Y and Martin P3M models for this role in 1931, but both aircraft proved to be underpowered and hampered by short ranges and low maximum payloads.

Figure 26: *PBY riding at sea anchor.*

Consolidated and Douglas both delivered single prototypes of their 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 plane.

Consolidated's XP3Y-1 design (company *Model 28*) was revolutionary in a number of ways. The aircraft had a parasol wing with internal bracing that allowed the wing to be a virtual cantilever, except for two small streamlined struts on each side. Stabilizing floats, retractable in flight to form streamlined wingtips, were another aerodynamic innovation, a feature 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.

The prototype was powered by two 825 hp (615 kW) Pratt & Whitney R-1830-54 Twin Wasp engines mounted on the wing's leading edges. Armament comprised four 0.30 in (7.62 mm) Browning machineguns and up to 2,000 lb (907 kg) of bombs.

Figure 27: *PBY waist gunner mounting port side gun blister.*

The XP3Y-1 had its maiden flight on 28 March 1935, after which it was transferred to the US Navy for service trials. The XP3Y-1 soon proved to have significant performance improvements over current 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 (671 kW) R-1830-64 engines. For the redesignated XPBY-1, Consolidated introduced redesigned vertical tail surfaces. The XPBY-1 had its maiden flight on 19 May 1936, during which a record non-stop distance flight of 3,443 miles (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 PBY design was gradually developed further and successive models introduced.

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.	684
PBY-5A	October 1941 - January 1945 Hydraulically-actuated, retractable tricycle landing gear 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.[60]	802
PBY-6A	January 1945 - May 1945 Incorporated changes from PBN-1,[61] 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 U.S. Army Air Forces, the U.S. 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.[62] 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 pound (908 kg) higher gross take-off weight. An auxiliary power unit was installed, along with a modernized electrical system, and the weapons were upgraded with continuous-feed mechanisms.[62]

138 of the 156 PBN-1s that were produced served with the Soviet Navy. The remaining 18 of them were assigned to training units at NAS Whidbey Island

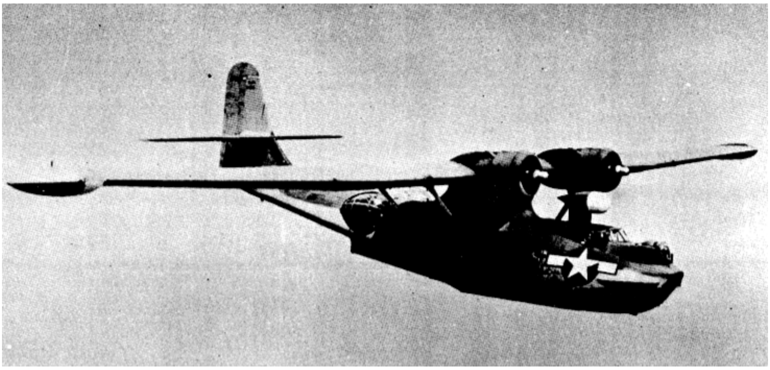


Figure 28: *A radar-equipped PBY-6A Catalina in flight.*

and the Naval Air Facility in Newport, Rhode Island.[63] Later, improvements found in the PBN-1 – notably, the larger tail – were incorporated into the amphibious PBY-6A.

Operational history

Roles in World War II

The final construction figure is estimated at around 4,000 aircraft, and these were deployed in practically all of the operational theatres of World War II. The PBY served with distinction and played a prominent and invaluable role in the war 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 two available aircraft with the range necessary. As a result, they were used in almost every possible military role until a new generation of aircraft became available.

A Catalina of No. 205 Squadron RAF was also involved in a dogfight with a Mitsubishi G3M *Nell* bomber of Mihoro Air Group near the Anambas Islands on 25 December 1941, in which the Catalina was shot down.[64]

Anti-submarine warfare

PBYs were the most extensively used ASW aircraft in both the Atlantic and Pacific Theaters of the Second World War, 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: John Cruickshank of

Figure 29: *A PBY-5A of VP-61 over the Aleutian Islands in 1943.*

the RAF, in 1944, against the *U-347* and in the same year Flight Lt. David Hornell of the RCAF (posthumously) against the *U-1225*. Catalinas destroyed 40 U-boats in all, but they suffered losses of their own.

Maritime patrol

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

- A Coastal Command Catalina located the German battleship *Bismarck* on May 26, 1941 while she tried to evade Royal Navy forces.[65]
- A flight of Catalinas spotted the Japanese fleet approaching Midway Island, beginning the Battle of Midway.[66]
- An RCAF Canso flown by Squadron Leader L.J. Birchall foiled Japanese plans to destroy the Royal Navy's Indian Ocean fleet on April 4, 1942 when it detected the Japanese carrier fleet approaching Ceylon (Sri Lanka).[67]

Night attack and naval interdiction

Several squadrons of PBY-5As and -6As in the Pacific theater were specially modified to operate as night convoy raiders. Outfitted with state-of-the-art magnetic anomaly detection gear and painted flat black, these ”Black Cats” attacked Japanese supply convoys at night. Catalinas were surprisingly successful in this highly unorthodox role.[68] Between August 1943 and January 1944, Black Cat squadrons had sunk 112,700 tons of merchant shipping, damaged 47,000 tons, and damaged 10 Japanese warships.

The Royal Australian Air Force (RAAF) also operated Catalinas as night raiders, with four squadrons Nos. 11, 20, 42, and 43 mounting mine-laying operations from 23 April 1943 until July 1945 in the southwest Pacific deep into Japanese-held waters, that bottled up ports and shipping routes and kept ships in the deeper waters to become targets for US submarines; they tied up the major strategic ports such as Balikpapan that shipped 80% of Japanese oil supplies. In late 1944, their precision mining sometimes exceeded 20 hours in duration from as low as 200 feet in the hours of darkness. One included the bottling up the Japanese fleet in Manila Bay planned to assist General MacArthur’s landing at Mindoro in the Philippines. They also operated out of Jinamoc in Leyte Gulf, and mined ports on the Chinese coast from Hong Kong as far north as Wenchow. They were the only non-American heavy bombers squadrons operating north of Morotai in 1945. The RAAF Catalinas regularly mounted nuisance night bombing raids on Japanese bases, they earned the motto of ’The first and the Furthest’ as a testimony to their design and endurance. These raids included the major base at Rabaul. RAAF aircrews developed ’terror bombs’, essentially empty beer bottles with razor blades inserted into the necks, these produced high pitched screams as they fell and kept Japanese soldiers awake and in fear of their life.[69]

Search and rescue

PBYs were employed by every branch of the US military as rescue aircraft. A PBY piloted by Lt. Cmdr. Adrian Marks (USN) rescued 56 sailors from the USS *Indianapolis* after the ship was sunk during World War II. PBYs continued to function in this capacity for decades after the end of the war.

Early commercial use

PBYs were also used for commercial air travel. 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. Qantas offered non-stop service between Perth and Colombo, a distance of 3,592 nm (5,652 km). As the PBY typically cruised at 110 knots, this took from 28–32 hours and was called the ”flight of the double sunrise”, since the

Figure 30: *Search and Rescue OA-10 at USAF Museum*

passengers saw two sunrises during their non-stop journey. The flight was made with radio silence (because of the possibility of Japanese attack) and had a maximum payload of 1000 lbs or three passengers plus 65 kg of armed forces and diplomatic mail.[70]

Post-World War II employment

An Australian PBY made the first trans-Pacific flight across the South Pacific between Australia and Chile in 1946, making numerous stops at islands along the way for refueling, meals, and overnight sleep of its crew.

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 ones 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.[59] The PBY subsequently equipped the world's smaller armed services, in fairly substantial numbers, into the late 1960s.

The U.S. Air Force's Strategic Air Command had PBYs (designated OA-10s) in service as scouting airplanes 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

Figure 31: *Civilian PBY Catalina, modified for aerial firefighting, arrives at the Seaplane Base, NAS Whidbey Island, Oak Harbor, Washington, 18 September 2009*

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 in well-maintained condition until 1982. Catalinas were convenient for supplying military detachments scattered among the Amazon waterways. They reached places where only long-range transport helicopters would dare to go. 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.[71]

Jacques-Yves Cousteau used a PBY-6A (N101CS) as part of his diving expeditions. His second son, Philippe, was killed while attempting a water landing in the Tagus river near Lisbon, Portugal, June 28, 1979. His plane had just been repaired when he took it out for a flight. As he landed, one of the plane's propellers separated, cut through the cockpit and killed the younger Cousteau.

Of the few dozen remaining airworthy Catalinas, the majority of them are in use today as aerial firefighting planes.

China Airlines, the official airline of the Republic of China (Taiwan) was founded with two PBY amphibious flying boats.

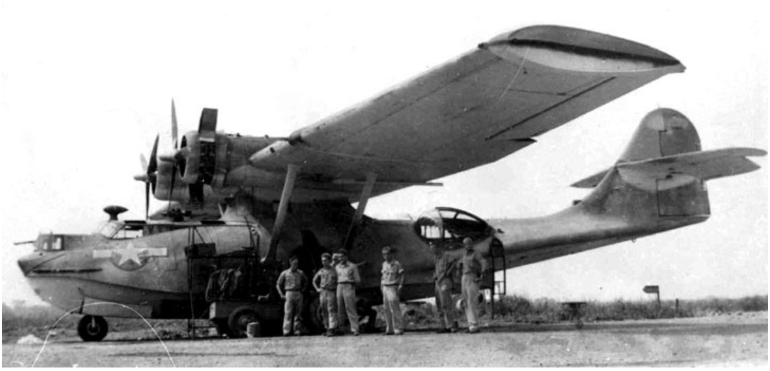


Figure 32: *A US Army Air Forces OA-10 and her crew.*

Catalina affair

The Catalina Affair is the name given to a Cold War incident in which a Swedish Air Force PBY Catalina was shot down by Soviet fighters over the Baltic Sea in June 1952 while investigating the earlier crash of a Swedish Douglas DC-3.

Variants

XP3Y-1
: Prototype Model 28 flying boat later re-designated XBPY-1, one built (USN Bureau No. 9459). Later fitted with a 48-foot diameter ring to sweep magnetic sea mines. A 550-HP Ranger engine drove a generator to produce a magnetic field.[72]

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

PBY-1 (Model 28-1)
: Initial production variant with two 900hp 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 1000hp R-1830-66 engines, 66 built.

Figure 33: *Catalina Mk Is of British No. 205 Squadron RAF undergoing servicing in their hangar at RAF Seletar, Singapore.*

PBY-4 (Model 28-4)
Powered by two 1050hp R-1830-72 engines, 33 built (including one initial as a XBPY-4 which later became the XBPY-5A).

PBY-5 (Model 28-5)
Either two 1200hp R-1830-82 or -92 engines and provision for extra fuel tanks, 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-5
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 1200hp 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 Corps, the RAF (as the Catalina IIIA) and one to the United States Coast Guard.

PBY-6A
Amphibious version with two 1200hp 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.

Figure 34: *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*

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

PB2B-1
Boeing Canada built version of the PBY-5, 165 built most supplied to the RAF and RNZAF as the Catalina IVB.

PB2B-2
Boeing Canada built version of the PBY-5 but having a taller fin of the PBN-1, 67 built most supplied to the RAF as the Catalina VI.

PBN-1

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

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.

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

OA-10A

USAAF designation of Canadian Vickers-built version of the PBV-1, 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.

Catalina I

Direct purchase aircraft for the Royal Air Force, same as the PBY-5 with six 0.303in guns (one in bow, four in waist blisters and one aft of the hull step) and powered by two 1200hp 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 US Navy PBY-5As used by the RAF on the North Atlantic Ferry Service, 12 aircraft.

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.

GST

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

Survivors

Figure 35: *Restored Catalina, displayed in IWM Duxford*

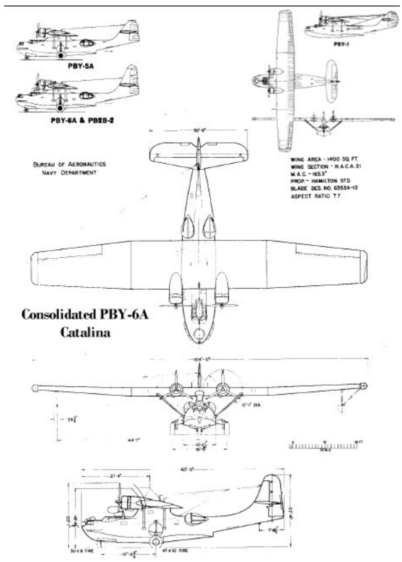
Specifications (PBY-5A)

Data from Encyclopedia of World Air Power,[73] Jane's Fighting Aircraft of World War II,[61] Handbook of Erection and Maintenance Instructions for Navy Model PBY-5 and PBY-5A Airplanes[74] *and* Quest for Performance[75]

General characteristics

- **Crew:** 8 — pilot, co-pilot, bow turret gunner, flight mechanic, radioman, navigator and two waist gunners
- **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)
- **Powerplant:** 2× Pratt & Whitney R-1830-92 Twin Wasp radial engines, 1,200 hp (895 kW each) each
  - **Zero-lift drag coefficient:** 0.0309
- **Drag area:** 43.26 ft² (4.02 m²)
- **Aspect ratio:** 7.73

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

- PB2Y Coronado

Comparable aircraft

- Dornier Do 24

- Grumman Albatross
- Kawanishi H6K
- Short Sunderland
- Harbin PS-5
- Canadair CL-215

Related lists

- List of PBY Catalina operators
- List of flying boats

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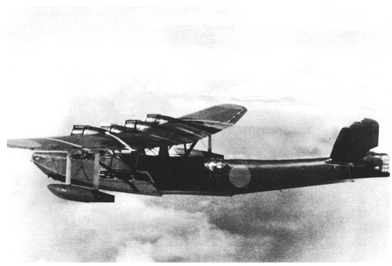
External links

- Picture of PH-PBY, a Consolidated PBY-5A Catalina[76]
- Photos of EC-FMC, a Consolidated PBY-5A Catalina[77] located in Ocaña, Spain
- PBY Catalina Foundation[78]
- PBY Catalina International Association[79]
- PBY.com[80]
- PBY Memorial Association[81]
- Second Emergency Rescue Squadron Memorial Page[82]
- Lt. Nathan Gordon, PBY pilot and Medal of Honor recipient[83]
- Catalina Group of New Zealand[84]
- Black Cats: U.S. Navy PBY Catalinas fighting in the Pacific during WWII[85]
- (in French) *Naissance d'un PBY 6A Catalina "Calypso"* (Birth of a PBY 6A Catalina named *Calypso*[86]
- The Catalina Society (Plane Sailing) UK[87]
- Catalina images[88]

Kawanishi H6K

H6K	
	
Role	Patrol flying boat
Manufacturer	Kawanishi
First flight	14 July 1936
Introduced	January 1938
Retired	1945 (Japan) 1948 (Indonesia)
Primary user	IJN Air Service
Number built	215

The **Kawanishi H6K** was an Imperial Japanese Navy flying boat 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).

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 had 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.[89] 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.

Operational history

H6Ks were deployed from 1938 onwards, first seeing service in the Sino-Japanese War and were in widespread use by the time full-scale the Pacific War erupted, in 1942. During the war, four *kokutai* operated 66 H6Ks.

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 was 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 fighter. 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

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 built.

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, 10 (100+? 124 if other numbers are all correct) built.

H6K4-L
Transport version of H6K4, similar to H6K2-L, but with Mitsubishi Kinsei 46 engines, including two modifications of the H6K4, 20 built.

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

Indonesia

- Ex-Japanese Aircraft was operated by Indonesian guerilla forces.

Japan

- Imperial Japanese Navy Air Service
- Imperial Japanese Airways

  Used airway to Timor and Koror.

Specifications (H6K4)

Data from[9091]

General characteristics

- **Crew:** nine
- **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 m² (1,830 ft²)
- **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:** 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/m² (20 lb/ft²)
- **Power/mass:** 0.17 kW/kg (0.11 hp/lb)

Armament

- 1 × 7.7 mm (0.3 in) Type 97 machine gun in nose
- 1 × Type 97 machine gun in spine
- 2 × Type 97 machine guns in waist blisters
- 1 × 20 mm Type 99 cannon in tail turret
- 2 × 800 kg (1764 lb) torpedoes **or** 1000 kg (2205 lb) of bombs

See also

Comparable aircraft

- Dornier Do 24
- PBY Catalina

Related lists

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

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Index