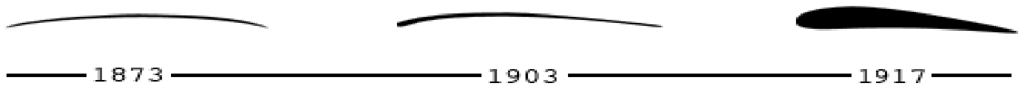
UNIT II: Aerodynamics

Aerfoil – Nomenclature and types:

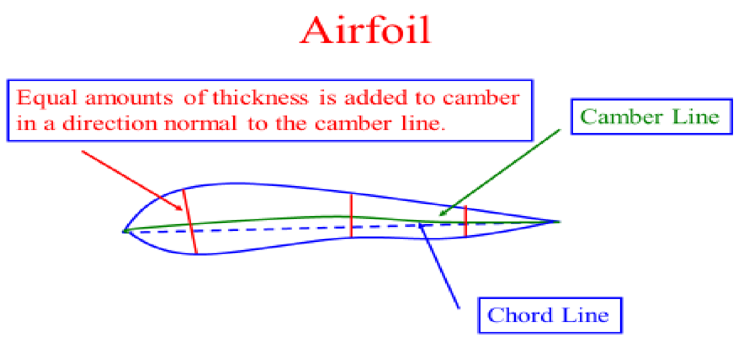
Use of aerfoil:

- Wings
- Propellers and Turbofans
- Helicopter Rotors
- Blade profiles of Compressors and Turbines
- Hydrofoils (wing-like devices which can lift up a boat above waterline)
- Wind Turbines

Evolution of aerfoil profile:



Early Designs - Designers mistakenly believed that these airfoils with sharp leading edges will have low drag.
In practice, they stalled quickly, and generated considerable drag

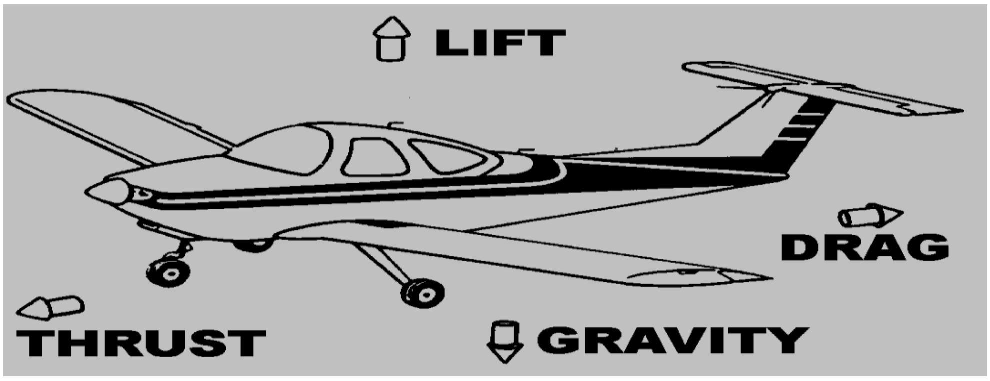


Aerodynamic forces on wings; Generation of lift; Sources of drag:

Aerfoil is defined by the following characteristics:

- Chord Line
- Camber line drawn with respect to the chord line.
- Thickness Distribution which is added to the camber line, normal to the camber line.
- Symmetric airfoils have no camber.

Aerodynamic Forces:



Lift (force)

Lift is the sum of all the fluid dynamic forces on a body perpendicular to the direction of the external flow approaching that body.

Sometimes the term **dynamic lift** or **dynamic lifting force** is used for the perpendicular force resulting from motion of the body in the fluid, as in an aerodyne, in contrast to the static lifting force resulting from buoyancy, as in an aerostat.

Lift is commonly associated with the wing of a aircraft. However there are many other examples of lift such as propellers on both aircraft and boats, rotors on helicopters, sails and keels on sailboats, hydrofoils, wings on auto racing cars, and wind turbines. While the common meaning of the term "lift" suggests an upward action, the lift force is not necessarily directed up with respect to gravity.

Physical explanation

There are several ways to explain lift which are equivalent — they are different expressions of the same underlying physical principles:

Reaction due to deflection

Lift is created as the fluid flow is deflected by an airfoil or other body. The force created by this acceleration of the fluid creates an equal and opposite force according to Newton's third law of motion. Air deflected downward by an aircraft wing, or helicopter rotor, generating lift is known as downwash.

It is important to note that the acceleration of air flowing over an aircraft wing does not just involve the air molecules "bouncing off" the lower surface. Rather, air molecules closely follow both the top and bottom surfaces, and the airflow is deflected downward when the wing is producing lift. The acceleration of the air during the creation of lift can also been described as a "turning" of the airflow.

Many shapes, such as a flat plate set at an angle to the flow, will produce lift. This can be demonstrated simply by holding a sheet of paper at an angle in front of you as you move forward. However, lift generation by most shapes will be very inefficient and create a great deal of drag. One of the primary goals of airfoil design is to devise a shape that produces the most lift while producing the least Form drag.

Circulation

Another way to calculate lift is to determine the mathematical quantity called circulation; (this concept is sometimes applied approximately to wings of large aspect ratio as "lifting-line theory"). Again, it is mathematically equivalent to the two explanations above. It is often used by practising aerodynamicists as a convenient quantity, but is not often useful for a layperson's understanding. (That said, the vortex system set up round a wing is both real and observable, and is one of the reasons that a light aircraft cannot take off immediately after a jumbo jet.)

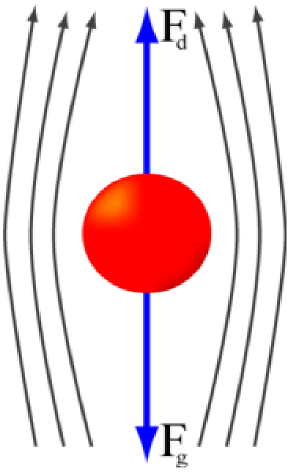
The circulation is the line integral of the velocity of the air, in a closed loop around the boundary of an airfoil. It can be understood as the total amount of "spinning" (or vorticity) of air around the airfoil. When the circulation is known, the section lift can be calculated using the following equation:

$$l = \rho V \times \Gamma$$

Where ρ is the air density, *V* is the free-stream airspeed, and Γ is the circulation. This is sometimes known as the **Kutta - Joukowski Theorem.**

A similar equation applies to the sideways force generated around a spinning object, the Magnus effect, though here the necessary circulation is induced by the mechanical rotation, rather than aerfoil action.

Sources of Drag:



An object falling through a gas or liquid experiences a force in direction opposite to its motion. Terminal velocity is achieved when the drag force is equal to force of gravity pulling it down.

In fluid dynamics, **drag** is the force that resists the movement of a solid object through a fluid (a liquid or gas). Drag is made up of friction forces, which act in a direction parallel to the object's surface (primarily along its sides, as friction forces at the front and back cancel themselves out), plus pressure forces, which act in a direction perpendicular to the object's surface. For a solid object moving through a fluid or gas, the drag is the sum of all the aerodynamic or hydrodynamic forces in the direction of the external fluid flow. (Forces perpendicular to this direction are considered lift). It therefore acts to oppose the motion of the object, and in a powered vehicle it is overcome by thrust.

In astrodynamics, depending on the situation, **atmospheric drag** can be regarded as inefficiency requiring expense of additional energy during launch of the space object or as a bonus simplifying return from orbit.

Types of drag:

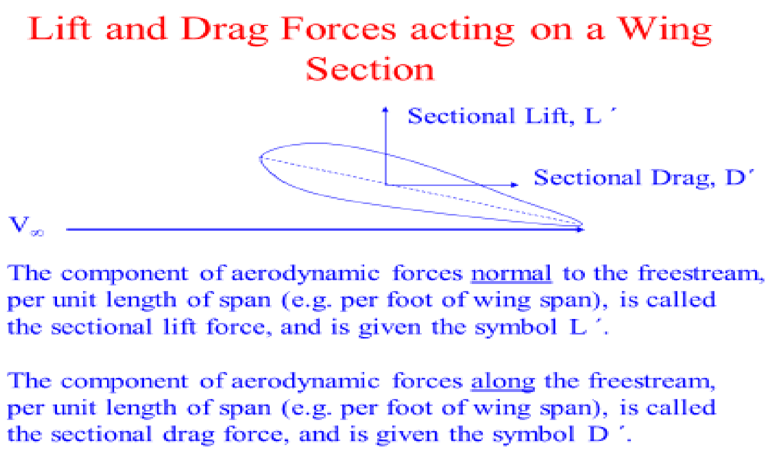
Types of drag are generally divided into three categories: parasitic drag, lift-induced drag and wave drag.

- Parasitic drag includes form drag, skin friction and interference drag.
- Lift-induced drag is only relevant when wings or a lifting body are present, and is therefore usually discussed only in the aviation perspective of drag.
- Wave drag occurs when a solid object is moving through a fluid at or near the speed of sound in that fluid.

The overall drag of an object is characterized by a dimensionless number called the drag coefficient, and is calculated using the drag equation. Assuming a constant drag coefficient, drag will vary as the square of velocity. Thus, the resultant power needed to overcome this drag will vary as the cube of velocity.

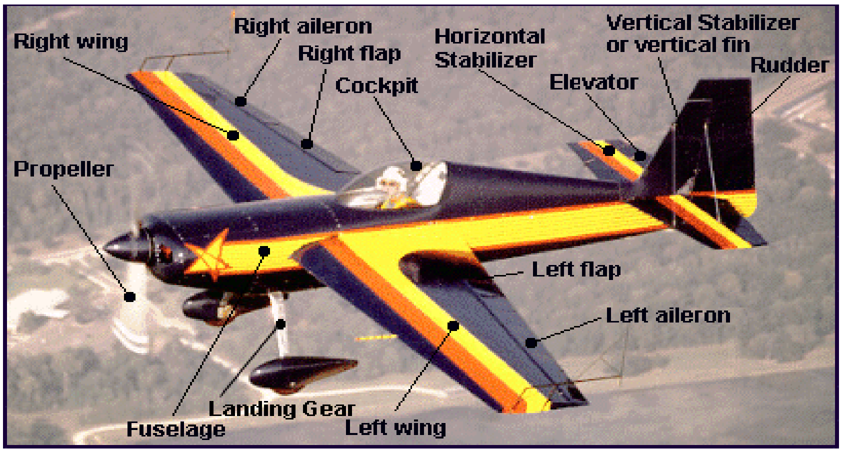
Wind resistance is a layman's term used to describe drag. Its use is often vague, and is usually used in a relative sense (e.g. A badminton shuttlecock has more *wind resistance* than a squash ball).

Force and moment coefficients, Centre of Pressure. Control surfaces:



Sectional Lift and Drag Coefficients

- The sectional lift coefficient C_l is defined as: $$C_l = \frac{L'}{\frac{1}{2}\rho V_\infty^2 c}$$
- Here c is the airfoil chord, i.e. distance between the leading edge and trailing edge, measured along the chordline.
- The sectional drag force coefficient C_d is likewise defined as: $$C_d = \frac{D'}{\frac{1}{2}\rho V_\infty^2 c}$$



Rotary Wing Aircraft Concepts – Propellor Theory:

HELICOPTERS

A helicopter main rotor or rotor system is a type of fan that is used to generate both the aerodynamic lift force that supports the weight of the helicopter, and thrust which counteracts aerodynamic drag in forward flight. Each main rotor is mounted on a vertical mast over the top of the helicopter, as opposed to a helicopter tail rotor, which is connected through a combination of drive shaft(s) and gearboxes along the tail boom. A helicopter's rotor is generally made up of two or more rotor blades. The blade pitch is typically controlled by a swash plate connected to the helicopter flight controls. Rotors are sometimes referred to as rotary wings, for they are the wings (as well as propellers) of a rotary-wing aircraft.

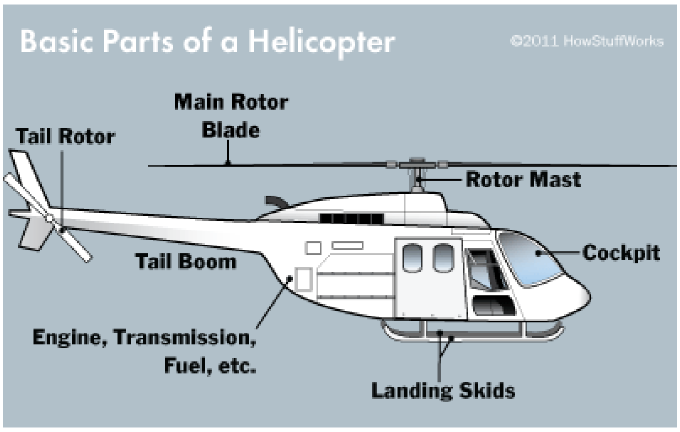
Design

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

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

Parts and functions

- The simple rotor (Main Rotor), rotor head with mast
- Tail Rotor, Tail Boom
- Swash plate
- Cockpit, Fuselage, Cabin
- Landing skids



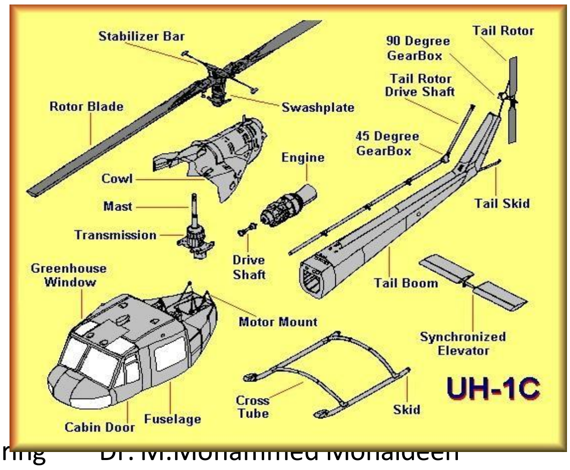
Main rotor

The main rotor serves to provide lift and propulsion to the helicopter. The main rotor blade performs the same function as an airplane's wings, providing **lift** as the blades rotate -- lift being one of the critical aerodynamic forces that keeps aircraft aloft. A pilot can affect lift by changing the rotor's revolutions per minute (rpm) or its **angle of attack**, which refers to the angle of the rotary wing in relation to the oncoming wind.

1. **Rotor mast** -- Also known as the rotor shaft, the mast connects the transmission to the rotor assembly. The mast rotates the upper swash plate and the blades.

2. **Stabilizer** -- The stabilizer bar sits above and across the main rotor blade. Its weight and rotation dampen unwanted vibrations in the main rotor, helping to stabilize the craft in all flight conditions. Arthur Young, the gent who designed the Bell 47 helicopter, is credited with inventing the stabilizer bar.

3. **Transmission** -- Just as it does in a motor vehicle, a helicopter's transmission transmits power from the engine to the main and tail rotors. The transmission's main gearbox steps down the speed of the main rotor so it doesn't rotate as rapidly as the engine shaft. A second gearbox does the same for the tail rotor, although the tail rotor, being much smaller, can rotate faster than the main rotor.



Fuselage

The fuselage holds the aircraft together and accommodates passengers and cargo, as appropriate.

Cockpit

The cockpit, at the front end of the fuselage, is the control and command centre, where the pilots sit and all the instrumentation is located.

Cabin

The cabin serves to accommodate passengers and cargo.

Landing skids

The skids serve to stand the helicopter while on the ground.

Tail boom

The tail boom holds the tail rotor for stabilizing the aircraft.

Tail rotor

The tail rotor prevents the helicopter from spinning as well as turns the aircraft.

Engine

The engine generates power for the aircraft. Early helicopters relied on reciprocating gasoline engines, but modern helicopters use gas turbine engines like those found in commercial airliners.

Swash plate

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

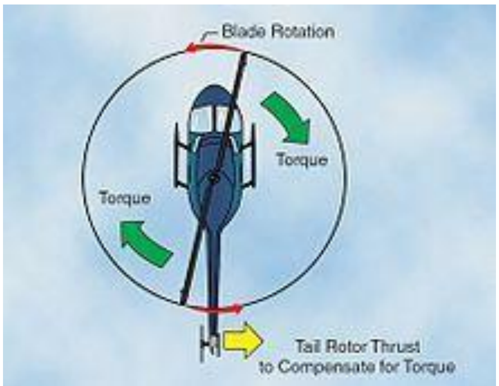
The swash plate is two concentric disks or plates, one plate rotates with the mast, connected by idle links, while the other does not rotate. The rotating plate is also connected to the individual blades through pitch links and pitch horns. The non-rotating plate is connected to links which are manipulated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

HELICOPTERS CAN BE USED FOR VARIOUS PURPOSE LIKE

Types

Helicopter arrangements

Rotor configurations



Most helicopters have a single, main rotor but require a separate rotor to overcome torque. This is accomplished through a variable pitch, anti-torque rotor or tail rotor. When viewed from above, the main rotors of helicopter designs from Germany, United Kingdom, The United States and Canada rotate counter-clockwise, all others rotate clockwise. This can make it difficult when discussing aerodynamic effects on the main rotor between different designs, since the effects may manifest on opposite sides of each aircraft.

Anti-torque: Torque effect on a helicopter

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

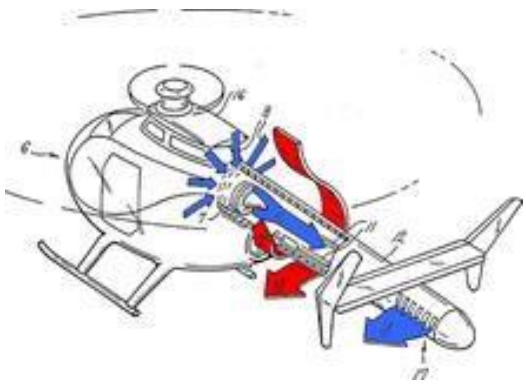
Tail rotor

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

Ducted fan

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

NOTAR



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

Tip jets

Another single main rotor configuration without a tail rotor is the tip jet rotor, where the main rotor is not driven by the mast, but from nozzles on the rotor blade tips; which are either pressurized from a fuselage-mounted gas turbine or have their own turbojet, ramjet or rocket thrusters. Although this method is simple and eliminates torque, the prototypes that have been built are less fuel efficient than conventional helicopters and produced more noise. The Percival P.74 was underpowered and was not able to achieve flight, while the Hiller YH-32 Hornet had good lifting capability but performed poorly otherwise.

Dual rotors (counter-rotating)

Counter-rotating rotors are rotorcraft configurations with a pair or more of large horizontal rotors turning in opposite directions to counteract the effects of torque on the aircraft without relying on an anti-torque tail rotor. This allows the power normally required to drive the tail rotor to be applied to the main rotors, increasing the aircraft's lifting capacity. Primarily, there are three common configurations that use the counter-rotating effect to benefit the rotorcraft.

A. Tandem

Tandem rotors are two horizontal main rotor assemblies mounted one behind the other. Tandem rotors achieve pitch attitude changes to accelerate and decelerate the helicopter through a process called differential collective pitch. To pitch forward and accelerate, the rear rotor increases collective pitch, raising the tail and the front rotor decreases collective pitch, simultaneously dipping the nose. To pitch upward while decelerating (or moving rearward), the front rotor increases collective pitch to raise the nose and the rear rotor decreases collective pitch to lower the tail. Yaw control is developed through opposing cyclic pitch in each rotor; to pivot right, the front rotor tilts right and the rear rotor tilts left, and to pivot left, the front rotor tilts left and the rear rotor tilts right.

B. Coaxial

Coaxial rotors are a pair of rotors mounted one above the other on the same shaft and turning in opposite directions. The advantage of the coaxial rotor is that, in forward flight, the lift provided by the advancing halves of each rotor compensates for the retreating half of the other, eliminating one of the key effects of dissymmetry of lift: retreating blade stall. However, other design considerations plague coaxial rotors. There is an increased mechanical complexity of the rotor system because it requires linkages and swashplates for two rotor systems.

C. Intermeshing

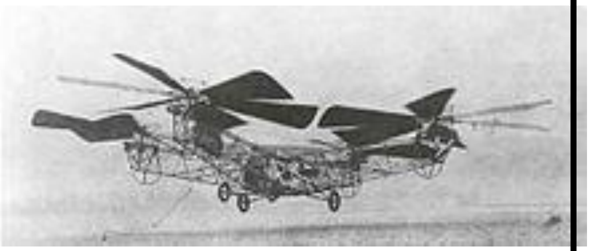
Intermeshing rotors on a helicopter are a set of two rotors turning in opposite directions, with each rotor mast mounted on the helicopter with a slight angle to the other so that the blades intermesh without colliding. This configuration is sometimes referred to as a synchropter. Intermeshing rotors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

firefighting and rescue missions. The latest Kaman model, the Kaman K-MAX, is a dedicated sky crane design.

Transverse

Transverse rotors are mounted on the end of wings or outriggers, perpendicular to the body of the aircraft. Similar to tandem rotors and intermeshing rotors, the transverse rotor also uses differential collective pitch. But like the intermeshing rotors, the transverse rotors use the concept for changes in the roll attitude of the rotorcraft. This configuration is found on two of the first viable helicopters, the Focke-Wulf Fw 61 and the Focke-Achgelis Fa 223, as well as the world's largest helicopter ever built, the Mil Mi-12. It is also the configuration found on tiltrotors, such the Bell-Boeing V-22 Osprey and the Agusta Westland AW609.

Quadrotor:



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

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

Blade design

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

Limitations and hazards

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

Performance requirements of Civil and Military aircraft:

Airframe:

The structural backbone of an aircraft that balances the internal and external loads acting upon the craft is called airframe. These loads consist of internal mass inertia forces (equipment, payload, stores, fuel, and so forth), flight forces (propulsion thrust, lift, drag, maneuver, wind gusts, and so forth), and ground forces (taxi, landing, and so forth).

The strength capability of the airframe must be predictable to ensure that these applied loads can be withstood with an adequate margin of safety throughout the life of the airplane.

In addition to strength, the airframe requires structural stiffness to prevent excessive deformation under load and to provide a satisfactory natural frequency of the structure (the number of times per second the structure will vibrate when a load is suddenly imposed or changed).

The aerodynamic loads on the airframe can oscillate in magnitude under some circumstances, and if these oscillations are near the same rate as the natural frequency of the structure, runaway deflections (called flutter) and failure can occur. Consequently, adequate structural stiffness is needed to provide a natural frequency far above the danger range.

The overall airframe structure is made up of a number of separate components, each of which performs discrete individual functions. The fuselage provides the accommodations of crew, passengers, cargo, fuel, and environmental control systems.

The empennage consists of the vertical and horizontal stabilizers, which are used, respectively, for turning and pitching flight control. The wing passing through the air provides lift to the aircraft. Its related control devices, leading-edge slats and trailing-edge flaps, are used to increase this lift at slow airspeeds, such as during landing and takeoff, to prevent stalling and loss of lift. The ailerons increase lift on one side of the wing and reduce lift on the other in order to roll the airplane about its fore-and-aft axis.

Performance requirements (range, payload, speed, altitude, landing and takeoff distance, and so forth) dictate that the airframe be designed and constructed so as to minimize its weight. All the airframe material must be arranged and sized so that it is utilized as near its capacity as possible, and so that the paths between applied loads and their reactions are as direct and as short as possible. The accomplishment of these goals, however, is compromised by constraints such as maintenance of the aerodynamic shape, the location of equipment, minimum sizes or thicknesses that are practical to manufacture, and structural stability, among others.

To maintain structural efficiency (minimum weight), the material that forms the aerodynamic envelope of the airplane is also utilized as a primary load-carrying member of the airframe. For example, the thin sheets that are commonly used for outer fuselage skins are very efficient in carrying in-plane loads like tension and shear when they are stabilized (prevented from moving or deflecting out of the way when loads are applied). This structural support is provided by circumferential frames and longitudinal primary members called longerons.

The compression loads are also carried in the longerons and the thin skins when they are additionally stabilized by multiple secondary longitudinal stiffeners that are normally located between the frames. Illustration *a* shows a typical fuselage primary load path structure indicating the frames and longerons. This skeleton will be covered by thin skins.