Aircraft Configurations

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Push-Pull Configuration and Pusher Configuration

Push-pull configuration

Cessna Skymaster push-pull aircraft.

An aircraft constructed with a **push-pull configuration** has a mixture of forward-mounted (tractor) propellers and backward-mounted (pusher) propellers.

Historical

An early example of a "push-pull" aircraft was the Caproni Ca.1 which had two wing-mounted tractor propellers and one centre-mounted pusher propeller.

Claudius Dornier was the first aviation designer to heartily embrace the concept for production aircraft, as many of his flying boats used variations of the tandem "push-pull" engine layout :

- Dornier Wal (1922)

- Dornier Do X (1929)
- Dornier Do 18 (1935)
- Dornier Do 26 (1938)

Design Benefits

While pure pushers decreased in popularity during the First World War, the push-pull configuration has continued to be used. The advantage it provides is the ability to mount two propellers on the aircraft's centreline, thereby avoiding the increased drag that comes with twin wing-mounted engines. It is also easier to fly if one of the two engines fails, as the thrust provided by the remaining engine is symmetrical in the horizontal plane. In contrast, a conventional twin-engine aircraft will yaw in the direction of the failed engine and become uncontrollable below a certain airspeed, known as Vmc, which varies with the type of aircraft. Conventional push-pull designs, such as the Cessna Skymaster and Adam A500, have the engines mounted on the nacelle so that the aircraft's tail, suspended via twin booms, is behind the pusher propeller. In contrast, both the World War II-era Dornier Do 335 and the early 1960s-designed French Moynet M 360 Jupiter experimental private plane had their pusher propeller at the rear of their fuselage.

Piloting

Pilots in the United States who obtain a multi-engine rating in an aircraft with this push-pull, or "centerline thrust," configuration are restricted to flying centerline-thrust aircraft; pilots who obtain a multi-engine rating in conventional twin-engine aircraft do not have a similar limitation with regard to centerline-thrust aircraft.

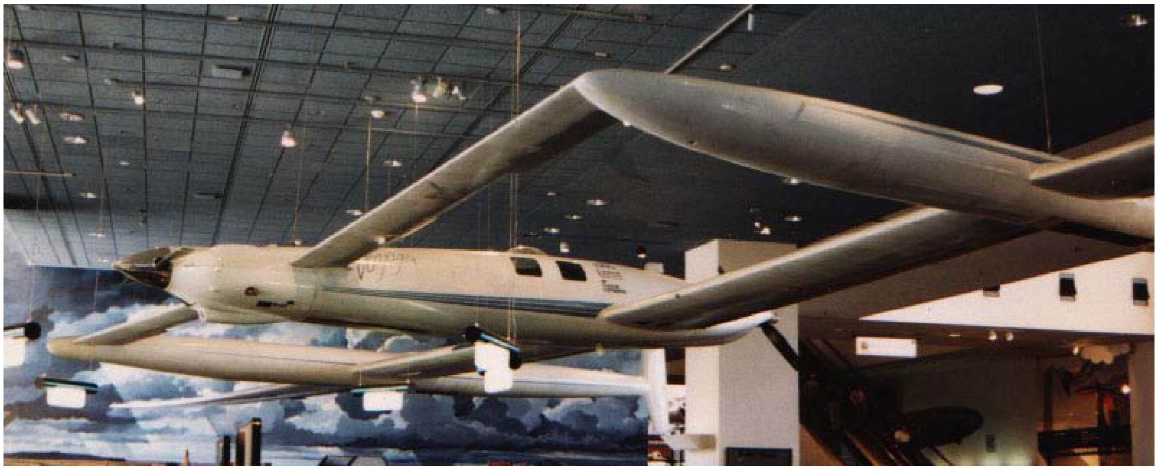
Military Application

Despite its distinct advantages push-pull configurations are rare in military aircraft. This is mainly due to the increased risk to the pilot in the case of a crash-landing or the need to parachute from the plane. In a crash the rear engine threatens to kill the pilot by crushing him between itself and the forward engine; in the case of bailing-out the pilot is in danger of hitting the rear propeller.

Dornier Seawings Seastar

Rutan Model 40 Defiant

Adam A500



Rutan Model 76 Voyager

Pusher configuration

Rutan Long-EZ pusher configuration home-built aircraft.

An aircraft constructed with a **pusher configuration** has the engine(s) mounted forward of "rearward facing" propeller(s), so that the airframe is propelled by force applied in compression from the rear rather than in tension from the front.

Sometimes the propeller is situated at the rear of the fuselage, but it is more commonly mounted behind the crew compartment, with one or two booms supporting the tail. The engine and propeller can also be mounted on the wing – in which case it is typically located behind the trailing edge rather than forward of the leading edge.

History

Quad City Challenger – a typical pusher

Many early aircraft were **pushers**, including the Wright Flyer, and the Curtiss biplane used by Eugene Ely for the first ship take-off on January 18, 1911.

In the early years of the First World War pushers were favoured by the British and French because they enabled a forward-firing gun to be used without being obstructed by the arc of the propeller. Such aircraft included the Vickers F.B.5 Gunbus, the Royal Aircraft Factory F.E.2 and the Airco DH.2. (Germany did not have the same requirement due to the early development of Fokker's interrupter gear.)

Single-engine pushers usually had the engine mounted on the centreline at the rear of the aircraft's nacelle. Such aircraft had no true fuselage, the tail section being mounted on a framework that cleared the propeller.

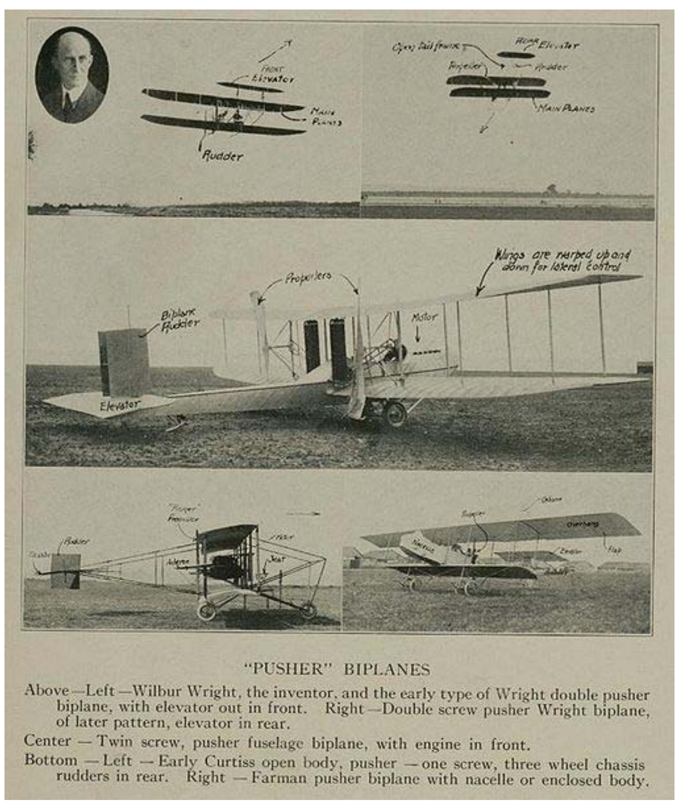
With the widespread adoption of interrupter gears in 1916/17, the tractor configuration became universally favoured, especially for warplanes. Pushers remained a minority of new aircraft designs into the 1930s and 1940s. Most pusher aircraft were, like the Supermarine Walrus, seaplanes with a single engine. The push-pull configuration, combining the tractor and pusher configuration (that is – with one or more propellers facing forwards and one or more others facing back) was widely used as a means of reducing the asymmetric effects of a single engine failing. Large multi-engine aircraft with this configuration, such as the Short Singapore, continued to be built.

Possibly the most extreme example of the type is the Convair B-36, the largest bomber ever operated by the United States, which wing-mounted six 3,800 hp Pratt & Whitney Wasp Major radial engines in a pusher configuration, augmented in the B-36D by four General Electric J47 turbojets. The Saab 21 was also initially built as a pusher since jet engines were not available.

The Quad City Challenger and the Cirrus VK-30 are examples of modern light aircraft with a pusher configuration.

There is a revival of pusher configurations on the Unmanned aerial vehicles with propellers such as Boeing ScanEagle, RQ-1 Predator, MQ-1C Warrior, RQ-2 Pioneer, RQ-5 Hunter, RQ-7 Shadow, MQ-9 Reaper, RQ-11 Raven and RQ-15 Neptune.

Advantages



An early diagram of Wilbur Wright's pusher bi-plane

- Efficiency can be gained by mounting a propeller behind the fuselage, because it re-energizes the boundary layer developed on the body, and reduces the form drag by keeping the flow attached. However, this effect is not nearly as pronounced on a small airplane as it is on a submarine or ship, where it is quite important due to the much higher Reynolds number at which they operate.
- Wing efficiency increases due to the absence of prop-wash over any section of the wing.
- Rear thrust is somewhat less stable in flight than with a tractor configuration. This has the potential to make an aircraft more maneuverable.
- Especially in a single-engined pusher aircraft, the pilot's view both forward and downwards is improved because the engine and propeller do not block forward vision, and because the more rearward centre of gravity makes placement of the cockpit forward of the wings more practical. Consequently, this configuration was widely used for early combat aircraft, and remains popular today among ultralight aircraft.
- The propeller of a single-engined airplane can be placed closer to the elevators and rudder. This increases the speed of the air flowing over the control surfaces, improving pitch and yaw control at low speed, particularly during takeoff when the engine is at full power. This can be beneficial while bush flying, especially when taking off and landing on airstrips bounded by obstacles that must be avoided while the airplane is moving slowly.
- The engine is mounted behind the crew and passenger compartments, so fuel does not have to flow past personnel, any leak will vent behind the aircraft, and any engine fire will be directed behind the aircraft (however, this arrangement puts the empennage at greater risk, if there is one—but this is less of an issue if the fire occurs on, or as a consequence of, landing). Similarly, propeller failure is unlikely to directly endanger the crew.
- The cockpit is generally quieter in a pusher aircraft because both the engine and propeller are behind the crew.
- At the time when many military aircraft were pushers, the engine afforded rear protection to the pilot, and simplified the installation of gun armament.

Disadvantages

- Early pusher aircraft were structurally more complicated than equivalent tractor types, especially as a result of efforts to mount the empennage behind the rear mounted propeller. This resulted in increased drag – and therefore aircraft with inferior performance compared with most tractor types with the same engine and payload. This tendency is less marked with modern aerodynamic knowledge and constructional methods, but it remains true that putting the propeller first (as in a tractor) solves some layout problems in propeller-driven aircraft design.
- It is claimed that the pusher configuration might endanger the aircraft's occupants in a crash or crash-landing. If the engine is placed behind the cabin, it may drive forward under its own momentum during a crash, entering the cabin and injuring the occupants; however there is no case where this has been reported to have occurred (in the US and UK accident records). Conversely, if the engine is placed

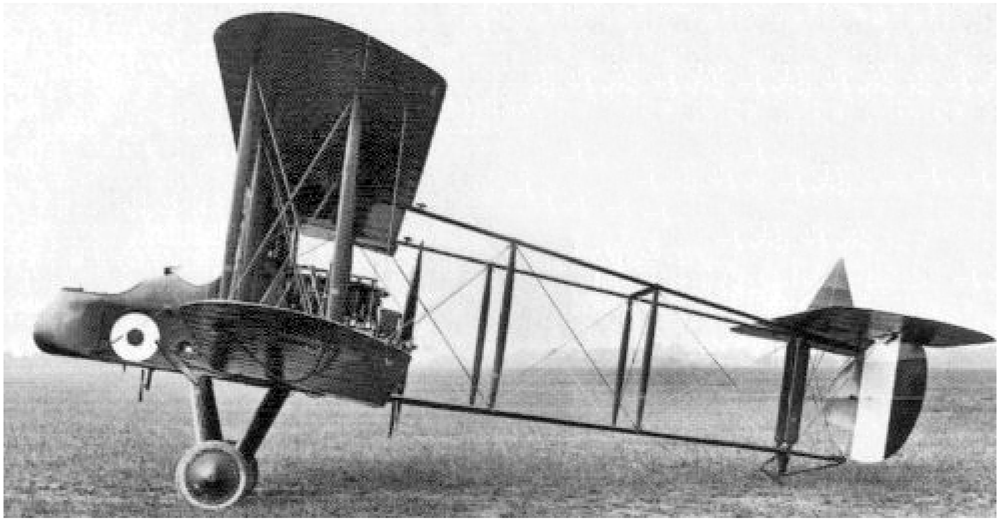
in front of the cabin, it might act as a battering ram and plow through obstacles in the airplane's path, providing an additional measure of safety (however, fuel and oil in the engine area is more likely to be a fire hazard if the engine hits the ground first, and high-energy pieces of propeller may be flung into the cabin area).

- Due to center of gravity often being further behind on longitudinal axis than on most tractor airplanes, the pushers can be more prone to flat spin, especially if loaded improperly.
- Crew members may strike the propeller while attempting to bail out of a single-engined airplane with a pusher prop. This scenario may be part of the reason that pusher props have rarely been used on post-WWI fighters despite the theoretical increase in maneuverability. Modern lightweight aircraft, however, often have a parachute system that saves the entire aircraft, so there is no need to bail out.
- A less dire but more practical concern is foreign object damage. The pusher configuration generally places the propeller(s) aft of the main landing gear. Objects on the ground kicked up by the wheels can find their way into the propeller, causing damage or accelerated wear to the blades. However, pusher configurations are used by thousands of ultralight aircraft on grass airfields, with few problems. A few centreline pusher designs (such as the Rutan Long-EZ pictured above) place the propeller arc very close to the ground while flying nose-high during takeoff or landing, possibly making the prop more likely to strike vegetation when the airplane operates from a turf airstrip.
- When an airplane flies in icing conditions, a layer of ice can accumulate on the wings. If an airplane with wing-mounted pusher engines experiences wing icing and subsequently flies into warmer air, the pusher props might ingest pieces of ice as they shed, posing a hazard to the propeller blades and other parts of the airframe that can be struck by chunks of ice flung by the props.
- In early pusher combat aircraft, spent ammunition cases caused similar problems – and devices for catching and collecting them so that they could not damage the propeller had to be devised.
- The propeller increases airflow around an air-cooled engine in the tractor configuration, but does not provide this same benefit to an engine mounted in the pusher configuration. Some aviation engines experience cooling problems when used as pushers.
- The warming airflow from a running engine is also lost in a pusher aircraft. In early aircraft, and in modern ultra-lights, where there is no alternative form of heating for the cockpit, pushers can therefore be very cold to fly.
- Normally (as in the Beechcraft Starship) the engine of a pusher exhausts forward of the propeller, and in this case the exhaust may contribute to corrosion or other damage to the propeller. This is usually minimal, and may be mainly visible in the form of soot stains on the blades.
- Propeller noise might increase because the engine exhaust flows through the props. This effect may be particularly pronounced when using turboprop engines due to the large volume of exhaust they produce. Similarly, vibration may be induced by the propeller passing through the wing downwash, causing it to move asymmetrically through air of differing energies and directions.

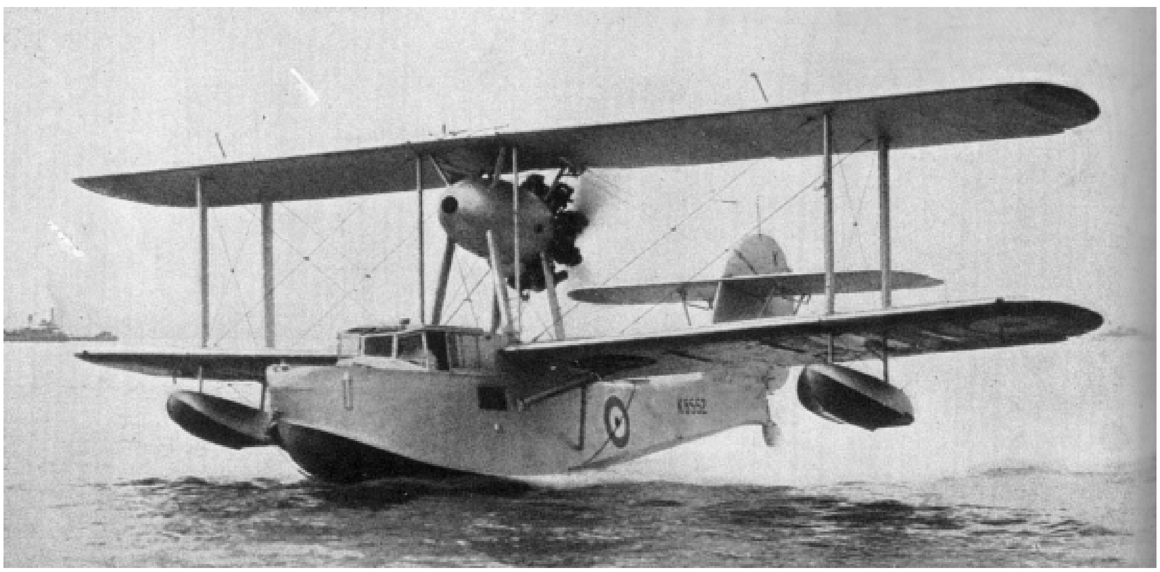
- The absence of prop-wash over the wings can reduce the airflow across the wing flaps, making them less effective. Wing-mounted pusher engines block portions of the trailing edges of the wings, reducing the total width available for flaps and ailerons.
- Placement of the propeller in front of the tail can have a negative side effect: strong pitch and yaw changes may occur as the engine's power setting changes and the airflow over the tail correspondingly speeds up or slows down.

Wright "Flyer" (reproduction of 1908–09 model)

Experimental fighter XP-55 (1943)



F.E.2b pusher (1914). The propeller is just behind the wing.



Supermarine Walrus seaplane (1933)

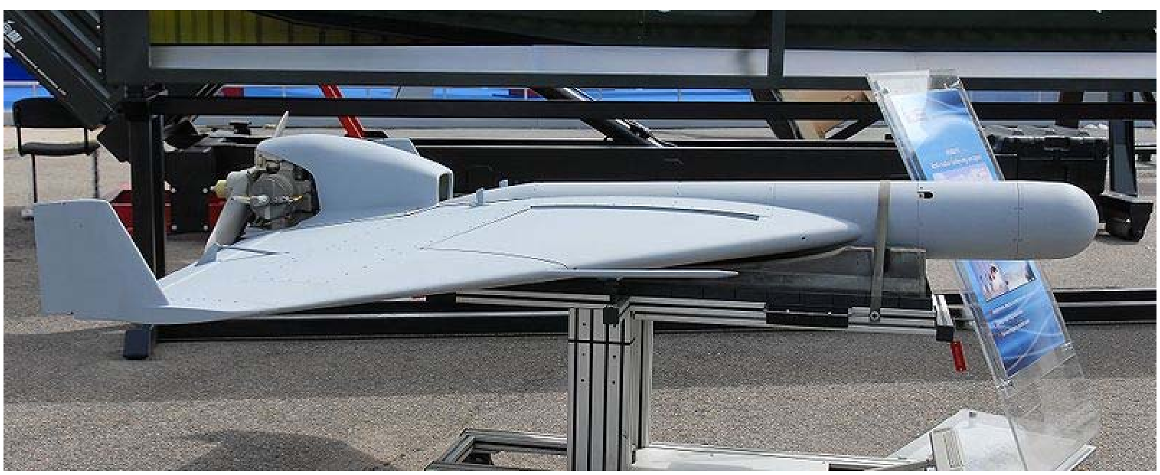
First versions of Saab J21 (1943)

Convair B-36 Peacemaker (1946)

Experimental flying wing Northrop XB-35 (1946)

Piaggio P-180 Avanti (1986)

UAV SAGEM Sperwer B (1990s)



IAI Harpy (1994)

IAI Heron (2006)

UCAV MQ-9 Reaper (2001)

NAL Saras

Experimental fighter XP-56 (1943)

Chapter- 2

T-tail and Tiltwing

T-tail

British Aerospace Avro RJ-85 - previously BAe 146 of SN Brussels Airlines (Belgium)

Rossiya Russian Airlines Tupolev Tu-154M.

Piper PA-44-180 Seminole

Grob motor glider

Beechcraft 1900D of the Swiss Air Force

A **T-tail** is an aircraft tail stabilizer configuration in which the horizontal surfaces (tailplane and elevators) are mounted to the top of the vertical stabilizer. Traditionally, the horizontal control surfaces are mounted to the fuselage at the base of the vertical stabilizer. The resulting arrangement looks like the capital letter T when viewed from the front or back, hence the name.

Benefits

The tailplane surfaces are kept well out of the airflow behind the wing, giving smoother flow, more predictable design characteristics, and better pitch control. This is especially important for planes operating at low speed, where clean airflow is required for control. deHavilland Canada's line of larger STOL aircraft all use this arrangement for this reason. T-tail configuration also allows high performance aerodynamics and excellent glide ratio as the empennage is not affected by wing slipstream. Therefore the T-tail configuration is especially popular on gliders.

The effective distance between wing and tailplane can be increased without a significant increase in the weight of the aircraft. The distance between the two planes gives the moment, or "leverage", by which the tailplane can control the aircraft's pitch attitude - with a greater distance, smaller, lighter tailplanes and elevators can be used.

The tail surfaces are mounted well out of the way of the rear fuselage, permitting this site to be used for the aircraft's engines. This is why the T-tail arrangement is also commonly found on airliners with rear-mounted engines, including trijets. The Douglas DC-9, Bombardier CRJ200, Embraer ERJ 145, Boeing 717, Boeing 727, Fokker 100, Vickers VC-10, Hawker Siddeley Trident, BAC 1-11, Tu-134, Tu-154, Il-62, and McDonnell Douglas MD-80, McDonnell Douglas MD-90, all used the T-tail for this reason.

The horizontal stabilizer is kept farther away from the ground, which helps reduce damage to it by objects on the ground when taking off or landing. This is not normally a large concern for engine-powered, full-scale ('real') planes, but for planes having no stout landing gear, such as gliders and model airplanes it can be. This benefit is also shared by V-tails and cruciform tails.

Drawbacks

The aircraft will tend to be much more prone to a dangerous deep stall condition, where blanking of the airflow over the tailplane and elevators by a stalled wing can lead to total loss of pitch control. The F-101 Voodoo suffered from this throughout its service life. For similar reasons, T-tailed aircraft can be much more difficult to recover from a fully-developed spin.

The vertical stabilizer must be made considerably stronger and stiffer to support the forces generated by the tailplane. Unless expensive composite materials are used, this inevitably makes it heavier as well.

The T-tail configuration can cause several maintenance concerns as well. The control runs to the elevators are more complex and elevator surfaces are much more difficult to casually inspect from the ground.

Because of concerns about being able to clear the tail, the first high-speed aircraft with a T-tail, the Lockheed F-104 Starfighter, was at first fitted with a downward-firing ejector seat. For later models of this aircraft, capabilities of ejection seats improved, so it was changed to an upward-firing one, to overcome problems in low-altitude escapes.

Due to a lack of airflow over the elevator from a forward mounted engine (piston or turboprop), low speed control is reduced and low speed operation is more difficult for aircraft not designed for low speed operation.

A compromise is also possible, with the tailplane mounted part way up the fin rather than right at the top. The Sud Aviation Caravelle is an aircraft with this configuration.

Tiltwing

Hiller X-18 tilting its wing

A **tiltwing** aircraft features a wing that is horizontal for conventional forward flight and rotates up for vertical takeoff and landing. It is similar to the tiltrotor design where only the propeller and engine rotate. Tiltwing aircraft are typically fully capable of VTOL operations.

The tiltwing design offers certain advantages in vertical flight relative to a tiltrotor. Because the slipstream from the rotor strikes the wing on its smallest dimension, the tiltwing is able to apply more of its engine power to lifting the aircraft. For comparison, the V-22 Osprey tiltrotor loses about 10% of its thrust to interference from the wings. However, the fixed wing of a tiltrotor aircraft offers a superior angle of attack — thus more lift and a shorter takeoff roll — when performing STOL/STOVL operations. The main drawback of the tiltwing is control during hover. The wing tilted vertically represents a large surface area for crosswinds to push.

List of Tiltwing aircraft

Tiltwing designs with rocket, jet, or propeller propulsion

- 1957 - Vertol VZ-2
- 1959 - Hiller X-18
- 1964 - LTV XC-142
- 1965 - Canadair CL-84

Chapter- 3

Tricycle Gear and Twin Boom

Tricycle gear

A Mooney M20J with a retractable tricycle landing gear

Polish 3Xtrim 3X55 Trener with a fixed tricycle landing gear taxiing.

Tricycle gear describes an aircraft undercarriage, or *landing gear*, arranged in a tricycle fashion. The tricycle arrangement has one wheel in the front, called the *nose wheel*, and two or more main wheels slightly aft of the center of gravity. Because of the ease of operating tricycle gear aircraft on the ground, the configuration is the most widely used on aircraft.

Several early aircraft had primitive tricycle gear, notably the Curtiss Pushers of the early 1910s. Waldo Waterman's 1929 tailless *Whatsit* was one of the first to have a steerable nose wheel.

Tricycle gear is essentially the reverse of conventional landing gear or *taildragger*. Tricycle gear aircraft have the advantage that it is much more difficult to make them 'nose over' as can happen if a taildragger hits a bump or has the brakes heavily applied. In a nose over, the airplane's tail tips up and the propeller strikes the ground, causing damage. Tricycle gear planes are also easier to handle on the ground and reduce the possibility of a ground loop, though they can be susceptible to wheel-barrowing. This is due to the main gear being behind the center of mass. Tricycle gear also provides an advantage in visibility to the pilot as the nose of the aircraft is level and, unlike in aircraft with conventional landing gear, does not block the view ahead. The nose wheel equipped aircraft also is easier to handle on the ground in high winds due to its wing negative angle of attack. Student pilots are able to safely master nosewheel equipped aircraft more quickly.

In the United States, students trained on taildragger aircraft are assumed to be competent in tricycle-equipped aircraft, but students trained on tricycles must receive training in taildraggers.

Tricycle gear aircraft are easier to land because the attitude required to land on the main gear is the same as that required in the flare, and they are less vulnerable to crosswinds. As a result, the majority of modern aircraft are fitted with tricycle gear. Almost all jet-powered aircraft have been fitted with tricycle landing gear, to avoid the blast of hot, high-speed gases causing damage to the ground surface, in particular runways and taxiways. The few exceptions have included the Yakovlev Yak-15, the Supermarine Attacker, and prototypes such as the Heinkel He 178, the Messerschmitt Me 262 V3, and the Nene powered version of the Vickers VC.1 Viking.

The taildragger configuration does have advantages. The rear wheel means the plane naturally sits in a nose-up attitude when on the ground; this is useful for operations on unpaved surfaces like gravel where debris could damage the propeller. The tailwheel also transmits loads to the airframe in a way that is less likely to cause airframe damage over time operating on rough fields. The simpler main gear and small tailwheel result in both a lighter weight and less complexity if retractable. Likewise, a fixed-gear taildragger exhibits less interference drag and form drag in flight than a fixed-gear aircraft with tricycle gear. Tail wheels are smaller and less expensive to buy and maintain and man-handling a tailwheel aircraft on the ground is easier. Most tailwheel aircraft are lower in overall height and thus may fit in lower hangars. Tailwheel aircraft are also more suitable for fitting with skis in wintertime.

Twin boom

de Havilland Sea Vixen (2004).

Twin-boom aircraft have their tailplanes and vertical stabilizers mounted on the tail of either two fuselages or on two booms fixed to either both sides of the single fuselage, the wings or the engine nacelles.

The reason for this design choice may be:

- To be able to place a cargo door in the back of the aircraft (examples include the C-82 Packet and C-119 Flying Boxcar)
- To construct propeller aircraft in pusher configuration or jet aircraft with the engine mounted directly to the aft of the fuselage (Bell XP-52, De Havilland Vampire Saab 21)
- For unobstructed field of view or field of fire to the rear (Focke-Wulf Fw 189)
- Twin aircraft, constructed by putting two copies of an existing traditional aircraft side-by-side, (P-82 Twin Mustang, Messerschmitt Me 609)
- To accommodate early inline engines and their lengthy turbochargers in the most aerodynamically efficient/practical planform (P-38 Lightning) & (P-61 Black Widow)

- To increase an aircraft structure's rigidity, strength, and internal volume (Rutan Voyager, Scaled Composites Grizzly, Virgin Atlantic GlobalFlyer, Transavia PL-12 Airtruk)
- To provide for room to carry external cargo, such as Scaled Composites WhiteKnightTwo. Burt Rutan refers to this design concept as "open architecture".

de Havilland Vampire T11 of the UK Vampire Preservation Group displays at the Cotswold Air Show (2010).

Other examples of twin boom aircraft:

- Adam A700
- Adam A500
- Blohm & Voss BV 138
- Cessna Skymaster/O-2 Skymaster
- De Havilland Sea Vixen
- de Havilland Venom
- Fokker F.25
- Fokker G.I
- Heinkel He 111Z *Zwilling*
- Hughes XF-11
- Lockheed P-38 Lightning
- Messerschmitt Me 409
- North American Rockwell OV-10 Bronco

- Saab 21
- Sadler Vampire
- Scaled Composites White Knight
- SIPA S-200 Minijet
- Sukhoi Su-12
- Sukhoi Su-80
- Schweizer RU-38 Twin Condor
- US Army RQ-7 Shadow

Chapter- 4

Twin Tail, Twinjet and V-tail

Twin tail

A twin-tailed B-25 Mitchell in flight.

A **twin tail** is a specific type of vertical stabilizer arrangement found on the empennage of some aircraft. Two vertical stabilizers — often smaller on their own than a single conventional tail would be — are mounted at the outside of the aircraft's horizontal stabilizer. This arrangement is also known as an **H-tail**, as it resembles a capital "H" when viewed from rear.

A special case of twin tail is **twin boom tail** or **double tail** where the aft airframe consists of two separate fuselages, "tail booms", which each have one fin and rudder but share a conjoined one single horizontal stabilizer. Examples of this construction are Lockheed P-38 Lightning, Northrop P-61 Black Widow, De Havilland Vampire and C-119 Boxcar

Design

Separating the control surfaces allows for additional rudder area or vertical surface without requiring a massive single tail. On multi-engine propeller designs twin fin and rudders operating in the propeller slipstream give greater rudder authority and improved control at low airspeeds, and when taxiing. A twin tail can also simplify hangar requirements, give dorsal gunners enhanced firing area, and in some cases reduce the aircraft's weight. It also affords a degree of redundancy - if one tail is damaged, the other may remain functional.

Many canard aircraft designs incorporate twin tails on the tips of the main wing. *Very* occasionally, three or more tails are used, as on the Breguet Deux-Ponts, Lockheed Constellation and Boeing 314 Clipper. A very unusual design can be seen on the E-2 Hawkeye, which has two additional vertical tails fixed to the horizontal stabilizer between the normal vertical twin-tail surfaces. This arrangement was chosen for the stringent size limitations of carrier-based aircraft.

The twin tail of a Chrislea Super Ace, built in 1948

Significant aircraft with twin tails include the B-24 Liberator, Handley-Page Halifax Avro Lancaster, and P-38 Lightning. The arrangement is not limited to World War II-vintage aircraft, however. Many fighter aircraft, like the F-14 Tomcat, F-15 Eagle, Sukhoi Su-27, Mig-29, and A-10 Thunderbolt II, make use of twin tail configurations, as do civilian and cargo designs like the Antonov An-14, Antonov An-22, Antonov An-28, Antonov An-38, Antonov An-225, Beechcraft 18, Beriev Be-12, ERCO Ercoupe, Burt Rutan’s Long-EZ and SpaceShipOne also Shorts 330.

Future Aircraft

Airbus has filed a patent for a new, twin-tail, trijet design, but it is unknown if this will ever come to market.

Twinjet

A **twinjet** or **twin jet** is a jet aircraft powered by two engines. Such configuration of an airplane is the most popular today for commercial airliners, for fighters, and many other kinds, because while offering safety from a single engine failure, it is also acceptably fuel-efficient.

Aircraft configurations

As of today, there are three most common configurations of this kind of an airplane. One has an engine mounted beneath each wing, and another has one engine mounted on each side the rear fuselage, close to its empennage. In the third configuration, both jet engines are within the fuselage, side-by-side. The third configuration is notable for being used on most fighters since 1960s, and still continuing, for example in the Su-27 'Flanker', the F-15 Eagle, or the F-22 Raptor.

Failure safety

When flying far from diversionary airports, (so called ETOPS/LROPS flights), the aircraft must be able to reach an alternate on the remaining engine within a specified time in case of one engine failure. Power is not an issue. One of the engines is more than powerful enough to keep the aircraft aloft. Mostly, it is about maintenance and design requirements ensuring that a failure of one engine cannot make the other one fail, also. The engines and related systems need to be independent and (in essence) independently maintained. ETOPS/LROPS is often incorrectly thought to apply only to long overwater flights. In fact it applies to any flight more than specified distances from an available diversion airport. Overwater flights near diversion airports need not be ETOPS/LROPS compliant.

In the event of an engine failure, the remaining engine must provide enough thrust to keep the airplane in flight even if the failure occurs during take-off at a point where it is too late to reject the take-off. In other words a fully-laden twinjet must be able to climb on one engine.

Due to the lack of engine redundancy, in the event of volcanic ash ingestion as happened with the air travel disruption after the 2010 Eyjafjallajökull eruption, airline operators of twinjets must be equally as cautious and safety conscious as operators of aircraft with three or more engines in any areas affected by aerial ash fallout. Thus far in the course of modern aviation history, two four-engined passenger aircraft; a British Airways Flight 9 in 1982 and a KLM Flight 867 in 1989, suffered engine failures due to volcanic dust ingestion.

Efficiency

Twin jets tend to be more fuel-efficient than aircraft with three or more engines. Fuel efficiency in airliners is a high priority, and a high percentage airliners use two engines. The Boeing 737 twinjet stands out as the most produced jet airliner. Other examples include the Boeing 767, 787, the Airbus A320, and the A350.

Many airlines use twin jets exclusively nowadays, such as American Airlines, Continental Airlines, and US Airways in the United States.

Introduction to transoceanic flights

Since the 1990s airlines have increasingly turned from four-engined to twin-engined airliners to operate transatlantic and transpacific routes. On a nonstop flight from America to Asia the long-range aircraft usually follows the Great Circle route. Hence, in case of an engine failure in a twinjet (like Boeing 777), it is never too far from an emergency landing fields in western Canada, Alaska, or eastern Russia. The Boeing 777 has also been approved by the Federal Aviation Administration for flights between North America and Hawaii, which is the world's longest regular airline route with no emergency landing fields along the way.

V-tail

1950 V-tailed B35 still operated by the National Test Pilot School at the Mojave Airport

The V-tail of a Belgian Air Force Fouga Magister.

An Ultraflight Lazair showing its inverted V-tail covered with translucent Tedlar

In aircraft, a **V-tail** (sometimes called a **Butterfly tail**) is an unconventional arrangement of the tail control surfaces that replaces the traditional fin and horizontal surfaces with two surfaces set in a V-shaped configuration when viewed from the front or rear of the aircraft. The rear of each surface is hinged, and these movable sections, sometimes called **ruddervators**, combine the tasks of the elevators and rudder.

Design use

The V-tail has not been a popular choice for aircraft manufacturers. The most popular V-tailed aircraft in mass production was the Beechcraft Bonanza Model 35, often known as the *V-tail Bonanza* or simply *V-Tail*. Other examples include the F-117 Nighthawk stealth fighter, the Fouga Magister trainer, and the MQ-1 Predator UAV. The X-shaped tail surfaces of the experimental Lockheed XFV were essentially a V tail that extended both above and below the fuselage. Over 2000 Ultraflight Lazair ultralights were produced, all featuring an inverted V-tail.

Advantages

Ideally, with fewer surfaces than a conventional three-aerofoil tail or a T-tail, the V-tail is lighter, has less wetted surface area, and thus produces less drag. However, NACA studies indicated that the V-tail surfaces must be larger than simple projection into the vertical & horizontal planes would suggest, such that total wetted area is roughly constant; reduction of intersection surfaces from three to two, does, however, produce a net reduction in drag through elimination of some interference drag.

In modern day light jet general aviation aircraft such as the Cirrus Jet, Eclipse 400 or the unmanned aerial drone Global Hawk, the power plant is often placed outside the aircraft to protect the passengers and make certification easier. In such cases V-tails are used to avoid placing the vertical stabilizer in the exhaust of the engine, which would disrupt the flow of the exhaust reducing thrust, and wear on the stabilizer, possibly leading to damage over time.

Disadvantages

Combining the pitch and yaw controls is difficult and requires a more complex control system. The V-tail arrangement also places greater stress on the rear fuselage when pitching and yawing.

In the mid-1980s, the Federal Aviation Administration grounded the Beechcraft Bonanza due to safety concerns. While the Bonanza met the initial certification requirements, it had a history of fatal mid-air breakups during extreme stress, at a rate exceeding the accepted norm. The type was deemed airworthy and restrictions removed after Beechcraft issued a structural modification as an Airworthiness Directive.

Ruddervators

Ruddervators are the control surfaces on an airplane with a V-tail configuration. They are located at the trailing edge of each of the two airfoils making up the tail of the plane. The first use of ruddervators may have been on the Coandă-1910's X-tail, although there is no proof that the aircraft ever flew. The later Coandă-1911 flew with ruddervators on its X-tail. Later Polish engineer Jerzy Rudlicki designed the first practical ruddervators in 1930, tested on a modified Hanriot H-28 trainer in 1931.

The name derives from a combination of the word rudder and elevator. In a conventional aircraft tail configuration, the rudder provides yaw (horizontal) control and the elevator provides pitch (vertical) control.

Ruddervators provide the same control effect as conventional control surfaces, but through a more complex control system that actuates the control surfaces in unison. Yaw moving the nose to the left is produced on an upright V tail by moving the pedals left which deflects the left-hand ruddervator down and left and the right-hand ruddervator up and left. The opposite produces yaw to the right. Pitch nose up is produced by moving the control column or stick back which deflects the left-hand ruddervator up and right and the right-hand ruddervator up and left. Pitch nose down is produced by moving the control column or stick forward which induces the opposite ruddervator movements.

Ruddervators have also been used on some airships, such as the US Navy's N class blimps. Accurate pitch trimming of airships can be difficult and this configuration improves clearance beneath the tail.

Chapter- 5

Autogyro

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

Configuration

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

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

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

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

Flight controls

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

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

Pusher vs tractor configuration

Montgomerie Merlin single-seat autogyro

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

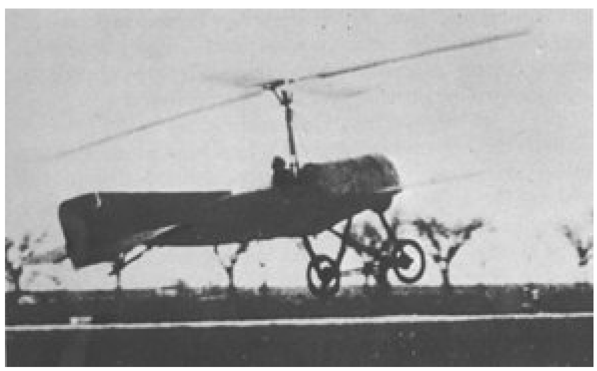
Bensen in the decades following World War II, and came into widespread use shortly afterward.

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

History

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

Early development



The first autogyro to fly successfully (1923)

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

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

De la Cierva's first three designs (C.1, C.2, and C.3) were unstable because of aerodynamic and structural deficiencies in their rotors. His fourth design, the C.4, made the first successful flight of an autogyro on 9 January 1923, piloted by Alejandro Gomez Spencer at Cuatro Vientos airfield in Madrid, Spain. De la Cierva had fitted the rotor of the C.4 with flapping hinges to attach each rotor blade to the hub. The flapping hinges allowed each rotor blade to flap, or move up and down, to compensate for dissymmetry of lift, the difference in lift produced between the right and left sides of the rotor as the autogyro moves forward. Three days later, the engine failed shortly after takeoff and the aircraft descended slowly and steeply to a safe landing, validating De la Cierva's efforts to produce an aircraft that could be flown safely at low airspeeds.

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

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

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

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

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

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

De la Cierva's early autogyros were fitted with fixed rotor hubs, small fixed wings, and control surfaces like those of a fixed wing aircraft. At low airspeeds, the control surfaces became ineffective and could readily lead to loss of control, particularly during landing. In response, Cierva developed a direct control rotor hub, which could be tilted in any direction by the pilot. De la Cierva's direct control was first developed on the Cierva C.19 Mk. V and saw production on the Cierva C.30 series of 1934. In March 1934 this type of autogyro became the first rotorcraft to take off and land on the deck of a ship, when a C.30 performed trials onboard the Spanish navy seaplane tender *Dédalo* off Valencia.

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

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

World War II

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

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

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

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

Postwar developments

The autogyro was resurrected after World War II when Dr. Igor Bensen, a Russian immigrant, saw a captured German U-Boat's Fa 330 gyroglider and was fascinated by its characteristics. At work he was tasked with the analysis of the British military "Rotachute" gyro glider designed by expatriate Austrian Raoul Hafner. This led him to adapt the design for his own purposes and eventually market the B-7. Bensen submitted an improved version, the Bensen B-8M, for testing to the United States Air Force, which designated it the X-25. The B-8M was designed to use surplus McCulloch engines used on flying unmanned target drones.

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

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

Bensen Gyrocopter

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

Bensen Aircraft B8MG Gyrocopter

Bensen-type autogyros use a pusher configuration for simplicity and to increase visibility for the pilot. Power can be supplied by a variety of engines. McCulloch drone engines, Rotax marine engines, Subaru automobile engines, and other designs have been used in Bensen-type designs.

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

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

The success of Bensen triggered a number of other designs, some of them fatally flawed with an offset between the centre of gravity and thrust line, risking a Power Push-Over (PPO or bunt-over) causing death to the pilot and giving gyroplanes in general a poor reputation - in contrast to Cierva's original intention and early statistics. Most new autogyros are now safe from PPO.

Certification by national aviation authorities

US certification

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

UK certification

A VPM M-16 commences its take-off roll

Some autogyros, such as the Rotorsport MT03, have type approval by the United Kingdom Civil Aviation Authority (CAA) under British Civil Airworthiness Requirements CAP643 Section T. Others operate under a permit to fly issued by the Popular Flying Association– similar to the US experimental aircraft certification.

However, the CAA's assertion that autogyros have a poor safety record means that permit to fly will only be granted to existing types of autogyro. All new types of autogyro must be submitted for full type approval under CAP643 Section T.

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

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

World records

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

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

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

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

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

Chapter- 6

Dihedral

The upward tilt of the wings and tailplane of an aircraft, as seen on this Boeing 737, is called dihedral angle

Dihedral angle is the upward angle from horizontal of the wings or tailplane of a fixed-wing aircraft. **Anhedral angle** is the name given to negative dihedral angle, that is, when there is a *downward* angle from horizontal of the wings or tailplane of a fixed-wing aircraft.

Dihedral angle (or anhedral angle) has a strong influence on **dihedral effect**, which is named after it. Dihedral effect is the amount of roll moment produced per degree (or radian) of sideslip. Dihedral effect is a critical factor in the stability of an aircraft about the roll axis (the spiral mode). It is also pertinent to the nature of an aircraft's dutch roll oscillation and to maneuverability about the roll axis.

Longitudinal dihedral is a comparatively obscure term related to the pitch (flight) axis of an airplane. It is the angle between the zero lift axis of the wing and horizontal tail. Longitudinal dihedral can influence the nature of controllability about the pitch axis and the nature of an aircraft's phugoid-mode oscillation.

When the term "dihedral" (of an aircraft) is used by itself it is usually intended to mean "dihedral *angle*". However, context may otherwise indicate that "dihedral *effect*" is the intended meaning.

Dihedral angle and dihedral effect

Dihedral angle is the upward angle from horizontal of the wings of a fixed-wing aircraft, or of any paired nominally-horizontal surfaces on any aircraft. The term can also apply to the wings of a bird. Dihedral angle is also used in some types of kites such as box kites. Wings with more than one angle change along the full span are said to be *polyhedral*.

Dihedral angle has important stabilizing effects on flying bodies because it has a strong influence on the dihedral effect.

Dihedral effect of an aircraft is a rolling moment resulting from the vehicle having a non-zero angle of sideslip. Increasing the dihedral angle of an aircraft increases the dihedral effect on it. However, many other aircraft parameters also have a strong influence on dihedral effect. Some of these important factors are: wing sweep, vertical center of gravity, and the height and size of anything on an aircraft that changes its sidewards force as sideslip changes.

Longitudinal dihedral

Dihedral angle on an aircraft almost always implies the angle between two *paired* surfaces, *one on each side of the aircraft*. Even then, it is almost always between the left and right *wings*. However, dihedral in math means the angle between *any* two planes. So, in aeronautics, in one case, the term "dihedral" is applied to mean the difference in angles between two *front-to-back* surfaces:

Longitudinal dihedral is the difference between the angle of incidence of the wing and angle of incidence of the horizontal tail.

Longitudinal dihedral can also mean the angle between the zero lift axis of the two surfaces instead of between the root chords of the two surfaces. This is the more meaningful usage because the directions of zero-lift are pertinent to longitudinal trim and stability while the directions of the root chords are not.

History

In geometry, dihedral angle is the angle between two planes. Aviation usage differs slightly from usage in geometry. In aviation, the usage "**di**hedral" evolved to mean the positive, up angle between the left and right wings. While usage with the prefix "an-" (as in "**an**hedral") evolved to mean the negative, down angle between the wings.

The aerodynamic stabilizing qualities of dihedral angle were first described by Sir George Cayley in 1808-1809.

Uses of dihedral angle and dihedral effect

Aircraft stability analysis

In *analysis* of aircraft stability, dihedral effect is also a stability derivative called $\mathbf{C_{l\beta}}$ (pronounced "see-ell-beta") meaning the change in rolling moment coefficient (the "$\mathbf{C_l}$") per degree (or radian) of change in sideslip angle (the "β").

Provision of stability

The purpose of dihedral effect is to contribute to stability in the roll axis. It is an important factor in the stability of the *spiral mode* which is sometimes called "roll stability". It is important to note that dihedral effect does not contribute *directly* to the restoring of "wings level", but that its action is *indirect*. It indirectly helps restore "wings level" through its effect on the spiral mode (as described below).

Wing clearance

Aircraft designers may increase dihedral angle to provide increased clearance between wing tips and the runway. The increased dihedral effect caused by this may need to be compensated for by one or more other means, such as decreasing the dihedral angle on the horizontal tail.

Using dihedral angle to adjust dihedral effect

During the design of a fixed-wing aircraft (or any aircraft with horizontal surfaces), changing dihedral angle is usually a relatively simple way to adjust the overall dihedral effect. This is to compensate for other design elements' influence on the dihedral effect. These other elements (such as wing sweep, vertical mount point of the wing, etc.) may be more difficult to change than the dihedral angle. As a result, differing amounts of dihedral angle can be found on different types of fixed-wing aircraft. For example, the dihedral angle is usually greater on low-wing aircraft than on otherwise-similar high-wing aircraft. This is because "highness" of a wing (or "lowness" of vertical center of gravity compared to the wing) naturally creates *more* dihedral effect itself. This makes it so less dihedral angle is needed to get the amount of dihedral effect needed.

Common Confusions

Dihedral effect is defined simply to be the rolling moment caused by sideslip and nothing else. Rolling moments caused by other things that may be related to sideslip have different names.

Dihedral effect is not caused by *yaw rate*, nor by the *rate of sideslip change*. Since dihedral effect is noticed by pilots when "rudder is applied", many pilots and other near-experts explain that the rolling moment is caused by one wing moving more quickly through the air and one wing less quickly. Indeed, these are actual effects, but they are not the dihedral effect, which is caused by being *at* a sideslip angle, not by getting to one. These other effects are called "rolling moment due to yaw rate" and "rolling moment due to sideslip rate" respectively.

Dihedral effect is not roll stability in and of itself. Roll stability is less-ambiguously termed "spiral mode stability" and dihedral effect is a contributing factor to it, but dihedral effect is not any kind of stability by itself.

How dihedral angle creates dihedral effect and stabilizes the spiral mode

The following discusses how dihedral angle creates dihedral effect and how dihedral effect contributes to stability of the *spiral mode*. A *stable* spiral mode will cause the aircraft to eventually return to a nominally "wings level" bank angle when the angle of the wings is disturbed to become off-level.

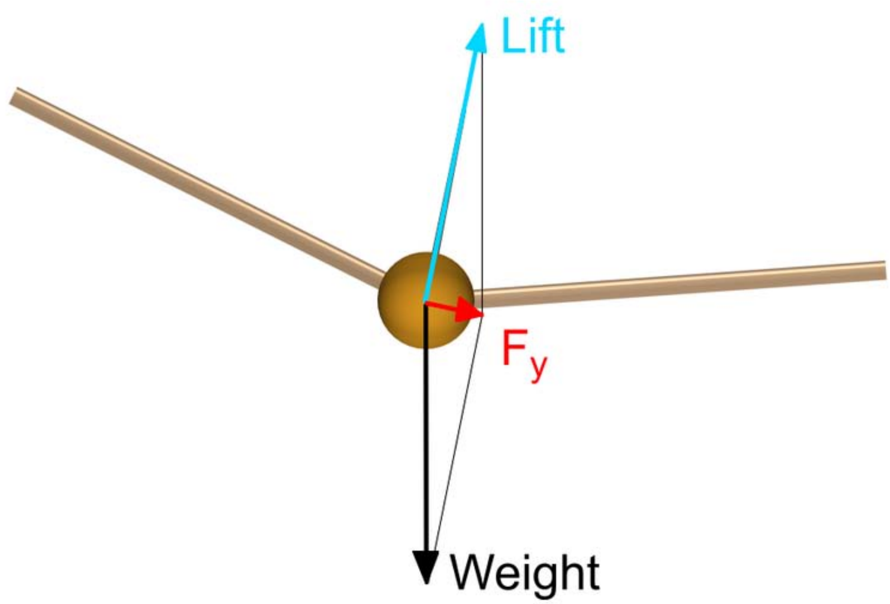


Fig. 1: Uncompensated lift component produces a side force F_y, which causes the aircraft to sideslip.

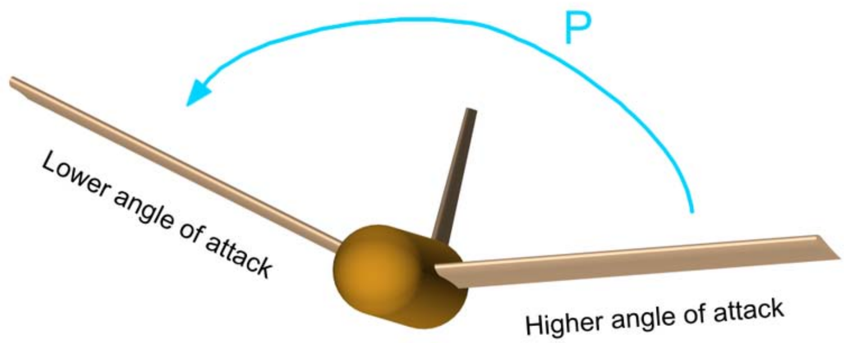


Fig. 2: Non-zero sideslip sets the lower, upwind wing to a higher angle of attack, resulting in stabilising roll moment P.
The aircraft is shown flying towards the viewer.

If a disturbance causes an aircraft to roll away from its normal wings-level position as in Figure 1, the aircraft will begin to move somewhat sideways toward the lower wing. In Figure 2, the airplane's flight path has started to move toward its left while the nose of the airplane is still pointing in the original direction. This means that the oncoming air is arriving somewhat from the *left* of the nose. Because of this, the airplane now has *sideslip* angle in addition to the bank angle. Figure 2 shows the airplane as it presents itself to the oncoming air.

How dihedral angle creates rolling moment from sideslip (dihedral effect)

In Figure 2, the sideslip conditions (not the roll angle which is also shown) make the dihedral angle *geometrically* produce greater angle of attack on the forward-yawed wing and smaller angle of attack on the rearward-yawed wing. This alteration of angle of attack by sideslip is visible to the eye in Figure 2. Since greater angle of attack makes greater lift, the forward wing will have more lift and the rearward wing will have less lift. This difference in lift between the wings is a rolling moment, and since it is caused by sideslip, it is dihedral effect (or more correctly, it is a *contribution* to the total dihedral effect of the aircraft).

How dihedral effect stabilizes the spiral mode

The rolling moment created by the sideslip (labeled as "P") *tends* to roll the aircraft back to wings level. More dihedral effect tries to roll the wings in the "leveling" direction more strongly, and less dihedral effect tries to roll the wings in the "leveling" direction less strongly. Dihedral effect *helps* stabilize the spiral mode by *tending* to roll the wings toward level in proportion to the amount of sideslip that builds up. It's not the whole picture however. At the same time that angle of sideslip is building up, the vertical fin is trying to turn the nose back into the wind, much like a weathervane, minimizing the amount of sideslip that can be present. If there is no sideslip, there can be no restoring rolling moment. If there is less sideslip, there is less restoring rolling moment. So, yaw stability created by the vertical fin *fights* the tendency for dihedral effect to roll the wings back level by *not letting as much sideslip build up*.

The spiral mode is the tendency to slowly diverge from, or the tendency to slowly return to wings level. If the spiral mode is stable, the aircraft will slowly return to wings-level, if it is unstable, the aircraft will slowly diverge from wings-level. Dihedral effect and yaw stability are the two primary factors that affect the stability of the spiral mode, although there are other factors that affect it less strongly.

Other factors contributing to dihedral effect

The CG of a paraglider is very low, making a strong contribution to dihedral effect.

Factors of design other than dihedral angle also contribute to dihedral effect. Each increases or decreases total aircraft dihedral effect to a greater or lesser degree.

Sweepback

Wing sweepback also increases dihedral effect. This is one reason for anhedral configuration on aircraft with high sweep angle, as well as on some airliners, even on low-wing aircraft such as Tu-134 and Tu-154.

Vertical position of the center of mass

The center of mass, usually called the center of gravity or "CG", is the balance point of an aircraft. If suspended at this point and allowed to rotate, a body (aircraft) will be balanced. The front-to-back location of the CG is of primary importance for the general stability of the aircraft, but the vertical location has important effects as well.

The vertical location of the CG changes the amount of dihedral effect. As the "vertical CG" moves lower, dihedral effect increases. This is caused by the center of lift and drag being further above the CG and having a longer moment arm. So, the same forces (lift and drag) that change as sideslip changes produce a larger moment about the CG of the aircraft. This is sometimes referred to as the pendulum effect.

An extreme example of the effect of vertical CG on dihedral effect is a paraglider. The dihedral effect created by the *very* low vertical CG more than compensates for the negative dihedral effect created by the strong anhedral of the necessarily strongly downward curving wing.

Effects of too much dihedral effect

A side effect of too much lateral stability, caused by excessive dihedral among other things, can be yaw-roll coupling (a tendency for an aircraft to dutch roll). This can be unpleasant to experience, or in extreme conditions it can lead to loss of control or can overstress an aircraft.

Other Dihedral-related terminology

Anhedral on the wings and tailplane of an RAF Harrier GR7A

Anhedral

Military fighter aircraft often have near zero or even negative dihedral angle. This reduces dihedral effect, reducing the stability of the spiral mode. A too-stable spiral mode decreases maneuverability and is undesirable for fighter-type aircraft.

Anhedral angles are also seen on aircraft with a high mounted wing, such as the BAe 146 and Lockheed Galaxy. In such designs, the high mounted wing is above the center of gravity which confers extra dihedral effect due to the pendulum effect also called the keel effect, so additional dihedral angle is often not required. In fact, such designs can have excessive dihedral effect and so be excessively stable in the spiral mode, so the anhedral angle is added to cancel out some of the dihedral effect to ensure that the aircraft can be easily maneuvered.

Polyhedral

McDonnell Douglas F-4 Phantom II showing polyhedral wing and anhedral tail

Most aircraft have been designed with planar wings with simple dihedral (or anhedral). Some older aircraft such as the Vought F4U Corsair and the Beriev Be-12 were designed with gull wings bent near the root. Modern polyhedral wing designs generally cant upwards near the wingtips, increasing dihedral effect without increasing the angle the wings meet at the root, which may be difficult to alter for some other reason.

Polyhedral is seen on gliders and some other aircraft. The McDonnell Douglas F-4 Phantom II is one such example, unique among jet fighters for having dihedral wingtips. This was added after prototype flight testing (the original prototype of the F-4 had a flat wing) showed the need to correct some unanticipated spiral mode instability - angling the wingtips, which were already designed to fold up for carrier operations, was a more practical solution than re-engineering the entire wing.

Chapter- 7

Ground Effect Vehicle

A-90 Orlyonok

A **ground effect vehicle (GEV)** is one that attains level flight near the surface of the Earth, made possible by a cushion of high-pressure air created by the aerodynamic interaction between the wings and the surface known as ground effect. Also known as a **wing-in-ground-effect** (**WIG**) **vehicle**, **flarecraft**, **sea skimmer**, **ekranoplan**, SkimMachine, or **wing-in-surface-effect ship** (**WISE**), a GEV can be seen as a transition between a hovercraft and an aircraft. The International Maritime Organization (IMO) has classified the GEV as a ship. A GEV differs from an aircraft in that it cannot operate without ground effect, so its operating height is limited relative to its wingspan.

In recent years a large number of different GEV types have evolved for both civilian and military use. However, these craft are not in wide use.

History

Small numbers of experimental vehicles were built in Scandinavia just before World War II. By the 1960s, the technology started to improve, in large part due to the independent contributions of Rostislav Alexeev in the Soviet Union and German Alexander Lippisch, working in the United States. Alexeev worked from his background as a ship designer whereas Lippisch worked from his own background as an aeronautical engineer. The influence of Alexeev and Lippisch is still noticeable in most GEV vehicles seen today.

The Soviet Central Hydrofoil Design Bureau (CHDB), led by Alexeev, was the center of ground-effect craft development in the USSR; in Russian, the vehicle came to be known as an Ekranoplan (Russian: *экранопла́н*, *экран* "screen" + *план* "plane", from *эффект экрана*, literally in Russian *'screen effect'* , for 'ground effect' in English). The military potential for such a craft was soon recognised and Alexeev received support and financial resources from Soviet leader Nikita Khrushchev.

Some manned and unmanned prototypes were built, ranging up to eight tons in displacement. This led to the development of the "Caspian Sea Monster", a 550-ton military *ekranoplan*. Although it was designed to travel a maximum of 3 m (9.8 ft) above the sea, it was found to be most efficient at 20 m (66 ft), reaching a top speed of 300 kn (350 mph; 560 km/h) (400 kn (460 mph; 740 km/h) in research flight).

The Soviet *ekranoplan* program continued with the support of Minister of Defense Dmitri Ustinov. It produced the most successful *ekranoplan* so far, the 125-ton A-90 *Orlyonok*. These craft were originally developed as very high-speed military transports, and were based mostly on the shores of the Caspian Sea and Black Sea. The Soviet Navy ordered 120 *Orlyonok*-class *ekranoplans*. But this figure was later reduced to fewer than thirty vehicles, with planned deployment mainly in the Black Sea and Baltic Sea fleets.

A few *Orlyonoks* served with the Soviet Navy from 1979 to 1992. In 1987, the 400-ton *Lun*-class *ekranoplan* was built as a missile launcher. A second *Lun*, renamed *Spasatel*, was laid down as a rescue vessel, but was never finished.

Minister Ustinov died in 1985, and the new Minister of Defense, Marshal Sokolov, effectively stopped the funding for the program. Only three operational *Orlyonok*-class *ekranoplans* (with revised hull design) and one *Lun*-class *ekranoplan* remained at a naval base near Kaspiysk.

The two major problems that the Soviet *ekranoplans* faced were poor longitudinal stability and a need for reliable navigation.

Since the fall of the Soviet Union, *ekranoplans* have been produced by the Volga Shipyard in Nizhniy Novgorod.

GEV developed since the 1980s have been primarily smaller craft designed for the recreational and civilian ferry markets. Germany, Russia, and the United States have provided most of the momentum with some development in Australia, China, Japan, and Taiwan. In these countries, small craft up to ten seats have been designed and built. Other larger designs as ferries and heavy transports have been proposed, though none have gone on to further development.

After the collapse of the Soviet Union, smaller *ekranoplans* for non-military use have been under development. The CHDB had already developed the eight-seat Volga-2 in 1985, and Technologies and Transport developed a smaller version by the name of Amphistar.

In Germany, Lippisch was asked to build a very fast boat for Mr. Collins from Collins Radio Company in the USA. He developed the X-112, a revolutionary design with reversed delta wing and T-tail. This design proved to be stable and efficient in ground effect and even though it was successfully tested, Collins decided to stop the project and sold the patents to a German company called Rhein Flugzeugbau (RFB) which further developed the model.

Tandem flarecraft Skimmerfoil Jörg IV located at the SAAF museum, Port Elizabeth, South Africa

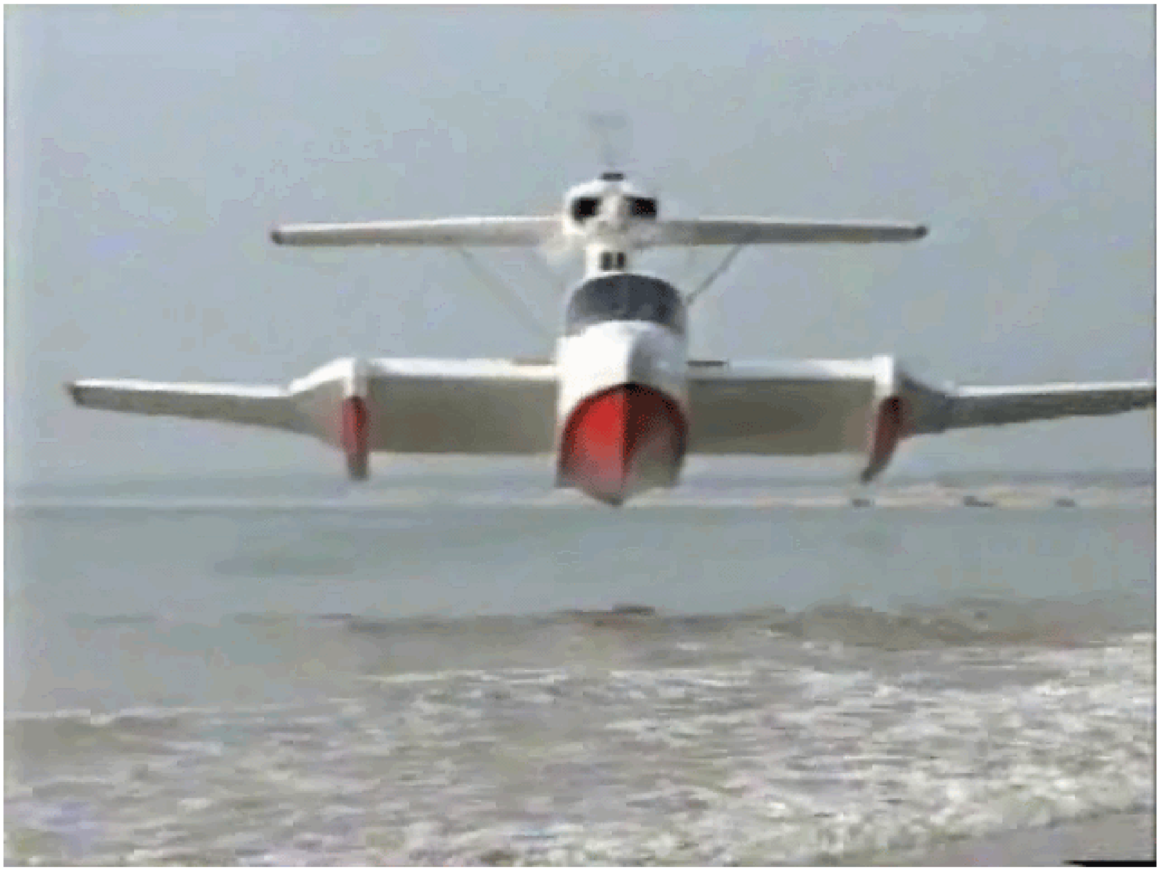
Hanno Fischer took over the works from RFB and created his own company called Fischer Flugmechanik. Their two-seat Airfisch 3 and their later model that seats 6 passengers have been a successful design. This craft, the FS-8, was to be produced by Hanno Fischer / Fischer Flugmechanik for a Singapore-Australian joint venture called Flightship. The company no longer exists but the prototype craft was bought over by Wigetworks, a company based in Singapore and renamed as AirFish 8.

An ongoing research project in collaboration with the university of Duisburg-Essen, involves the development of the *Hoverwing*.

Günther Jörg in Germany, who had also been working on Alexeev's first designs, and was familiar with the challenges of GEV design, developed a GEV with two wings in a tandem arrangement, the Jörg-II. It was the third, manned, tandem airfoil boat, named "Skimmerfoil", which was developed during his consultancy period in South Africa. It was a simple and low-cost design, but has not been produced to date. The consultancy of Dipl. Ing. Günther Jörg was founded with a fundamental knowledge of Wing in Ground Effect physics, as well as results of fundamental tests under different conditions and designs that began in 1960. In 1984, Günther Jörg received the "PHILIP MORRIS AWARD". In 1987, the Botec Company was founded.

Current development

Besides the development of appropriate design and structural configuration, special automatic control systems and navigation systems are also being developed. These include special altimeters with high accuracy for small altitude measurements and also lesser dependence on weather conditions. After extensive research and experimentation, it has been shown that "phase radio-altimeters" are most suitable for such applications as compared to laser, isotropic or ultrasonic altimeters.



Sea Eagle

Universal Hovercraft developed the first flying hovercraft, a prototype of which first took flight in 1996 on the Mississippi River, near Cordova, Illinois. Since 1999, Universal Hovercraft has been selling plans, parts, kits , and manufactured GEV hovercraft called the Hoverwing.

In Singapore, Wigetworks has continued the development of the technology and has successfully obtained the full certification from Lloyd's Register for entry into class. AirFish 8 - 001 was successfully registered into Singapore Registry of Ships (SRS) on 31 Mar 10. It is the first WIG craft to be flagged with the SRS which is one of the world's top 10 largest ship registry. Wigetworks has also partnered National University of Singapore's Engineering Department to develop higher capacity WIG crafts.

Iran deployed three squadrons of Bavar-2 two-seat GEVs in September, 2010. It carries one machine gun and surveillance gear, and is said to employ some form of stealth technology.

Classification

One of the problems that have delayed the development of these craft is the classification and legislation to be applied. IMO has studied the application of rules based on the

International Code of Safety for High-Speed Craft (HSC code) which was developed for fast ships such as hydrofoils, hovercraft, catamarans and the like. The Russian Rules for classification and construction of small type A ekranoplans is a document upon which most GEV design is based. However in 2005, the IMO classified the WISE or GEV crafts under the category of ships.

The International Maritime Organization recognizes three classes of ground effect craft:

1. **Type A**: a craft which is certified for operation only in ground effect;
2. **Type B**: a craft which is certified to temporarily increase its altitude to a limited height outside the influence of ground effect but not exceeding 150 m above the surface; and
3. **Type C**: a craft which is certified for operation outside of ground effect and exceeding 150 m above the surface.

Note: These classes currently only apply to craft carrying 12 passengers or more

Advantages and disadvantages

A ground effect craft may have better fuel efficiency than an equivalent aircraft flying at low level due to the close proximity of the ground, reducing lift-induced drag. There are also safety benefits for the occupants of the craft in flying close to the water as an engine failure will not result in severe ditching. However, this particular configuration is difficult to fly even with computer assistance. Flying at very low altitudes, just above the sea, is dangerous if the craft banks too far to one side while making a small radius turn.

A takeoff must be into the wind, which in the case of a water launch, means into the waves. This creates drag and reduces lift. Two main solutions to this problem have been implemented. The first was used by the Russian Ekranoplan program which placed engines in front of the wings to provide more lift. The Caspian Sea Monster had eight such engines, some of which were not used once the craft was airborne. A second approach is to use some form of an air-cushion to raise the vehicle most of the way out of the water, making take-off easier. This is used by German Hanno Fischer in the Hoverwing (successor to the Airfisch ground effect craft), which uses some of the air from the engines to inflate a skirt under the craft in the style of a sidewall hovercraft.

Wing configurations

Inverse delta

Developed by Alexander Lippisch, this wing allows stable flight in ground effect through self stabilization. This is the main Class B form of ground effect craft.

Ekranoplan wing

This was the profile designed by Rostislav Alexeyev. The wings are significantly shorter than comparable aircraft, and this configuration requires a high aft-placed horizontal tail and front-aft wings to maintain stability.

Tandem wings

Tandem Wing can have two configurations.

- A biplane-style Type-1 utilizing a shoulder mounted main lift wing and a belly-mounted sponsons similar to those on combat and transport helicopters.
- A canard-style type-2 with a mid-size horizontal stabilizer near the nose of the craft directing airflow under the Main Lift Airfoil. This Type-2 tandem design is a major improvement during take-off as it creates an air cushion to lift the craft above the water at a lower speed, thereby reducing water drag which is the biggest obstacle to successful seaplane launches.
- A Tandem Wing Style with double-wing system as built in Tandem Airfoilboat constructions by Dipl. Ing. Günther Jörg. This system is self-stabilizing and leads to a very secure and comfortable Wing in Ground Effect Flight which is very economical as well.

Russian light ekranoplan Aquaglide-2

Design

The important design principle is that the wing lift reduces as the operating altitude increases, so the ekranoplan is dynamically stable in the vertical dimension. Once moving at speed, the ekranoplan is no longer in contact with the water, and can move over ice, snow or level land with equal ease, though flight over land would involve extreme risks unless the surface is dependably flat.

The KM, as the Caspian Sea Monster was known in the Soviet military development program, was over 100 metres (328 ft) long, weighed 540 t (531 long tons) fully loaded, and could travel over 400 kilometres per hour (249 mph), a mere few metres above the surface of the water. Another model was the Lun, entering service with the Black Sea Fleet in 1987; the Lun-class vehicles had a top speed of 297 knots (550 km/h) (341 mph) flying in ground effect and 550 knots at altitude. The Lun ekranoplan had a potential lifting power of 1,000 tonnes (984 long tons).

Chapter- 8

Ornithopter

Cybird radio-controlled ornithopter

An **ornithopter** (from Greek *ornithos* "bird" and *pteron* "wing") is an aircraft that flies by flapping its wings. Designers seek to imitate the flapping-wing flight of birds, bats, and insects. Though machines may differ in form, they are usually built on the same scale as these flying creatures. Manned ornithopters have also been built, and some have been successful. The machines are of two general types: those with engines, and those powered by the muscles of the pilot.

Early history of the ornithopter

The idea of constructing wings in order to resemble the flight of birds dates to the ancient Greek legend of Daedalus (Greek demigod engineer) and Icarus (Daedalus's son). The Chinese *Book of Han* records that Xin Dynasty Emperor Wang Mang oversaw the earliest ornithopter flight test in 19 AD.

One man said that he could fly a thousand *li* in a day, and spy out the (movements of the) Huns. (Wang) Mang tested him without delay. He took (as it were) the pinions of a great bird for his two wings, his head and whole body were covered over with feathers, and all this was interconnected by means of (certain) rings and knots. He flew a distance of several hundred paces, and then fell to the ground.

Among the first recorded attempts with gliders were those by the 11th century monk Eilmer of Malmesbury (recorded in the 12th century) and the 9th century poet Abbas Ibn Firnas (recorded in the 17th century); the reported flights were probably just glides and resulted in injury. Roger Bacon, writing in 1260, was also among the first to consider a technological means of flight. In 1485, Leonardo da Vinci began to study the flight of birds. He grasped that humans are too heavy, and not strong enough, to fly using wings simply attached to the arms. Therefore he proposed a device in which the aviator lies down on a plank and works two large, membranous wings using hand levers, foot pedals, and a system of pulleys.

The first ornithopters capable of flight were constructed in France. In 1858 Pierre Julien's model flew an estimated forty feet. Gustave Trouvé's 1870 model flew a distance of 70 metres in a demonstration for the French Academy of Sciences. The wings were flapped by gunpowder charges activating a bourdon tube. Jobert in 1871 used a rubber band to power a small model bird. Alphonse Penaud, Abel Hureau de Villeneuve, Victor Tatin, Frank Kieser, and others also made designs and models.

From 1884 on, Lawrence Hargrave built scores of ornithopters powered by rubber bands, springs, steam, or compressed air. He introduced the use of small flapping wings providing the thrust for a larger fixed wing. This eliminated the need for gear reduction, thereby simplifying the construction. To achieve a more birdlike appearance, this approach is not generally favored today.

In the 1930s, Erich von Holst carried the rubber band powered bird model to a high state of development and great realism. Also in the 1938, Alexander Lippisch and other researchers in Germany harnessed the piston internal combustion engine.

Manned flight

Otto Lilienthal on August 16, 1894 with his *kleiner Schlagflügelapparat*

Schmid 1942 Ornithopter

The *UTIAS Ornithopter No.1*

Manned ornithopters fall into two general categories: Those powered by the muscular effort of the pilot (human-powered ornithopters), and those powered by an engine.

Around 1894, Otto Lilienthal became famous in Germany for his widely publicized and successful glider flights. Lilienthal also studied bird flight and conducted some related experiments. He constructed an ornithopter, although its complete development was prevented by his untimely death.

In 1929, a man-powered ornithopter designed by Alexander Lippisch (designer of the Me163 Komet) flew a distance of 250 to 300 metres after tow launch. Since a tow launch was used, some have questioned whether the aircraft was capable of flying on its own. Lippisch asserted that the aircraft was actually flying, not making an extended glide. (Precise measurement of altitude and velocity over time would be necessary to resolve this question.) Most of the subsequent human-powered ornithopters likewise used a tow launch, and flights were brief simply because human muscle power diminishes rapidly over time.

In 1942, Adalbert Schmid made a much longer flight of a human-powered ornithopter at Munich-Laim. It travelled a distance of 900 metres, maintaining a height of 20 metres throughout most of the flight. Later this same aircraft was fitted with a 3 hp Sachs motorcycle engine. With the engine, it made flights up to 15 minutes in duration. Schmid later constructed a 10 hp ornithopter based on the Grunau-Baby IIa sailplane, which was flown in 1947. The second aircraft had flapping outer wing panels.

In 2005, Yves Rousseau was given the Paul Tissandier Diploma, awarded by the FAI for contributions to the field of aviation. Rousseau attempted his first human-muscle-powered flight with flapping wings in 1995. On 20 April 2006, at his 212th attempt, he succeeded in flying a distance of 64 metres, observed by officials of the Aero Club de France. Unfortunately, on his 213th flight attempt, a gust of wind led to a wing breaking up, causing the pilot to be gravely injured and rendered paraplegic.

A team at the University of Toronto Institute for Aerospace Studies, headed by Professor James DeLaurier, worked for several years on an engine-powered, piloted ornithopter. In July 2006, at the Bombardier Airfield at Downsview Park in Toronto, Professor DeLaurier's machine, the UTIAS Ornithopter No.1 made a jet-assisted takeoff and 14-second flight. According to DeLaurier, the jet was necessary for sustained flight, but the flapping wings did most of the work.

On August 2, 2010, Todd Reichert of the University of Toronto Institute for Aerospace Studies piloted a human-powered ornithopter named Snowbird. The 32-metre (105 ft 0 in) wingspan 92.59 pounds (42.00 kg) aircraft was constructed from carbon fibre, balsa and foam. The pilot sits in a small cockpit suspended below the wings and pumps a bar with his feet to operate a system of wires that flap the wings up and down. The pilot steers using a pair of metal bars attached to rudders on the back of the aircraft. Towed by a car until airborne, it then sustained 19.3 seconds of flight over a distance of 145 metres, an average speed of 15.91 miles per hour. Although similar tow-launched flights have been made in the past, improved data collection was used to verify that the ornithopter was capable of self-powered flight once aloft.

Applications for unmanned ornithopters

Practical applications capitalize on the resemblance to birds or insects. The Colorado Division of Wildlife has used these machines to help save the endangered Gunnison Sage Grouse. An artificial hawk under the control of an operator causes the grouse to remain on the ground so they can be captured for study.

Because ornithopters resemble birds or insects, they could be used for military applications, such as spying without alerting the enemies that they are under surveillance.

AeroVironment, Inc., led by Paul B. MacCready (Gossamer Albatross), has developed a remotely piloted ornithopter the size of a large insect for possible spy missions.

MacCready also developed in the mid-1980s, for the Smithsonian Institution, a half-scale radio controlled replica of the giant pterosaur, *Quetzalcoatlus northropi*. It was built to star in the IMAX movie *On the Wing*. The model had a wingspan of 5.5 metres (18 feet) and featured a complex, computerized autopilot control system, just as the full-size pterosaur relied on its neuromuscular system to make constant adjustments in flight.

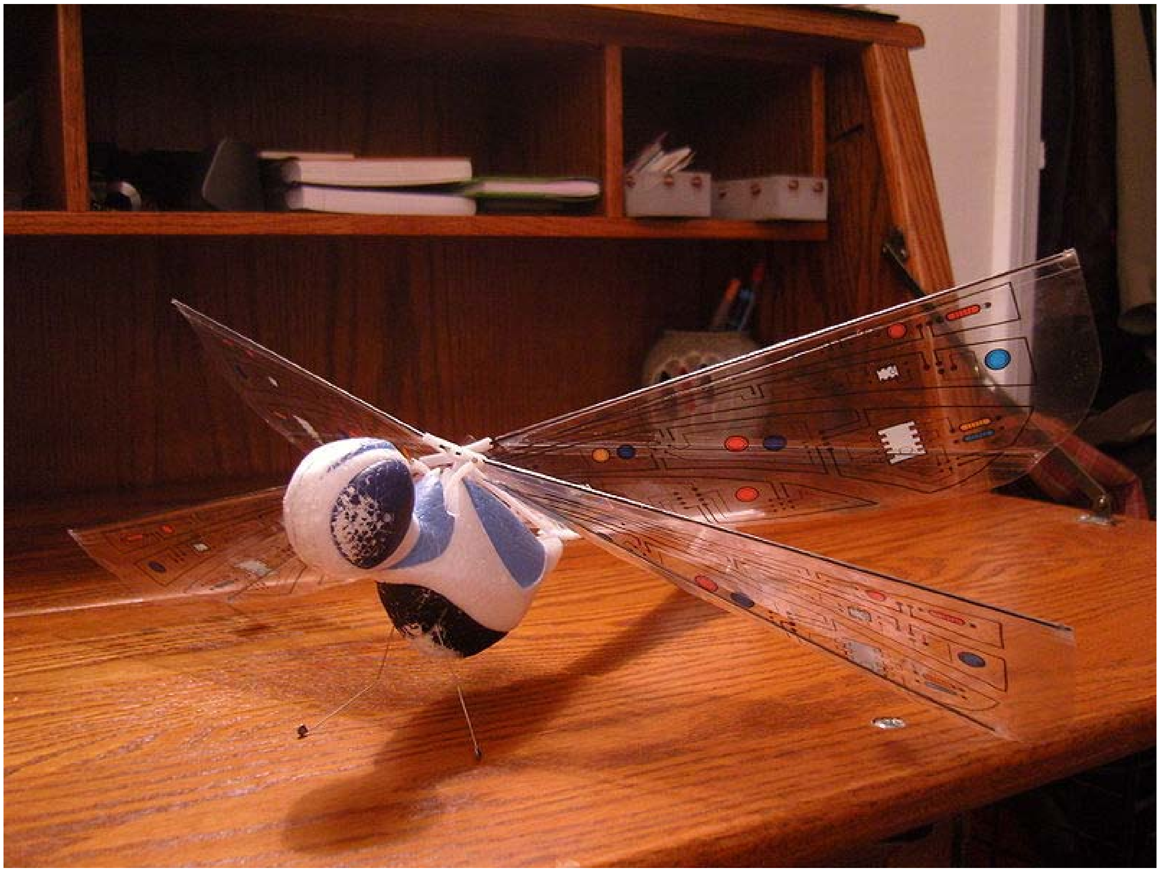
Researchers hope to eliminate the motors and gears of current designs by more closely imitating animal flight muscles. Georgia Tech scientist Robert C. Michelson is developing a Reciprocating Chemical Muscle for use in micro-scale flapping-wing aircraft. Michelson uses the term "entomopter" for this type of ornithopter. SRI International is developing polymer artificial muscles which may also be used for flapping-wing flight.

In 2002, Krister Wolff and Peter Nordin of Chalmers University of Technology in Sweden, built a flapping wing robot that learned flight techniques. The balsa wood design was driven by machine learning software technology known as a steady state linear evolutionary algorithm. Inspired by natural evolution, the software "evolves" in response to feedback on how well it performs a given task. Although confined to a laboratory apparatus, their ornithopter evolved behavior for maximum sustained lift force and horizontal movement.

Since 2002, Prof. Theo Van Holten has been working on an ornithopter which is constructed like a helicopter. The device is called the ornicopter and was made by constructing the main rotor so that it would have no reaction torque at all.

In 2008, Schiphol Airport started using a real looking mechanical hawk designed by falconer Robert Musters. The radio controlled robot bird is used to scare away birds that could damage the engines of airplanes.

Ornithopters as a hobby



The Dragonfly is a toy made by Wow-Wee.

Hobbyists can build and fly their own ornithopters. These range from light-weight models powered by rubber band, to larger models with radio control.

The rubber-band-powered model can be fairly simple in design and construction. Hobbyists compete for the longest flight times with these models. An introductory model can be fairly simple in design and construction, but the advanced competition designs are extremely delicate and challenging to build. Roy White holds the United States national record for indoor rubber-powered, with his flight time of 21 minutes, 44 seconds.

Commercial free-flight rubber-band powered toy ornithopters have long been available. The first of these was sold under the name *Tim Bird* in Paris in 1879. Later models were also sold as Tim Bird (made by G de Ruymbeke, France, since 1969).

Commercial radio controlled designs stem from Percival Spencer's engine-powered Seagulls, developed circa 1958, and Sean Kinkade's work in the late 1990s to present day. The wings are usually driven by an electric motor. Many hobbyists enjoy experimenting with their own new wing designs and mechanisms. The opportunity to interact with real birds in their own domain also adds great enjoyment to this hobby. Birds are often curious and will follow or investigate the model while it is flying. In a few cases, RC birds have been attacked by birds of prey, crows, and even cats. More recent cheaper models such as the Dragonfly from WowWee have extended the market from dedicated hobbyists to the general toy market,

Some helpful resources for hobbyists include The Ornithopter Design Manual, book written by Nathan Chronister, and The Ornithopter Zone web site, which includes a large amount of information about building and flying these models.

Aerodynamics

As demonstrated by birds, flapping wings offer potential advantages in maneuverability and energy savings compared with fixed-wing aircraft, as well as potentially vertical take-off and landing. It has been suggested that these advantages are greatest at small sizes and low flying speeds.

Unlike airplanes and helicopters, the driving airfoils of the ornithopter have a flapping or oscillating motion, instead of rotary. As with helicopters, the wings usually have a combined function of providing both lift and thrust. Theoretically, the flapping wing can be set to zero angle of attack on the upstroke, so it passes easily through the air. Since typically the flapping airfoils produce both lift and thrust, drag-inducing structures are minimized. These two advantages potentially allow a high degree of efficiency.

In propeller- or jet-driven aircraft, the propeller creates a relatively narrow stream of relatively fast moving air. The energy carried by the air is lost. The same amount of force can be produced by accelerating a larger mass of air to a smaller velocity, for example by using a larger propeller or adding a bypass fan to a jet engine. Use of flapping wings offers even larger displaced air mass, moved at lower velocity, thus improving efficiency.

Wing Design

Birds inspired Leonardo da Vinci when he designed his ornithopter in 1490. Leonardo da Vinci was interested in flying during 1488–1514. He never saw his dream of flight take place because his ornithopter was too heavy and required too much energy to produce lift or thrust. In 1929, the human-powered ornithopter constructed by Alexander Lippisch was towed into the air and glided around. In 1959, in England, another ornithopter was towed into the air and demonstrated the ornithopter being a birdlike machine. By the 1960s, there were powered unmanned ornithopter flights of various sizes demonstrating how ornithopters flew. In 1991 Harris and DeLaurier flew the first successful engine-powered remotely piloted ornithopter in Toronto, Canada. By 1999, there was an ornithopter design that was designed to take off from a level pavement.

Lift is the force that uses Bernoulli's principle to keep things in the air and weight is the force that pulls things towards the ground. Thrust is the force that moves things through the air while Drag is the force of flight that is an aerodynamic force that reduces speed.

In order to create an effective ornithopter, it had to be able to flap its wings to generate enough power to get off the ground and travel through the air. Efficient flapping of the wing is characterized by pitching angles, lagging plunging displacements by approximately 90 degrees. Flapping wings increase drag and are not as efficient as propeller-powered aircraft. To increase efficiency of the ornithopter, more power is required on the down stroke than on the upstroke. If the wing on the ornithopter was not flexible and flapped at the same angle while moving up and down, it would act like a huge board moving in two dimensions, not producing lift or thrust. The flexibility and move-ability of the wing let it twist and bend to the reactions of the ornithopter while in flight.

The interest in developing a successful powered ornithopter similar to birds and bats, was one many sought after. In order to get around the problem of not having enough energy for sustained flight, the ornithopter would be required to produce enough lift and thrust to travel through the air. Alphonse Pénaud introduced the idea of a powered ornithopter in 1874. His design had limited power and was uncontrollable causing it to be transformed into a toy for children.

The wing design is designed with the spar as far forward of the airfoil but still having acceptable dimensions of strength. Engineers and researchers have experimented with wings that require carbon fiber, plywood, fabric, ribs, and the trailing edge to be stiff, strong, and for the mass to be as low as possible. Any mass located to the aft or empennage, reduce the wings performance and hinder the design of the ornithopter. In order to calculate the performance of the ornithopter, the wings lift is determined by the lift of the wing versus weight, drag and thrust. A smooth aerodynamic surface with a double-surface airfoil is more efficient then a single-surface airfoil to produce more lift.

A variation of ornithopters has the wings and flapping surfaces towards the empennage to increase stabilizing forces and thrust. With different designs, ornithopters do not act like birds or bats in flight. Typically birds and bats have thin and cambered wings to produce lift and thrust. Ornithopters with thinner wings have a limited angle of attack but provide optimum minimum-drag performance in a single value of lift coefficient.

Although Hummingbirds fly with fully extended wings, an ornithopter would not be able to effectively fly that way. If an ornithopter wing were to fully extend and twist and flap in small movements it would cause a stall but if it were to twist and flap in very large motions, then it would act like a windmill causing an inefficient flying situation.

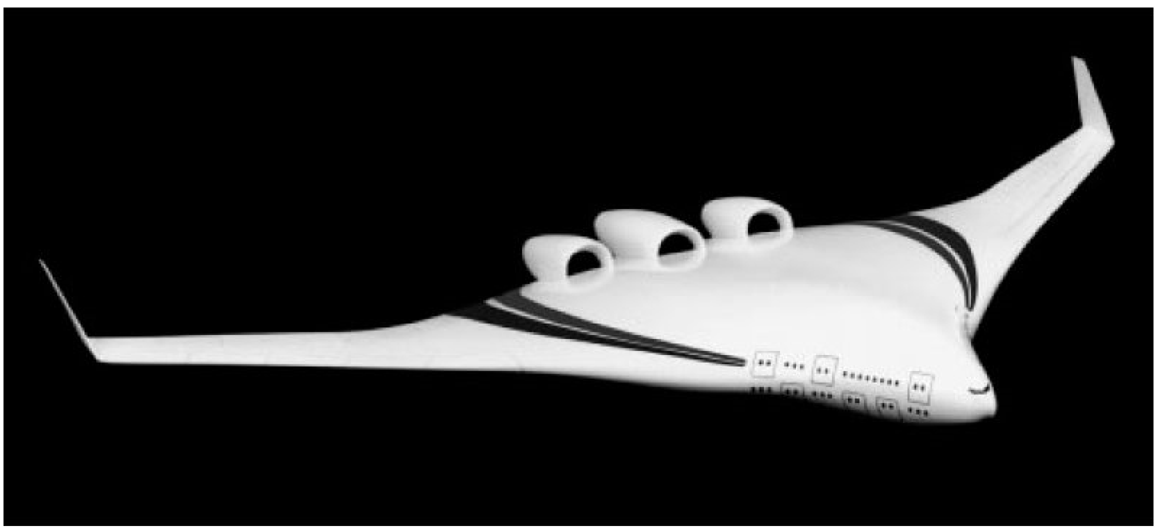
A team of engineers and researchers called "Fullwing" has created an ornithopter that has an average lift of over 8 pounds, an average thrust of 0.88 pounds, and has a propulsive efficiency of 54%. The wings were tested in a low speed wind tunnel measuring the aerodynamic performance. Discovering that the higher the frequency of the wing beat, the higher the average thrust of the ornithopter.

It is unclear what the ornithopters future would be. With the development of Airplanes, Helicopters, VTOL, UAV, and other aircraft, it is unclear where the ornithopter will fit into society. Canada is currently working with ornithopters to produce more effective flying machines. Although the idea of the ornithopter is not new, there is not little understanding behind the idea.

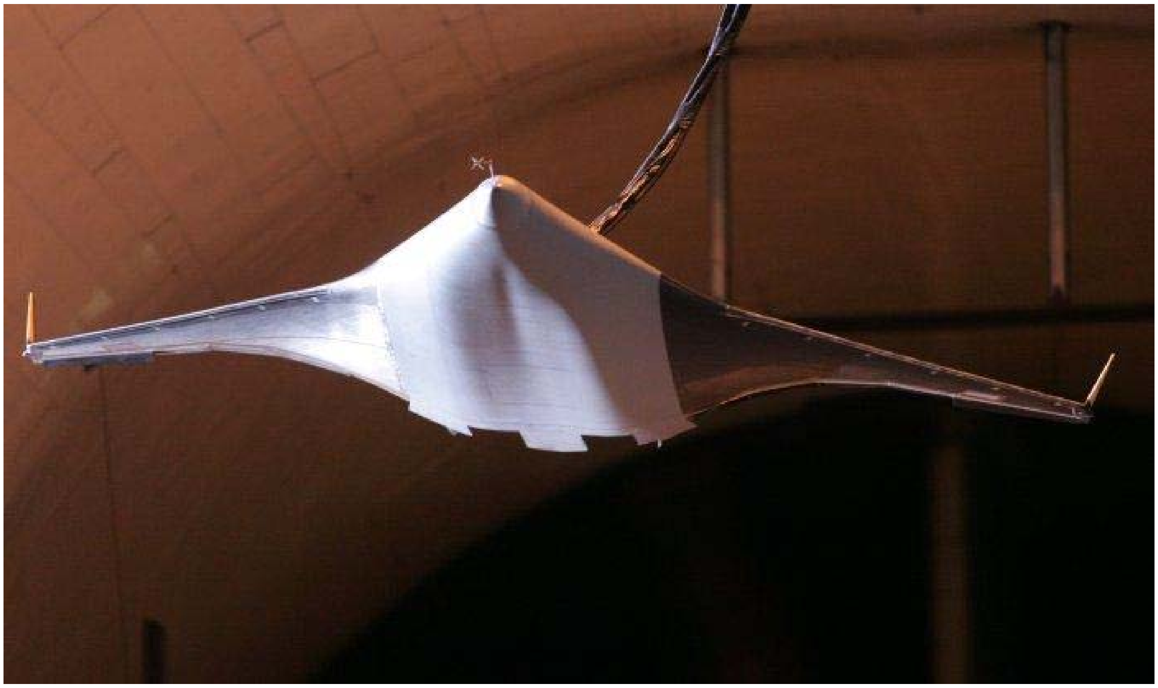
Chapter- 9

Blended Wing Body and Coleopter

Blended wing body



Computer-generated model of the Boeing X-48.



NASA's prototype of a Blended Wing aircraft

Blended Wing Body, or BWB, designates an alternative airframe design which incorporates design features from both a futuristic fuselage and flying wing design. The purported advantages of the BWB approach are efficient high-lift wings and a wide airfoil-shaped body. This enables the entire craft to contribute to lift generation with the result of potentially increased fuel economy.

Flying wing designs are defined as having two separate bodies and only a single wing, though there may be structures protruding from the wing. Blended wing/body aircraft have a flattened and airfoil shaped body, which produces most of the lift to keep itself aloft, and distinct and separate wing structures, though the wings are smoothly blended in with the body.

History

An early aircraft exhibiting BWB design principles was the Stout Batwing. The designer William Bushnell Stout, toured the country promoting aircraft of the future would not have fuselages.

The Junkers G.38, flew in 1929. This "super jumbo" airliner of its day, seated thirty-four passengers, six in each of its two meter thick wings, and the balance in the central fuselage. In comparison, a contemporary passenger aircraft, the Ford Trimotor, carried a total of nine passengers in its more traditional wing and box fuselage design. Another example of similar design is Burnelli CBY-3. It had an airfoil shaped fuselage, producing significant part of the total lift. The CBY-3 had however a fairly conventional twin-boom empennage for added stability.

The Miles M.30 "X Minor" of the early 1940s was an experimental aircraft for research blended wing fuselage designs for an envisaged large airliner. Germany was designing blended wing body jet bombers at the very end of World War II.

In some ways, the B-2 Spirit stealth bomber is a design which falls between classic flying wing concepts and the BWB concept. It is usually classified as a flying wing, however, as the protruding body sections are not much larger than the underlying wing shape structure.

Currently, both NASA and Boeing are exploring BWB designs under the designation X-48. Studies suggest that BWB aircraft, configured for passenger flight, could carry from 450 to 800 passengers and achieve fuel savings of over 20 percent. NASA has been developing, since 2000, a remotely controlled model with a 21 ft (6.4 m) wingspan. This research is focused on establishing the base data concerning the lift, stall and spin characteristics inherent in a Blended Wing Body design.

Progression of aircraft design concepts from conventional airliner (1), blended wing-body (2), hybrid flying wing (3), flying wing (4). Note that the progression does not represent either a chronological or technical progression; the YB-49 (4), representing a true flying wing, actually predates all other depicted aircraft, while the "conventional" Boeing 757 (1) is a relatively new and technologically advanced aircraft.

Potential advantages

- Significant payload advantages in strategic airlift/air freight and aerial refueling roles

Coleopter

VXT-8 mockup on display at the Hiller Aviation Museum

A **coleopter** is a type of Vertical Take-Off and Landing aircraft design that uses a ducted fan as the primary fuselage of the entire aircraft. Generally they appear to be a large barrel-like extension at the rear, with a small cockpit area suspended above it. Like most ducted fan designs, coleopters are generally arranged to take off and land on its tail. The term is an anglicisation of the French *coléoptère* (beetle) after the first actual implementation of this design, the SNECMA Coléoptère of the mid 1950s.

The first design of an aircraft clearly using the coleopter concept was developed during World War II. From 1944 on the Luftwaffe was suffering from almost continual daytime attacks on its airfields, and was finding it almost impossible to conduct large scale operations. Their preferred solution was to introduce some sort of VTOL interceptor that could be launched from any open location, and there were many proposals for such a system. Heinkel conducted a series of design studies as part of their Wespe and Lerche programs. The Wespe intended to use a Benz 2,000 hp turboprop engine, but these were not forthcoming and the Lerch used two Daimler-Benz DB 605 piston engines instead. Nothing ever came of either design.

In the immediate post-war era, most VTOL research centered on the helicopter. However, as the limitations of the simple rotary wing became clear, teams started looking for other solutions and many turned to using jet engines directly for vertical thrust. SNECMA developed a series of such systems as part of their Atar Volant series during the 1950s. To further improve the design, SNECMA had Nord Aviation built an annular wing and adapted it to the last of the Volant series to produce the C.450 Coléoptère. The Coléoptère first flew on 6 May 1959, but crashed on 25 July and no replacement was built. Even in this limited testing period, the design showed several serious problems related to the high angular momentum of the engine, which made control tricky.

In the US, Hiller Helicopters had been working on a number of ducted fan flying platforms originally designed by Charles Zimmerman. After some early successes, the Army demanded a series of changes that continued to increase the size and weight of the platform, which introduced new stability problems. These generally required more size and power to correct, and no satisfactory design came from these efforts. Instead, Hiller approached the Navy with the idea of building a full coleopter design. This emerged as the Hiller VXT-8 which was significantly similar to the SNECMA design, although it used a propeller instead of a jet engine. However, the introduction of turbine-powered helicopters like the UH-1 Huey so significantly improved their performance over piston-powered designs that the Navy lost interest in the VXT-8 in spite of even better estimated performance. Only a mock-up was completed.

Convair selected the coleopter layout for their Model 49 proposal, entered into the Advanced Aerial Fire Support System (AAFSS). AAFSS asked for a new high-speed helicopter design for the attack and escort roles, and gathered an impressive array of compound helicopters, dual-rotor designs and similar advances on conventional designs, but nothing was as unconventional as the Model 49. The Army "went conventional" however, and selected the AH-56 Cheyenne and Sikorsky S-66 for further development.

Chapter- 10

Fixed-Wing Aircraft

PZL-104M Wilga 2000 of Polish Border Guard. This fixed-wing aircraft is notable for its full-span fixed aerodynamic slot on the leading edge of its wing.

A **fixed-wing aircraft**, typically called an **aeroplane**, **airplane** or simply **plane**, is an aircraft capable of flight using forward motion that generates lift as the wing moves through the air. Planes include jet engine and propeller driven vehicles propelled forward by thrust, as well as unpowered aircraft (such as gliders), which use thermals, or warm-air pockets to inherit lift. Fixed-wing aircraft are distinct from ornithopters in which lift is generated by flapping wings and rotary-wing aircraft in which wings rotate about a fixed mast.

Most fixed-wing aircraft are flown by a pilot on board the aircraft, but some are designed to be remotely or computer controlled.

Etymology

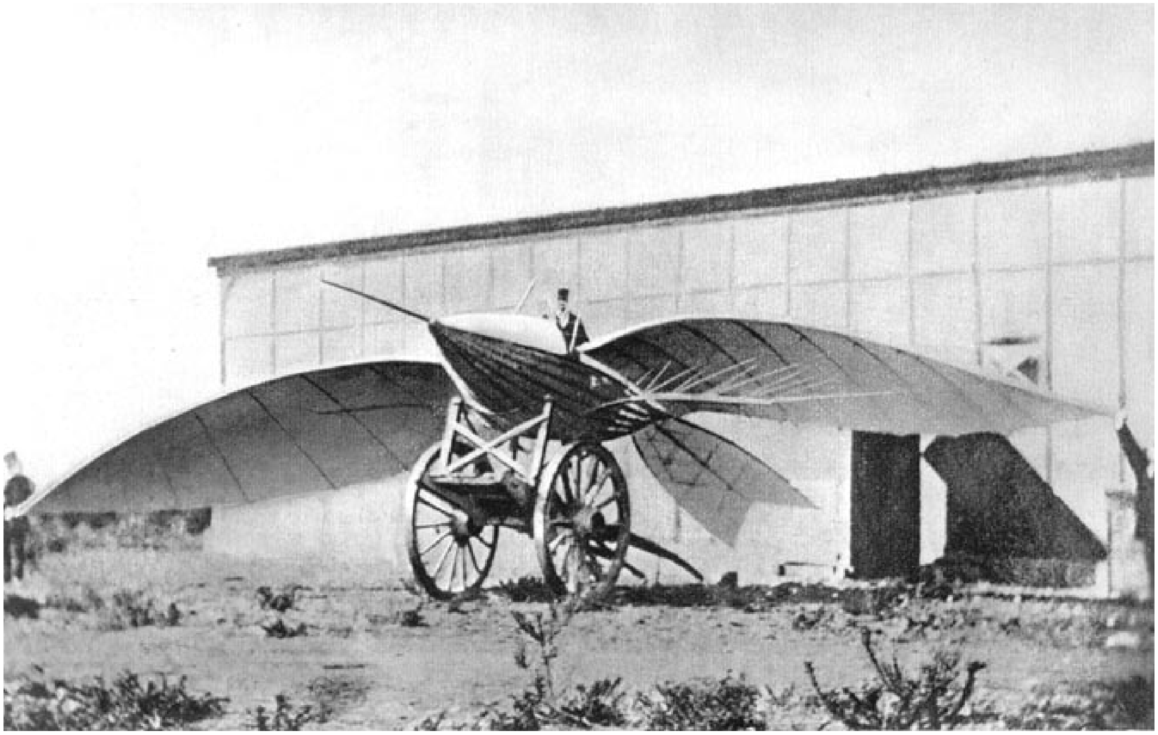
First attested in English in late 19th century, the word *aeroplane* derives from the French *aéroplane*, which comes from the Greek ἀήρ (*aēr*), "air" + πλάνος (*planos*), "wandering". An ancient Greek term coined from these two words was ἀερόπλανος (*aeroplanos*), "wandering in air".

In the United Kingdom and most of the Commonwealth, the term "aeroplane" is used. In the United States and Canada, the term "airplane" is applied to these aircraft. The form "aeroplane" is the older of the two, dating back to the mid- to late-19th century. The spelling "airplane" was first recorded in 1907.

History

Heavier-than-air flying machines are impossible.
—Lord Kelvin

The dream of flight goes back to the days of pre-history. Many stories from antiquity involve flight, such as the Greek legend of Icarus and Daedalus, and the Vimana in ancient Indian epics. Around 400 BC, Archytas, the Ancient Greek philosopher, mathematician, astronomer, statesman, and strategist, was reputed to have designed and built the first artificial, self-propelled flying device, a bird-shaped model propelled by a jet of what was probably steam, said to have actually flown some 200 m. This machine, which its inventor called *The Pigeon* (Greek: *η Περιστέρα* "hè Peristera"), may have been suspended on a wire or pivot for its flight. One of the first recorded – still dilettante – attempts with gliders were those by the 11th century monk Eilmer of Malmesbury (recorded in the 12th century) and the 9th century poet Abbas Ibn Firnas (recorded in the 17th century); both experiments ended with lasting injuries to their pilots. Leonardo da Vinci researched the wing design of birds and designed a man-powered aircraft in his *Codex on the Flight of Birds* (1502). In the 18th century, Francois Pilatre de Rozier and François Laurent d'Arlandes flew in an aircraft lighter than air, a balloon. The biggest challenge became to create other craft, capable of controlled flight.



Le Bris and his glider, Albatros II, photographed by Nadar, 1868.

Sir George Cayley, the founder of the science of aerodynamics, credited as the first person to separate the forces of lift and drag which are in effect on any flight vehicle, in 1799 he set forth the concept of the modern aeroplane as a fixed-wing flying machine with separate systems for lift, propulsion, and control. Cayley was building and flying models of fixed-wing aircraft as early as 1803, and he built a successful passenger-carrying glider in 1853. In 1856, Frenchman Jean-Marie Le Bris made the first powered flight, by having his glider *"L'Albatros artificiel"* pulled by a horse on a beach. On 28 August 1883, the American John J. Montgomery made a controlled flight in a glider. Other aviators who made similar flights at that time were Otto Lilienthal, Percy Pilcher and Octave Chanute.

In the 1890s, Australian inventor and aviator Lawrence Hargrave conducted research on wing structures and developed a box kite that lifted the weight of a man. His box kite designs were widely adopted and became the prevalent type of aircraft until 1909. Although he also developed a type of rotary aircraft engine, he did not create and fly a powered fixed-wing aircraft.

An article in the Bridgeport *Sunday Herald* claimed that on 14 August 1901, in Fairfield, Connecticut, Gustave Whitehead reportedly flew his engine-powered Number 21 aeroplane for half a mile at 15 m height. No photographs were taken, but a sketch of the plane in the air was published with the article.

The Wright brothers made their first successful test flights on 17 December 1903. Their flights are recognised by the Fédération Aéronautique Internationale (FAI), the standard setting and record-keeping body for aeronautics and astronautics, as "the first sustained and controlled heavier-than-air powered flight". By 1905, the Wright Flyer III was capable of fully controllable, stable flight for substantial periods.

On 12 November 1906, Santos-Dumont made what Brazilians say was the first airplane flight unassisted by catapult and set the first world record recognised by the Aéro-Club de France by flying 220 metres (720 ft) in less than 22 seconds. This flight was also certified by the *Fédération Aéronautique Internationale* (FAI).

World War I served as a testbed for the use of the aircraft as a weapon. Initially seen by the generals as a "toy", aircraft demonstrated their potential as mobile observation platforms, then proved themselves to be machines of war capable of causing casualties to the enemy. The earliest known aerial victory with a synchronised machine gun-armed fighter aircraft occurred on July 1, 1915, by German Luftstreitkräfte *Leutnant* Kurt Wintgens. "Fighter aces" appeared, described as "knights of the air"; the greatest (by number of air victories) was the German Manfred von Richthofen, the *Red Baron*. On the side of the allies, the ace with the highest number of downed aircraft was René Fonck, of France. All-metal-structure aircraft took their first steps into reality during the World War I era, through the work of Hugo Junkers in the creation of the Junkers J 1 in 1915.

Following the war, aircraft technology continued to develop. Alcock and Brown crossed the Atlantic non-stop for the first time in 1919, a feat first performed solo by Charles Lindbergh in 1927. The first commercial flights took place between the United States and Canada in 1919. The turbine or the jet engine was in development in the 1930s; military jet aircraft began operating in the 1940s.

Aircraft played a primary role in the Second World War, having a presence in all the major battles of the war: Pearl Harbor, the battles of the Pacific, the Battle of Britain. They were an essential component of the military strategies of the period, such as the German Blitzkrieg or the American and Japanese aircraft carrier campaigns of the Pacific.

In October 1947, Chuck Yeager was the first person to exceed the speed of sound, flying the Bell X-1.

Aircraft in a civil military role continued to feed and supply Berlin in 1948, when access to rail roads and roads to the city, completely surrounded by Eastern Germany, were blocked, by order of the Soviet Union.

The Cold War played a large role in the production of new aircraft, such as the B-52.

The first commercial jet, the de Havilland Comet, was introduced in 1952. The Boeing 707, the first widely successful commercial jet, was in commercial service for more than 50 years, from October 26, 1958 to June 22, 2010. The Boeing 727 was another widely used passenger aircraft, and the Boeing 747 was the world's biggest commercial aircraft between 1970 and 2005, when it was surpassed by the Airbus A380.

Overview

Structure

The Tupolev Tu-160, a supersonic, variable-geometry heavy bomber

The Lockheed P-38 Lightning, a twin-engine fixed-wing aircraft with a twin-boom configuration.

A Sukhoi Su-27UB of the Russian Knights aerobatic team showing two vertical stabilizers

An General Dynamics F-16 Fighting Falcon, a US military fixed-wing aircraft

The Mexican unmanned aerial vehicle S4 Ehécatl at take-off

A Boeing KC-135 Stratotanker refueling an McDonnell Douglas F-15 Eagle. The KC-135 holds the record for the longest military service.

The structure of a fixed-winged aircraft usually consists of the following major parts, however some varieties of aircraft, such as flying wing aircraft, may lack a discernible fuselage structure and horizontal or vertical stabilisers:

- A long narrow, cylindrical, spherical, odd shaped, form, called a *fuselage,* usually with tapered or rounded ends to make its shape aerodynamically smooth. The fuselage carries the human flight crew if the aircraft is piloted, the passengers if the aircraft is a passenger aircraft, other cargo or payload, and engines and/or fuel if the aircraft is so equipped. The pilots operate the aircraft from a *cockpit* located at the front or top of the fuselage and equipped with windows, controls, and instruments. Passengers and cargo occupy the remaining available space in the fuselage. Some aircraft may have two fuselages, or additional pods or booms.
- A *wing* (or wings in a multiplane) with an airfoil cross-section shape, used to generate aerodynamic lifting force to support the aircraft in flight by deflecting air downward as the aircraft moves forward. The wing halves are typically symmetrical about the plane of symmetry (for symmetrical aircraft). The wing also stabilises the aircraft about its roll axis and the ailerons control rotation about that axis.
- At least one control surface (or surfaces) mounted vertically usually above the rear of the fuselage, called a *vertical stabiliser.* The vertical stabiliser is used to stabilise the aircraft about its yaw axis (the axis in which the aircraft turns from side to side) and to control its rotation along that axis. Some aircraft have multiple vertical stabilisers.
- At least one horizontal surface at the front or back of the fuselage used to stabilise the aircraft about its pitch axis (the axis around which the aircraft tilts upward or downward). The horizontal stabiliser (also known as tailplane) is usually mounted near the rear of the fuselage, or at the top of the vertical stabiliser, or sometimes a canard is mounted near the front of the fuselage for the same purpose.
- On powered aircraft, one or more *aircraft engines* are propulsion units that provide thrust to push the aircraft forward through the air. The engine is optional in the case of gliders that are not motor gliders. The most common propulsion units are propellers, powered by reciprocating or turbine engines, jet engines or even rocket motors, which provide thrust directly from the engine and usually also from a large fan mounted within the engine. When the number of engines is even, they are distributed symmetrically about the roll axis of the aircraft, which lies along the plane of symmetry (for symmetrical aircraft); when the number is odd, the odd engine is usually mounted along the centreline of the fuselage.
- *Landing gear,* a set of wheels, skids, or floats that support the aircraft while it is on the surface.

Controls

A number of controls allow pilots to direct aircraft in the air. The controls found in a typical fixed-wing aircraft are as follows:

- A *yoke* or *joystick,* which controls rotation of the aircraft about the pitch and roll axes. A yoke resembles a kind of steering wheel, and a control stick is just a simple rod with a handgrip. The pilot can pitch the aircraft downward by pushing on the yoke or stick, and pitch the aircraft upward by pulling on it. Rolling the aircraft is accomplished by turning the yoke in the direction of the desired roll, or by tilting the control stick in that direction. Pitch changes are used to adjust the altitude and speed of the aircraft; roll changes are used to make the aircraft turn. Control sticks and yokes are usually positioned between the pilot's legs; however, a *sidestick* is a type of control stick that is positioned on either side of the pilot (usually the left side for the pilot in the left seat, and vice versa, if there are two pilot seats).
- *Rudder pedals,* which control rotation of the aircraft about the yaw axis. There are two pedals that pivot so that when one is pressed forward the other moves backward, and vice versa. The pilot presses on the right rudder pedal to make the aircraft yaw to the right, and on the left pedal to make it yaw to the left. The rudder is used mainly to balance the aircraft in turns, or to compensate for winds or other effects that tend to turn the aircraft about the yaw axis.
- A *throttle,* which adjusts the thrust produced by the aircraft's engines. The pilot uses the throttle to increase or decrease the rotation speed of the propeller (and thus the airspeed of the aircraft), and to adjust the aircraft's altitude (higher speeds cause the aircraft to climb, lower speeds cause it to descend). In some aircraft the throttle is a single lever that controls thrust; in others, adjusting the throttle means adjusting a number of different engine controls simultaneously. Aircraft with multiple engines usually have individual throttle controls for each engine.
- *Brakes,* used to slow and stop the aircraft on the ground, and sometimes for turns on the ground.

Other possible controls include:

- *Flap levers,* which are used to control the position of flaps on the wings.
- *Spoiler levers,* which are used to control the position of spoilers on the wings, and to arm their automatic deployment in aircraft designed to deploy them upon landing.
- *Trim controls,* which usually take the form of knobs or wheels and are used to adjust pitch, roll, or yaw trim. These are often connected to small airfoils on the trail edge of the control surfaces called 'trim tabs'.
- A *tiller,* a small wheel or lever used to steer the aircraft on the ground (in conjunction with or instead of the rudder pedals).
- A *parking brake,* used to prevent the aircraft from rolling when it is parked on the ground.

The controls may allow full or partial automation of flight, such as an autopilot, a wing leveler, or a flight management system. Pilots adjust these controls to select a specific attitude or mode of flight, and then the associated automation maintains that attitude or mode until the pilot disables the automation or changes the settings. In general, the larger and/or more complex the aircraft, the greater the amount of automation available to pilots.

On an aircraft with a pilot and copilot, or instructor and trainee, the aircraft is made capable of control without the crew changing seats. The most common arrangement is two complete sets of controls, one for each of two pilots sitting side by side, but in some aircraft (military fighter aircraft, some taildraggers and aerobatic aircraft) the dual sets of controls are arranged one in front of the other. A few of the less important controls may not be present in both positions, and one position is usually intended for the pilot in command (*e.g.,* the left "captain's seat" in jet airliners). Some small aircraft use controls that can be moved from one position to another, such as a single yoke that can be swung into position in front of either the left-seat pilot or the right-seat pilot (i.e. Beechcraft Bonanza).

Aircraft that require more than one pilot usually have controls intended to suit each pilot position, but still with sufficient duplication so that all pilots can fly the aircraft alone in an emergency. For example, in jet airliners, the controls on the left (captain's) side include both the basic controls and those normally manipulated by the pilot in command, such as the tiller, whereas those of the right (first officer's) side include the basic controls again and those normally manipulated by the copilot, such as flap levers. The unduplicated controls that are required for flight are positioned so that they can be reached by either pilot, but they are often designed to be more convenient to the pilot who manipulates them under normal condition.

Instruments

Instruments provide information to the pilot and the co-pilot. *Flight instruments* provide information about the aircraft's speed, direction, altitude, and orientation. *Powerplant instruments* provide information about the status of the aircraft's Aircraft engine/engines and APU. *Systems instruments* provide information about the aircraft's other systems, such as fuel delivery, electrical, and pressurisation. *Navigation and communication instruments* include all the aircraft's radios. Instruments may operate mechanically or electrically, requiring 12VDC, 24VDC, or 400 Hz power systems. An aircraft that uses computerised CRT or LCD displays almost exclusively is said to have a *glass cockpit.*

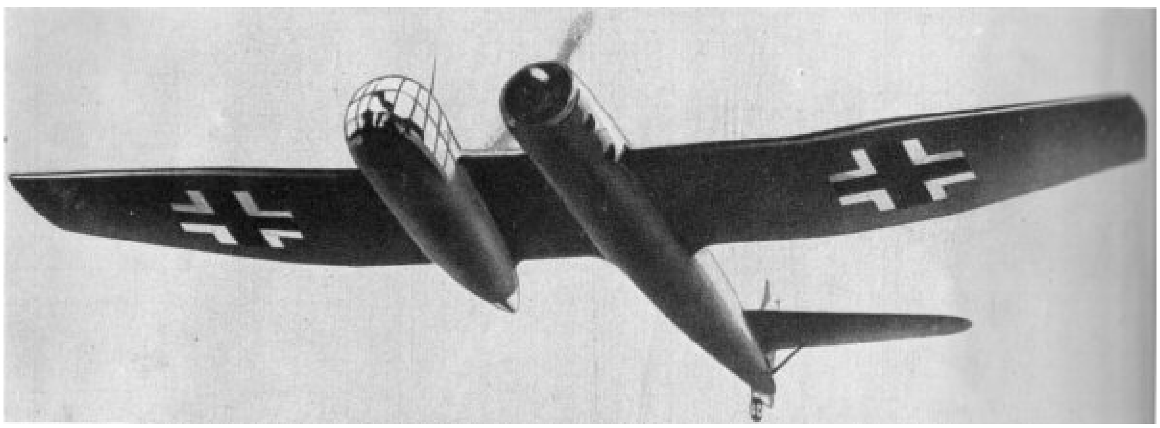
Basic instruments include:

- An *airspeed indicator,* which indicates the speed at which the aircraft is moving through the surrounding air.
- An *altimeter,* which indicates the altitude of the aircraft above mean sea level.
- A *Heading indicator,* (sometimes referred to as a "directional gyro (DG)") which indicates the magnetic compass heading that the aircraft's fuselage is pointing towards. The actual direction the aircraft is flying towards is affected by the wind conditions.
- An *attitude indicator,* sometimes called an *artificial horizon,* which indicates the exact orientation of the aircraft about its pitch and roll axes.

Other instruments might include:

- A *Turn coordinator,* which helps the pilot maintain the aircraft in a coordinated attitude while turning.
- A *Vertical Speed Indicator,* which shows the rate at which the aircraft is climbing or descending.
- A *horizontal situation indicator,* shows the position and movement of the aircraft as seen from above with respect to the ground, including course/heading and other information.
- Instruments showing the status of each engine in the aircraft (operating speed, thrust, temperature, and other variables).
- Combined display systems such as *primary flight displays* or *navigation displays.*
- Information displays such as on-board *weather radar* displays.

Design and construction



The Blohm & Voss BV 141 had an unusually asymmetric design.

Most aircraft are constructed by companies with the objective of producing them in quantity for customers. The design and planning process, including safety tests, can last up to four years for small turboprops, and up to 12 years for aircraft with the capacity of the A380.

During this process, the objectives and design specifications of the aircraft are established. First the construction company uses drawings and equations, simulations, wind tunnel tests and experience to predict the behavior of the aircraft. Computers are used by companies to draw, plan and do initial simulations of the aircraft. Small models and mockups of all or certain parts of the aircraft are then tested in wind tunnels to verify the aerodynamics of the aircraft.

When the design has passed through these processes, the company constructs a limited number of these aircraft for testing on the ground. Representatives from an aviation governing agency often make a first flight. The flight tests continue until the aircraft has fulfilled all the requirements. Then, the governing public agency of aviation of the country authorises the company to begin production of the aircraft.

In the United States, this agency is the Federal Aviation Administration (FAA), and in the European Union, Joint Aviation Authorities (JAA). In Canada, the public agency in charge and authorising the mass production of aircraft is Transport Canada.

In the case of the international sales of aircraft, a license from the public agency of aviation or transports of the country where the aircraft is also to be used is necessary. For example, aircraft from Airbus need to be certified by the FAA to be flown in the United States and vice versa, aircraft of Boeing need to be approved by the JAA to be flown in the European Union.

Quieter aircraft are becoming more and more needed due to the increase in air traffic, particularly over urban areas, as noise pollution is a major concern. MIT and Cambridge University have been designing delta-wing aircraft that are 25 times more silent (63 dB) than current craft and can be used for military and commercial purposes. The project is called the Silent Aircraft Initiative, but production models will not be available until around 2030.

Small aircraft can be designed and constructed by amateurs as homebuilts. Other homebuilt aircraft can be assembled using pre-manufactured kits of parts which can be assembled into a basic aircraft and must then be completed by the builder.

There are few companies that produce aircraft on a large scale. However, the production of an aircraft for one company is a process that actually involves dozens, or even hundreds, of other companies and plants, that produce the parts that go into the aircraft. For example, one company can be responsible for the production of the landing gear, while another one is responsible for the radar. The production of such parts is not limited to the same city or country; in the case of large aircraft manufacturing companies, such parts can come from all over the world.

The parts are sent to the main plant of the aircraft company, where the production line is located. In the case of large aircraft, production lines dedicated to the assembly of certain parts of the aircraft can exist, especially the wings and the fuselage.

When complete, an aircraft is rigorously inspected to search for imperfections and defects. After approval by inspectors, the aircraft is put through a series of flight tests to assure that all systems are working correctly and that the aircraft handles properly. Upon passing these tests, the aircraft is ready to receive the "final touchups" (internal configuration, painting, etc.), and is then ready for the customer.

Safety

There are three main statistics which may be used to compare the safety of various forms of travel:

Deaths per billion journeys

Bus: 4.3

Rail: 20

Van: 20

Car: 40

Foot: 40

Water: 90

Air: 117

Bicycle: 170

Motorcycle: 1640

Deaths per billion hours

Bus: 11.1

Rail: 30

Air: 30.8

Water: 50

Van: 60

Car: 130

Foot: 220

Bicycle: 550

Motorcycle: 4840

Deaths per billion kilometres

Air: 0.05

Bus: 0.4

Rail: 0.6

Van: 1.2

Water: 2.6

Car: 3.1

Bicycle: 44.6

Foot: 54.2

Motorcycle: 108.9

It is worth noting that the air industry's insurers base their calculations on the "number of deaths per journey" statistic while the industry itself generally uses the "number of deaths per kilometre" statistic in press releases.

Variants

Fixed-wing aircraft can be sub-divided according to the means of propulsion they use.

Unpowered

Aircraft that primarily intended for unpowered flight include gliders (sometimes called sailplanes), hang gliders and paragliders. These are mainly used for recreation. After launch, further energy is obtained through the skillful exploitation of rising air in the atmosphere. Gliders that are used for the sport of gliding have high aerodynamic efficiency. The highest lift-to-drag ratio is 70:1, though 50:1 is more common. Glider flights of thousands of kilometres at average speeds over 200 km/h have been achieved. The glider is most commonly launched by a tow-plane or by a winch. Some gliders, called motor gliders, are equipped with engines (often retractable) and some are capable of self-launching. The most numerous unpowered aircraft are hang gliders and paragliders. These are foot-launched and are generally slower, smaller and less expensive than sailplanes. Hang gliders most often have flexible wings which are given shape by a frame, though some have rigid wings. This is in contrast to paragliders which have no frames in their wings. Military gliders have been used in war to deliver assault troops, and specialised gliders have been used in atmospheric and aerodynamic research. Experimental aircraft and winged spacecraft have also made unpowered landings.

Propeller

Aquila AT01

Smaller and older propeller aircraft make use of reciprocating internal combustion engines that turns a propeller to create thrust. They are quieter than jet aircraft, but they fly at lower speeds, and have lower load capacity compared to similar sized jet powered aircraft. However, they are significantly cheaper and much more economical than jets, and are generally the best option for people who need to transport a few passengers and/or small amounts of cargo. They are also the aircraft of choice for pilots who wish to own an aircraft.

Turboprop aircraft are a halfway point between propeller and jet: they use a turbine engine similar to a jet to turn propellers. These aircraft are popular with commuter and regional airlines, as they tend to be more economical on shorter journeys.

Jet

A Ukrainian An-225 Mriya is the world's largest fixed-wing aircraft

Jet aircraft make use of turbines for the creation of thrust. These engines are much more powerful than a reciprocating engine. As a consequence, they have greater weight capacity and fly faster than propeller driven aircraft. One drawback, however, is that they are noisy; this makes jet aircraft a source of noise pollution. However, turbofan jet engines are quieter, and they have seen widespread usage partly for that reason.

The jet aircraft was developed in Germany in 1931. The first jet was the Heinkel He 178, which was tested at Germany's Marienehe Airfield in 1939. In 1943 the Messerschmitt Me 262, the first jet fighter aircraft, went into service in the German Luftwaffe. In the early 1950s, only a few years after the first jet was produced in large numbers, the De Havilland Comet became the world's first jet airliner. However, the early Comets were beset by structural problems discovered after numerous pressurisation and depressurisation cycles, leading to extensive redesigns.

Most wide-body aircraft can carry hundreds of passengers and several tons of cargo, and are able to travel for distances up to 17,000 km. Aircraft in this category are the Boeing 747, Boeing 767, Boeing 777, Boeing 787 and Airbus A350, Airbus A300/A310, Airbus A330, Airbus A340, Airbus A380, Lockheed L-1011 TriStar, McDonnell Douglas DC-10, McDonnell Douglas MD-11, Ilyushin Il-86 and Ilyushin Il-96.

Jet aircraft possess high cruising speeds (700 to 900 km/h, or 400 to 550 mph) and high speeds for take-off and landing (150 to 250 km/h). Due to the speed needed for takeoff and landing, jet aircraft make use of flaps and leading edge devices for the control of lift and speed, as well as thrust reversers to direct the airflow forward, slowing down the aircraft upon landing.

Supersonic jet

Supersonic aircraft, such as military fighters and bombers, Concorde, and others, make use of turbines (often utilising afterburners), that generate the huge amounts of power for flight faster than the speed of the sound. Flight at supersonic speed creates more noise than flight at subsonic speeds, due to the phenomenon of sonic booms. This limits supersonic flights to areas of low population density or open ocean. When approaching an area of heavier population density, supersonic aircraft are obliged to fly at subsonic speed.

Due to the high costs, limited areas of use and low demand there are no longer any supersonic aircraft in use by any major airline. The last Concorde flight was on 26 November 2003.

Solar-powered

Helios in flight

A solar-powered aircraft generates the needed energy by means of solar cells. On 8 July 2010 the manned Solar Impulse became the first solar-powered aeroplane to fly through an entire night.

Unmanned

An aircraft is said to be 'unmanned' when there is no person aboard the aircraft and control is achieved remotely or via other means such as gyroscopes or other forms of autonomous control. The aircraft is controlled only by remote controls or other electronic devices.

Rocket-powered

Bell X-1A in flight

Experimental rocket powered aircraft were developed by the Germans as early as World War II, and about 29 were manufactured and deployed. The first fixed wing aircraft to break the sound barrier in level flight was a rocket plane – the Bell X-1. The later North American X-15 was another important rocket plane that broke many speed and altitude records and laid much of the groundwork for later aircraft and spacecraft design. Rocket aircraft are not in common usage today, although rocket-assisted takeoffs are used for some military aircraft. SpaceShipOne is a well known current rocket aircraft, it is the prototype for development of a commercial sub-orbital passenger service. Another rocket plane is the XCOR EZ-Rocket.

Ramjet

USAF Lockheed SR-71 Blackbird trainer

A ramjet is a form of jet engine that contains no major moving parts and can be particularly useful in applications requiring a small and simple engine for high speed use, such as missiles. The D-21 Tagboard was an unmanned Mach 3+ reconnaissance drone that was put into production in 1969 for spying, but due to the development of better spy satellites, it was cancelled in 1971. The SR-71's Pratt & Whitney J58 engines ran 80% as ramjets at high speeds Mach 3.2. The SR-71 was dropped at the end of the Cold War, then brought back during the 1990s. They were used also in the Gulf War. The last SR-71 flight was in October 2001.

Scramjet

The Boeing X-43A, shortly after booster ignition

Scramjet aircraft are in the experimental stage. The Boeing X-43 is an experimental scramjet with a world speed record for a jet-powered aircraft – Mach 9.7, nearly 12,000 kilometres per hour (7,500 mph) at an altitude of about 36,000 metres (118,000 ft). The X-43A set the flight speed record on 16 November 2004. A scramjet actually has a very simple engine design. It works simply by air being forced into one side of a tube-like engine. That air is ignited by fuel, causing it to come out hotter and faster on the other side. This engine requires high speed in order to work, but it is rather fitting for the speeds at which it travels.

Chapter- 11

Gyrodyne

Fairey FB-1 Gyrodyne developed by Dr. Bennett

A **Gyrodyne** is a rotorcraft with a rotor system that is normally driven by its engine for takeoff and landing—hovering like a helicopter and has either one or two propellers mounted on wingtips, for propulsion and for torque correction. Dr. James Allan Jamieson Bennett conceived the gyrodyne while serving as Chief Engineer at Cierva Autogiro Company, Ltd. The gyrodyne was envisioned an intermediate type of rotorcraft, its rotor operating parallel to the flightpath to minimize axial flow with one or more propellers providing propulsion.

There is controversy over the correct usage of the term *gyrodyne* stemming from the difference between the description in Bennett's patent, the use of the term as a trademark by the Gyrodyne Company of America, the Federal Aviation Administration (FAA) classification of rotorcraft, and the terms **compound helicopter** and **compound gyroplane** frequently used to describe similar aircraft. In recent years, a related concept has been promoted under the name **heliplane**. Originally used to market gyroplanes built by two different companies, the term has been adopted to describe a Defense Advanced Research Projects Agency (DARPA) program to develop advances in rotorcraft technology with the goal of overcoming the current limitations of helicopters in both speed and payload.

History

In Britain, Dr. James Allan Jamieson Bennett, Chief Engineer of the Cierva Autogiro Company, in 1936 conceived an intermediate type of rotorcraft, which he named "gyrodyne" and which was tendered to the British Government in response to an Air Ministry specification. In 1939, Bennett was issued a patent from the UK Intellectual Property Office, assigned to the Cierva Autogiro Company. On 23 August 1940, the Autogiro Company of America, licensees of the Cierva Autogiro Company, Ltd., filed a corresponding patent application in the United States. On 27 April 1943, Patent# 2,317,340 was issued, assigned to the Autogiro Company of America. The patents describe a gyrodyne as:

a rotary wing aircraft intermediate in type, hereinafter referred to as "gyrodyne", between a rotaplane (with the rotor free for autorotation and an upward total axial flow through the rotor disc), on the one hand, and a pure helicopter (with the rotor driven, and a downward total axial flow through the rotor disc), on the other hand, that is with a mean axial flow through the rotor disc substantially zero at high forward speed.

Bennett's concept described a shaft-driven rotor, with anti-torque and propulsion for translational flight provided by one or more propellers mounted on short or stub wings. With thrust being provided by the propellers at cruise speeds, power would be provided to the rotor only to overcome the profile drag of the rotor, operating in a more efficient manner than the freewheeling rotor of an autogyro in autorotation. Bennett described this flight regime of the gyrodyne as an "intermediate state", requiring power to be supplied to both the rotor and the propulsion system.

Early development

The Cierva Autogiro Company, Ltd., C.41 gyrodyne pre-WW2 design study was updated and built by Fairey Aviation as the FB-1 Gyrodyne commencing in 1945. Fairey's development efforts were initially led by Bennett, followed by his successor Dr. George S. Hislop. George B.L. Ellis and Frederick L. Hodgess, engineers from the pre-WW2 Cierva Autogiro Company, Ltd., joined Bennett at Fairey Aviation. The first Fairey Gyrodyne prototype crashed during a test flight, killing the crew. The second Gyrodyne prototype was rebuilt as the Jet Gyrodyne and used to develop a pressure-jet rotor drive system later for the Rotodyne transport compound gyroplane. At the tip of each stub wing were rearward-facing propellers which provided both yaw control and propulsion in forward flight. The Jet Gyrodyne flew in 1954, and made a true transition from vertical to horizontal flight in March 1955.

This led to the prototype Fairey Rotodyne, which was developed to combine the efficiency of an fixed-wing aircraft at cruise with the VTOL capability of a helicopter to provide short haul airliner service from city centres to airports. It had short wings that carried turboprop engines for forward propulsion and up to 40% of the aircraft's weight in forward flight. The rotor was driven by tip-jets for take-off and landing and translational flight up to 80 mph. Despite considerable commercial and military interest worldwide in the prototype Type Y Rotodyne for air transport, Fairey decided to develop a larger and more powerful Type Z Rotodyne which, together with withdrawal of British Government support in 1962, resulted in the termination of the project. With the end of the Fairey Aviation programs, gyrodyne development came to a halt, although several similar concepts continued to be developed.

Similar developments

In 1954, the McDonnell XV-1 was developed as a rotorcraft with tip jets to provide vertical take off capability. The aircraft also had wings and a propeller mounted on the rear of the fuselage between twin tailbooms with two small anti-torque rotors mounted at the end. Two prototypes were built and tested, with the second XV-1 became the world's first rotorcraft to exceed 200 mph in level flight on 10 October 1956. The XV-1 project was terminated in 1957.

Compound autogyro

In 1998, Carter Aviation Technologies successfully flew its technology demonstrator aircraft. The aircraft is a compound autogyro with a high-inertia rotor and wings optimized for high-speed flight. In 2005, the aircraft demonstrated flight at mu-1, with the rotor tip spinning at a speed equal to the aircraft's forward airspeed, without any vibration or control issues occurring. The high-inertia rotor allows the aircraft to hover for a brief moment during landing, even though the rotor is unpowered, and a prerotating gearbox allows the rotor to be accelerated for an autogyro-style jump takeoff.

Heliplane

In 1954, Kayaba built an aircraft named the Heliplane. The Heliplane was a Cessna 170 with wings reduced to stubs sufficient to carry the undercarriage and a rotor powered by tip ram-jets.

DARPA is funding a project under the "Heliplane" name to develop the gyrodyne concept. Aircraft developed for the project will use a rotor for take-off and landing vertically, and hovering, together with substantial wings to provide most of the required lift at cruise, combining the large cargo capacity, fuel efficiency, and high cruise speed of fixed-wing aircraft with the hovering capabilities of a helicopter. The project is "..a multi-year $40-million, four-phase program. Groen Brothers is working on phase one of that program, a 15-month effort...(it) combines the "gyroplane" ..with a fixed-wing business jet. The team is using the A700, in the very-light-jet class, which was developed by Adam Aircraft Industries."

Trademark

"Gyrodyne" was granted as a trademark to the Gyrodyne Company of America in 1950. The company was not involved in gyrodyne development, but instead produced a turbineengined, remotely-piloted drone helicopter, with coaxial rotors, for the United States Navy, designated as the QH-50 DASH.

Examples

- Fairey Aviation Company (UK)
    - Fairey FB-1 Gyrodyne
    - Fairey Jet Gyrodyne
    - Fairey Rotodyne (1957)
- Kamov (USSR)
    - Kamov Ka-22 (1959)

Chapter- 12

Hydrogen-Powered Aircraft and Rocket-Powered Aircraft

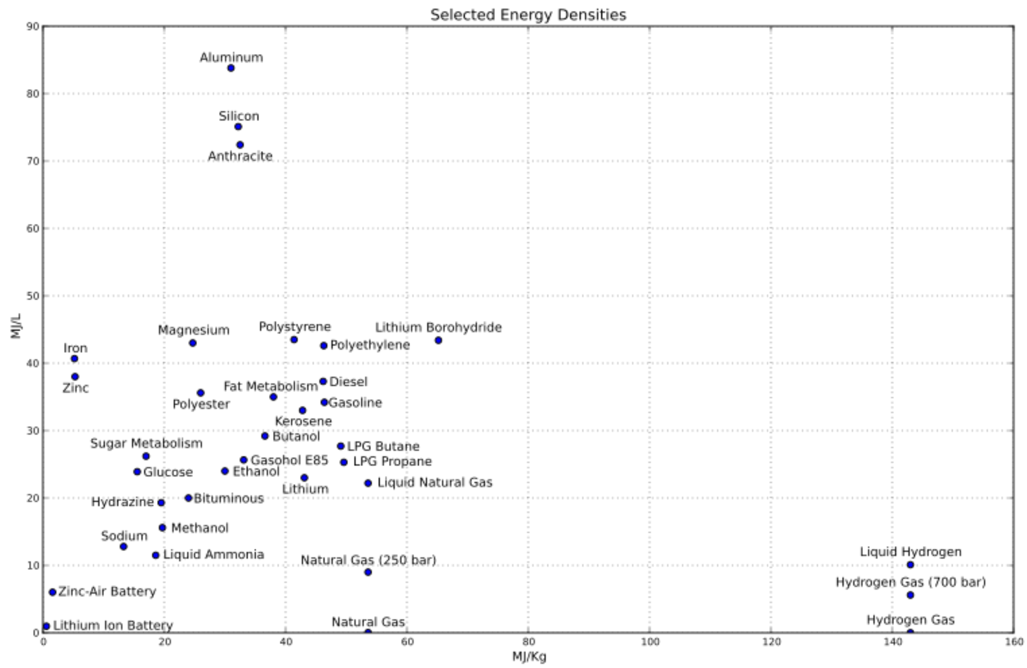
Hydrogen-powered aircraft

In 2008, The Boeing Fuel Cell Demonstrator achieved straight-level flight on a manned mission powered by a hydrogen fuel cell.

A **hydrogen-powered aircraft** is an airplane that uses hydrogen as a power source.

In aircraft hydrogen can either be burned in some kind of jet engine, or other kind of internal combustion engine, or can be used to power a fuel cell to generate electricity to power a propeller.

Properties of hydrogen



Energy density of fuels - horizontal per mass, vertical per volume

Being an alternative to jet fuel, hydrogen has a higher energy density per unit *mass* but a lower energy density per unit *volume*, and containing the hydrogen at high pressure would require a heavy container. In aircraft heavy containers are not an option, and therefore regular carbon fibre tanks are often used, which can only sustain a pressure of 350 bar. When compared to steel hydrogen containers (used in cars and ships), this is 500 to 700 bar. This decreases the amount of energy that can be spent on the propulsion by half. Alternatively, as with some rockets, cryogenic liquid hydrogen could be employed.

If hydrogen were available in quantity from renewable energy sources, its use in aircraft would produce fewer greenhouse gases (water vapor and a small amount of nitrogen) than current aircraft. Currently, very little hydrogen is produced using renewable energy sources, and there are several serious obstacles to the use of hydrogen in aircraft and other vehicles. According to research at the Pennsylvania State University in 2006, large commercial hydrogen aircraft could be built by 2020 but "will probably not enter service until closer to 2040."

The European Union's research project in cooperation with Airbus and 34 other partner companies dubbed CRYOPLANE assessed the technical feasibility, safety, environmental compatibility and economic viability of using liquid hydrogen as an aviation fuel. This was concluded in 2002 (with the final report published in 2003).

Liquid hydrogen is one of the best coolants used in engineering, and it has been proposed to use this property for cooling intake air for very high speed aircraft, of even for cooling the vehicle's skin itself particularly for scramjet-powered aircraft.

Properties of hydrogen aircraft

Hydrogen aircraft are usually designed with the liquid hydrogen fuel carried inside the fuselage, in order to minimize surface-area and reduce boil-off. Normal aircraft use wings for storing fuel.

Liquid hydrogen has about four times the volume for the same amount of energy of kerosene based jet-fuel. In addition, its highly volatile nature precludes storing the fuel in the wings, as with conventional transport aircraft. Therefore, most liquid hydrogen aircraft designs store the fuel in the fuselage, leading to a larger fuselage length and diameter than a conventional kerosene fueled aircraft. If that were the end of the story, the hydrogen-fueled aircraft would have lower performance than the kerosene aircraft due to the extra wetted area of the fuselage. The larger fuselage size causes more skin friction drag and wave drag. Hydrogen is about one-third of the weight of kerosene jet-fuel for the same amount of energy. This means that for the same range and performance (ignoring the effect of volume), the hydrogen aircraft would have about one-third of the fuel weight. For a Boeing 747-400 type aircraft, this would reduce the Takeoff Gross Weight from 800,000 lbs to approximately 600,000 lbs. Thus, the performance of a hydrogen-fueled aircraft is a trade-off of the larger wetted area and lower fuel weight. This trade-off depends on the size of the aircraft.

Liquid hydrogen was proposed for use on the scramjet-based National Aerospace Plane.

Hydrogen aircraft demonstrations

Several demonstrations of hydrogen-powered aircraft have been performed using purpose-build airplanes.

Boeing Research & Technology Europe (BR&TE) made a civilian aircraft from a 2-seat Dimona motor glider running on a fuel cell (called Theator Airplane)". Lange Aviation GmbH also made a hydrogen-powered airplane with its Antares DLR-H2 airplane.

These aircraft are of course configured in such fashion that the current low energy output from hydrogen propulsion (a result of the low-pressure hydrogen tanks) do not pose a problem. For example the Boeing Theator airplane only required 45 kW to take off, and 20 kW to stay airborne.

In July 2010 Boeing also unveiled its hydrogen powered Phantom Eye UAV, that uses two Ford Motor Company internal combustion engines converted to operate on hydrogen.

Current aircraft

- The Russian manufacturer Tupolev built a prototype hydrogen-powered version of the Tu-154 airliner, named the Tu-155, which made its first flight in 1989.

- Northrop Grumman has successfully tested their X-47B Unmanned Combat Air System (UCAS) for Carrier Operations during 2010. This unmanned aircraft, or drone, which is still a prototype, can be programmed to perform a particular mission totally autonomously and/or remotely controlled by a pilot. It can operate at altitudes up to 16,000 ft. The liquid hydrogen version that has been successfully tested on 2010 can fly for 5 to 7 days without refuelling.

Proposed hydrogen aircraft

- Reaction Engines Skylon orbital hydrogen fuelled jet plane
- Reaction Engines A2 antipodal hypersonic jet airliner
- DLR Smartfish
- Boeing plans to build a hydrogen-powered jet

Rocket-powered aircraft

Messerschmitt Me 163

A **rocket-powered aircraft** or **rocket plane** is an aircraft that uses a rocket for propulsion, sometimes in addition to airbreathing jet engines. Rocket planes can achieve much higher speeds than similarly-sized jet aircraft, but typically for at most a few minutes of powered operation, followed by a glide. Unhindered by the need for oxygen from the atmosphere they are suitable for very high altitude flight. They are also capable of delivering much higher acceleration and shorter takeoffs.

Rockets have been used simply to assist the main propulsion in the form of Jet Assisted Take Off (JATO) also known as "Rocket Assisted Take Off" (RATO). Not all rocket planes are of the conventional takeoff like "normal" aircraft. Some types have been air-launched from another plane, while other types have taken off vertically - nose in the air and tail to the ground ("tail-sitters"). It is also possible, that rocket planes launch vertically without changing their orientation.

Because of the heavy propellant use and the various practical difficulties of operating rockets, the majority of rocket planes have been built for experimental use, as interceptor fighters and space aircraft.

History

The first rocket-powered aircraft was the Lippisch Ente, flown in 1928. The Russian Bereznyak-Isayev BI-1 flew in 1942.

The Heinkel He 176 was the world's first aircraft to be propelled solely by a liquid-fuelled rocket, making its first powered flight on 20 June 1939 with Erich Warsitz at the controls.

The antipodal bomber was planned by the Germans late in WWII, however later calculations showed that it would not have worked, and would have been destroyed during reentry.

The only rocket planes ever to be mass-produced were the Messerschmitt Me 163 in 1944, one of several German World War II attempts at rocket-powered aircraft.. The Bachem Ba 349 was a WWII vertical takeoff manned rocket interceptor aircraft.

The Japanese also produced 850 Ohka, rocket powered suicide attack planes in WWII.

In 1946 the Soviet Mikoyan-Gurevich I-270 was built partly using technology developed by Sergei Korolev in 1943 and 1932.

In 1946 the rocket plane Bell X-1 was the first aircraft to break the speed of sound in level flight. The development of X-1 was the driving force behind the development of the Space Program.

In the 1950s the British developed mixed power designs to cover the performance gap that existed in then-current turbojet designs. The rocket was the main engine for delivering the speed and height required for high speed interception of high level bombers and the turbojet gave increased fuel economy in other parts of flight, most notably to make sure the aircraft was able to make a powered landing rather than risking an unpredictable gliding return. The Saunders-Roe SR.53 was a successful design and was due to be developed into production when economics forced curtailment of most British aircraft programmes in the late 1950s. The advancement of the turbojet engine output, the advent of missiles, and advances in radar had made a return to mixed power unnecessary.

The North American X-15 was used for several years and eventually reached Mach 6.7.

In the early 60s American research into the X-20 Dyna-Soar spaceplane was cancelled due to lack of purpose; later the studies contributed to the Space Shuttle. Another similar program was ISINGLASS which was to be a rocket plane launched from a B-52 carrier, which was intended to achieve Mach 22, but this was never funded.

Work on the Space Shuttle began in 1972 and Space Shuttle Columbia first launched in 1981.

The Lunar Landing Research Vehicle was a mixed powered vehicle- a jet engine cancelled 5/6 of the force due to gravity, and the rocket power was able to simulate the Apollo lunar lander.

The development of SpaceShipOne, first flown in 2003, and XCOR Aerospace's EZ-Rocket, suggests that rocket planes may become more common.

Planned rocket powered aircraft

- Reaction Engines Skylon
- Spaceship Two
- Lynx rocketplane
- ARES (martian rocketplane)