Helicopter

The Bell 206 of Canadian Helicopters

Robinson Helicopter Company (USA) R44, a four seat development of the R22

A **helicopter** is an aircraft which is lifted and propelled by one or more horizontal rotors (propellers). Helicopters are classified as **rotary-wing aircraft** to distinguish them from conventional **fixed-wing aircraft**. The word helicopter is derived from the Greek words *helix* (spiral) and *pteron* (wing). The engine-driven helicopter was invented by the Slovak inventor Jan Bahyl. The first stable, fully-controllable helicopter placed in production was invented by Igor Sikorsky.

Compared to conventional fixed-wing aircraft, helicopters are much more complex, more expensive to buy and operate, relatively slow, have shorter range and restricted payload. The compensating advantage is maneuverability: helicopters can hover in place, reverse, and above all take off and land vertically. Subject only to refuelling facilities and load/altitude limitations, a helicopter can travel to any location, and land anywhere with enough space (a diameter of length 1.5 times the rotor disk).

Compared to other vertical lift aircraft like Tiltrotors (V-22 Osprey for example)and Vectored Thrust airplanes (AV-8 Harrier for example), helicopters are very efficient, carrying more than twice the payload, consuming less fuel in hover and costing considerably less to buy and operate. However these other configurations have considerably more cruise speed than a helicopter (270 Km/Hr for a helicopter, 460 Km/Hr for a tiltrotor, 900+ Km/Hr for a vectored thrust airplane) , giving each their place in the operational spectrum.

Applications

Helicopters have many uses, both military and civil, including troop transportation, infantry support, firefighting, shipboard operations, business transportation, casualty evacuation (including MEDEVAC, and air/sea/mountain rescue), police and civilian surveillance, carrying goods (some helicopters can carry slung loads, accommodating awkwardly shaped items), or as a mount for still, film or television cameras.

Helicopters suffer from significantly higher operating and maintenance costs compared with fixed wing aircraft. The costs are due to inherent mechanical complexity and greater power requirements for a given gross weight. For these reasons, helicopters are not economically viable for commercial transportation. Speed and range limitations also constrain commercial applications.

History

AgustaWestland EH101

Since around 400 BC the Chinese had a flying top that was used as a children's toy. This toy eventually made its way to Europe via trade and has been depicted in a 1463 European painting. "Pao Phu Tau" was a 4th century book in China that described some of the ideas in a rotary wing aircraft.

The first somewhat practical idea of a human carrying helicopter was first conceived by Leonardo da Vinci around 1490, but it was not until after the invention of the powered aeroplane in the 20th century that actual models were produced. Developers such as Jan Bahyl, Oszkár Asbóth, Louis Breguet, Paul Cornu, Emile Berliner, Ogneslav Kostovic Stepanovic and Igor Sikorsky pioneered this type of aircraft, with Juan de la Cierva introducing the first practical autogiro in 1923 that was to be the basis for the modern helicopter. A flight of the first fully controllable helicopter was demonstrated by Raúl Pateras de Pescara 1916 in Buenos Aires, Argentina. The German Focke-Wulf Fw 61 first flew with limited control achieving vertical and forward flight in 1934. Mass production of the military version of the Sikorsky XR-4 began in May 1942 for the United States Army. The Bell 47 designed by Arthur Young became the first helicopter to be licensed (in March 1946) for certified civilian use in the United States.

Reliable helicopters capable of stable hover flight were developed decades after fixed wing aircraft. This is largely due to higher engine power density requirements when compared with fixed wing aircraft. Igor Sikorsky is reported to have delayed his own helicopter research until suitable engines were commercially available. Improvements in fuels and engines during the first half of the 20th century were a critical factor in helicopter development. The availability of lightweight turboshaft engines in the second half of the 20th century led to the development of larger, faster, and higher performance helicopters. Turboshaft engines are the preferred power plant for all but the smallest and least expensive helicopters today.

Generating lift

A conventional aircraft is able to fly because the forward motion of the angled wings creates lift by separating the air into two streams. One stream of air goes over the wing and one goes under. Because the air traveling over the top of the wing has a longer distance to travel, due to the curve on the upper part of the wing, (called camber) and because the air traveling over the top and bottom of the wing wants to meet at the same time, the air flowing over the top of the wing has to travel at a faster rate than the air flowing over the bottom. This faster speed reduces the internal pressure of the air causing a low pressure. Since a fluid wants to try to equalize itself by pushing toward the lower pressure, the air on the bottom of the wing pushes toward the air at the top of the wing, lifting the aircraft. A helicopter uses exactly the same method, except that instead of moving the entire aircraft, only the wings themselves are moved, in a circular motion. The helicopter's rotor can simply be regarded as rotating wings (hence the military appellation of "rotary wing aircraft").

The eight-bladed fenestron of the Eurocopter EC120B

Conventional layout

There are several possible design layouts for arranging a helicopter's rotors. The most common design is the Sikorsky-layout, which is used by approximately 95% of all helicopters manufactured to date. It is as follows: turning the rotor generates lift but it also applies a reverse torque to the vehicle, which would spin the helicopter fuselage in the opposite direction to the rotor. At low speeds, the most common way to counteract this torque is to have a smaller vertical propeller mounted at the rear of the aircraft called a tail rotor. This rotor creates thrust which is in the opposite direction from the torque generated by the main rotor. When the thrust from the tail rotor is sufficient to cancel out the torque from the main rotor, the helicopter will not rotate around the main rotor shaft.

The world's largest and smallest series-produced helicopters follow this principle. The Mil Mi-26 can lift 27 metric tons, the Robinson R22 has a crew of two and a gross weight of 1300 lbs (590 kg). Almost all civilian helicopters have the main rotor and tail rotor system. The world's fastest helicopter, the Westland Lynx can perform aerobatic loops and rolls with this conventional rotor system.

PZL Swidnik SW-4 (Poland)

Sometimes the blades of a tail rotor are not separated by the same angle, but laid out in an X-shape, which is supposed to reduce the noise levels for military use (e.g. AH-64 Apache). If the tail rotor is shrouded (i.e., a fan embedded in the vertical tail) it is called a fenestron. The fenestron rotor system on the model EC120 helicopter uses a shaft driven system and gearbox to turn the fan. It is less efficient but the advantages are that less noise is generated, it's safer for people that may walk near it and there is less chance of the blades being damaged by objects because it's shrouded, unlike the traditional tail rotor. Other helicopters use a NOTAR (an acronym meaning **no ta**il **r**otor) design: they blow air through a long slot along the tail boom, utilizing the Coanda effect to produce forces to counter the torque. Notars adjust thrust by opening and closing a sliding circular cover near the end of the tail boom.

The amount of power required to prevent a helicopter from spinning is significant. A tail rotor typically uses about 5 to 6% of the engine's power, and this power does not help the helicopter produce lift or forward motion. To reduce this waste during cruise, the vertical stabilizer is often angled to produce a force which helps counter the main rotor torque. At high speeds, it is possible for the vertical stabilizer to counteract the entire torque, leaving more power available for forward flight. This is commonly known as slip-streaming and can make hovering turns difficult on windy days. Another reason for the angled vertical stabilizer is to make it possible to stage a successful high-speed, run-on landing, in case of the tail rotor failure or damage.

Many military helicopters, especially attack types, have short wings called stub wings to add lift during forward motion. They are also used as external mounts for weapons. In extreme cases, such as that of the Mil Mi-24, the wings are large enough to obstruct airflow down from the rotors, making the helicopter all but unable to hover.

Alternative layouts

Irish Coast Guard Sikorsky S-61

There are alternatives to Sikorsky's layout, which save the weight of a tail boom and rotor. Such designs use two rotors which turn in opposite directions, or *contra-rotate*. All of these systems are designed for the same purpose: to produce a net rotational speed of zero. These methods introduce even more mechanical complexity to the design and are usually relegated to specialized helicopter types.

The **co-axial** design, where rotors are mounted on top of each other at the top of the fuselage and share a common main axle complex, was first built by Theodore von Karman and Asbóth Oszkár in 1918 and later became the hallmark of soviet Kamov design bureau (see for example the Kamov Ka-50 "Hokum"). Co-axial helicopters in flight are highly resistant to side-winds, which makes them suitable for shipboard use, even without a rope-pulley landing system. Another example is the Kamov Ka-26, a successful crop duster aircraft.

The Kaman system of *intermeshing rotors*, which was developed in Nazi Germany for a small anti-submarine warfare helicopter, features two main rotors on separate, obliquely mounted axles. The contra-rotating rotors are located on top of the fuselage, close to each other. During the Cold War the American Kaman company started to produce similar helicopters for USAF firefighting purposes. Kamans have high stability and powerful lifting capability, thus the latest Kaman V-Max model is a dedicated sky crane design, used for construction works.

In the flying-waggon or **tandem rotor** system (sometimes called "flying banana" for the peculiar shape of early U.S. examples), the two main rotors are located at the front and rear extremity of a long, boxy fuselage that resembles a railway wagon. A prime example is the Boeing CH-47 Chinook, that can carry 14 tons of payload. Waggon helicopters are practical for military logistical purposes, because entry and unloading is easily facilitated via the unobstructed front and rear ramps. The rotors and turbines are located very high on top of the fuselage, making them less sensitive to damage and dirt. The main drawback of a waggon is limited agility in air and the need for a highly trained crew, as the large main rotors have long outreach beyond the fuselage and may easily hit nearby obstacles (in 2001, a South Korean army CH-47 Chinook crashed onto a bridge for that reason while being shown live on TV).

A helicopter built by Juan de la Cierva had *three* main rotors. These were placed at the corners of an equilateral triangle and all turned the same direction.

Eurocopter Super Puma helicopters (Cougar Helicopters)

In the cross system, the rotary wing aircraft resembles a traditional fixed-wing airplane, with the two main rotors mounted at the extremities of its wings. Such helicopters are rare, because structural integrity of the wings is difficult to maintain against the amplified resonance of far off-board rotor-turbine units. The 1930s German FW-61 helicopter was built to such design. The world's largest ever helicopter, the Soviet Mil-V-12 prototype, was a cross of two Mil Mi-6 turbine-rotor units built onto a modified Antonov cargo plane. The U.S. V-22 Osprey tilting rotorcraft is similar, although its nacelles can be rotated, and shares some of the inherent technical problems of a cross system.

MD 600N (Helicopters of America)

A recent development in helicopter technology is the NOTAR system, which stands for NO TAil Rotor. The NOTAR eliminates the tail rotor by conducting high-velocity air through the tail boom. The NOTAR system was developed in the United States and is used exclusively by McDonnel Douglas Helicopters, or MD Helicopters.

The most unusual design is the roto-rocket principle, where the single main rotor draws power not from the shaft, but from its own wingtip jet nozzles, which are either pressurized from a fuselage-mounted gas turbine or have their own pulsejet combustion chambers. Although this method is simple and eliminates precession, development of such helicopters ceased soon, because their extreme noise levels preclude both military and civilian use.

Controlling flight

Useful flight requires that an aircraft be controlled in all three dimensions (see flight dynamics). In a fixed-wing aircraft, this is easy: small movable surfaces are adjusted to change the aircraft's shape so that the air rushing past pushes it in the desired direction. In a helicopter, however, there often isn't enough airspeed for this method to be practical.

Enstrom (USA) 280FX Shark, an aerodynamically restyled F28 for the corporate market.

For rotation about the vertical axis (yaw) the anti-torque system is used. Varying the pitch of the tail rotor alters the sideways thrust produced. Dual-rotor helicopters have a differential between the two rotor transmissions that can be adjusted by an electric or hydraulic motor to transmit differential torque and thus turn the helicopter. Yaw controls are usually operated with *anti-torque pedals*, on the floor in the same place as a fixed-wing aircraft's rudder pedals.

For pitch (tilting forward and back) or roll (tilting sideways) the angle of attack of the main rotor blades is altered or cycled during the rotation creating a differential of lift at different points of the rotary wing. More lift at the rear of the rotary wing will cause the aircraft to pitch forward, a increase on the left will cause a roll to the right and so on.

Helicopters maneuver with three flight controls besides the pedals. The *collective pitch control lever* controls the collective pitch, or angle of attack, of the helicopter blades altogether, that is, equally throughout the 360 degree plane-of-rotation of the main rotor system. When the angle of attack is increased, the blade produces more lift. The collective control is usually a lever at the pilot's left side, near his leg. Simultaneously increasing the collective and adding power with the throttle causes a helicopter to rise.

Sikorsky H-92 Superhawk

The *throttle* controls the absolute power produced by the engine that is connected to the rotor by a transmission. The throttle control is a twist grip on the collective control. RPM control is critical to proper operation for several reasons. Helicopter rotors are designed to operate at a specific RPM. If the RPM is too low, rapid descent with power, known as settling with power could result. If the RPM is too high, damage to the main rotor hub from excessive forces could result. In general, RPM must be maintained within a tight tolerance, usually a few percent. In many piston-powered helicopters, the pilot must manage the engine and rotor RPM. The pilot manipulates the throttle to maintain rotor RPM and therefore regulates the effect of drag on the rotor system. Turbine engined helicopters, and some piston helicopters, use servo-feedback loop in their engine controls to maintain rotor RPM and relieves the pilot of routine responsibility for that task.

The *cyclic* changes the pitch of the blades cyclically, causing the lift to vary across the plane of the rotor disk. This variation in lift causes the rotor disk to tilt, and the helicopter to move during hover flight or change attitude in forward flight. The cyclic is similar to a joystick and is usually positioned in front of the pilot. The cyclic controls the angle of the stationary section of the swashplate, which in turn controls the angle of the rotating section of the swashplate. The rotating section rotates with the rotor and is connected to blade pitch horns through pitch links, one link for each blade. When the swashplate is not tilted, the blades are all at the collective angle. When it is tilted, the links give a pitch-up at some azimuthal angle and a pitch-down at the opposite angle, hence creating a sinusoidal variation in blade angle of attack. This causes the helicopter to tilt in the same direction as the cyclic. If the pilot pushes the cyclic forward, then the helicopter tilts forward, and the rotor produces a thrust in the forward direction.

A twin-engine, twin-rotor, CH-113 Labrador

As a helicopter moves forward, the rotor blades on one side move at rotor tip speed plus the aircraft speed and is called the advancing blade. As the blade swings to the other side of the helicopter, it moves at rotor tip speed minus aircraft speed and is called the retreating blade. To compensate for the added lift on the advancing blade and the decreased lift on the retreating blade, the angle of attack of the blades is regulated as the blade spins around the helicopter. The angle of attack is increased on the retreating blade to produce more lift, compensating for the slower airspeed over the blade. And the angle of attack is decreased on the advancing blade to produce less lift, compensating for the faster airspeed over the blade.

If the angle of attack of any wing, including rotor blades, is too high, the airflow above the wing separates causing instant loss of lift and increase in drag. This condition is called aerodynamic stall. On a helicopter, this can happen in any of three ways.

1. As helicopter speed increases, the advancing blades approach the speed of sound and generate shock waves that disrupt the airflow over the blade causing loss of lift.
2. As helicopter speeds increase, the retreating blade experiences lower relative airspeeds and the controls compensate with higher angle of attack. With a low enough relative airspeed and a high enough angle of attack, aerodynamic stall is inevitable. This is called retreating blade stall.
3. Any low rotor RPM flight condition accompanied by increasing collective pitch application will cause aerodynamic stall.
4. Unique to helicopters is vertical ring vortex which is when a helicopter in a hover or decent comes into contact with its own down wash causing imense turbulence and complete loss of lift.

Ex-military Westland Scout AH.1 (XV134), now on the UK Civil Register.

Helicopters are powered aircraft, but they can still fly without power by using the momentum in the rotors and using downward motion to force air through the rotors. The main rotor acts like a "windmill" and turns. This technique is known as autorotation. A transmission connects the main rotor to the tail rotor so that all flight controls are available after engine failure. Autorotation can allow a pilot to make an emergency landing if the engine failure occurs while the helicopter is traveling high enough or fast enough. (see Height-velocity diagram).

A very peculiar feature of the cyclic is that the lift is made to occur 90 degrees of rotation before the direction of tilt. This is because when one tries to tilt a spinning object (like a rotor), it moves at right angles to the direction of the force. This is called "gyroscopic precession". So control forces on the rotor are rotated 90 degrees before the desired motion. For example, forward motion requires less lift at the front of the disk and more lift at the rear of the disk, so the pilot pushes the cyclic forward. The helicopter's control linkages rotate the pitching forces 90 degrees backwards against the rotor spin, to push on the sides of the rotor rather than its front and back.

It took inventors many years to recognize precession, and to learn how to arrange the cyclic's control system to overcome it.

Stability

Fixed wing aircraft are designed to be inherently stable. If a gust of wind or a nudge to one of the controls causes a fixed wing aircraft to pitch, roll, or yaw, the aerodynamic design of the aircraft will tend to correct the motion, and the aircraft will return to its original attitude. A small, fixed wing aircraft can be stable enough that a pilot can let go of the controls while looking at a map or dealing with a radio, and the plane will generally stay on course.

In contrast, helicopters are very unstable. Simply hovering requires continuous, active corrections from the pilot. When a hovering helicopter is nudged in one direction by a gust of wind, it will tend to continue in that direction, and the pilot must adjust the cyclic to correct the motion. Hovering a helicopter has been compared to balancing yourself while standing on a large beach ball.

Adjusting one flight control on a helicopter almost always has an effect that requires an adjustment of the other controls. Moving the cyclic forward causes the helicopter to move forward, but will also cause a reduction in lift, which will require extra collective for more lift. Increasing collective will reduce rotor RPM, requiring an increase in throttle to maintain constant rotor RPM. Changing collective will also cause a change in torque, which will require the pilot to adjust the foot pedals.

Small helicopters can be so unstable that it may be impossible for the pilot to ever let go of the cyclic while in flight. While fixed-wing aircraft are generally designed so pilots sit on the left side of the aircraft, freeing up their right hand for dealing with radios, engine controls, and the like, helicopters are generally designed so pilots sit on the right side of the aircraft so they can keep their right hand (usually the strong hand) on the cyclic at all times, leaving the radios and engine controls for their left hand (usually the weaker hand).

Limitations

HH-60 Jayhawk

The single most obvious limitation of the helicopter is its slow speed. The current record is around 400 km/h set by the Westland Lynx. There are several reasons why a helicopter cannot fly as fast as a fixed wing aircraft.

- When the helicopter is at rest, the outer tips of the rotor travel at a speed determined by the length of the blade and the RPM. In a moving helicopter, however, the speed of the blades relative to the air depends on the speed of the helicopter as well as on their rotational velocity. The airspeed of the forward-going rotor blade is much higher than that of the helicopter itself. It is possible for this blade to exceed the speed of sound, and thus produce vastly increased drag and vibration. It is theoretically possible to have spiralling rotors, similar in principle to variable-pitch swept wings, which could exceed the speed of sound, but no presently known materials are light enough, strong enough, and flexible enough to construct them.
- Most rotors are not rigid. Because the advancing blade has higher airspeed than the retreating blade, a perfectly rigid blade would generate more lift on that side and tip the aircraft over. In consequence, rotor blades are designed to "flap" - lift and twist in such a way that the advancing blade flaps up and develops a smaller angle of attack, thus producing less lift than a rigid blade would. Conversely, the retreating blade flaps down, develops a higher angle of attack, and generates more lift. At high speeds, the force on the rotors is such that they "flap" excessively and the retreating blade can reach too high an angle and stall. In some designs the hub is rigid. The blades are made from composites which can bend without breaking. Fully rigid rotors exist and create very responsive helicopters. In most such designs, the lift is varied cyclically and according to the speed of the helicopter. The adjustment is either by adjusting the angle of attack of the blades, or by engine-powered vacuum devices that suck air into the blades, adjusting the lift.

The Bristol Type 192 Belvedere (then taken on by Westland) twin rotor helicopter had a large cargo door and external hoist, and was used as personnel/paratroop transport, casualty evacuation, and for lifting large loads. The Belvedere had a production run of only 26 and went into RAF service in 1961.

- Rotorhead design is a limiting factor on many helicopters. Low or negative-G situations encountered in a semi-rigid system will result in blade flapping down until it hits the tail boom or other airframe structure, followed by rotor separation, causing a crash.
- Helicopters are susceptible to potentially disastrous vortex ring effects. In these, the downward wind from the rotor causes a circular vortex to form around the rotor. If this ring is augmented by terrain, wind, rain, or sea spray, the helicopter can lose enough lift to experience settling with power and hit the ground.

During the closing years of the 20th century designers began working on helicopter noise reduction. Urban communities have often expressed great dislike of noisy aircraft, and police and passenger helicopters can be unpopular. The redesigns followed the closure of some city heliports and government action to constrain flight paths in national parks and other places of natural beauty.

Helicopters vibrate. An unadjusted helicopter can easily vibrate so much that it will shake itself apart. To reduce vibration, all helicopters have rotor adjustments for height and pitch. Most also have vibration dampers for height and pitch. Some also use mechanical feedback systems to sense and counter vibration. Usually the feedback system uses a mass as a "stable reference" and a linkage from the mass operates a flap to adjust the rotor's angle of attack to counter the vibration. Adjustment is difficult in part because measurement of the vibration is hard. The most common adjustment measurement system is to use a stroboscopic flash lamp, and observe painted markings or coloured reflectors on the underside of the rotor blades. The traditional low-tech system is to mount coloured chalk on the rotor tips, and see how they mark a linen sheet.

Landing On a ship

Eurocopter BO 105

A **helicopter deck** (or **helo deck**) is a helicopter pad on the deck of a ship, usually located on the stern and always clear of obstacles that would prove hazardous to a helicopter landing. In the U.S. Navy it is commonly and properly referred to as the **flight deck**. In the Royal Navy, *landing on* is usually achieved by lining up slightly astern and on the port quarter, as the ship steams into the wind and the aircraft captain slides across and over the deck.

Shipboard landing for some helicopters is assisted though use of a haul-down device that involves attachment of a cable to a probe on the bottom of the aircraft prior to landing. Tension is maintained on the cable as the helicopter descends, assisting the pilot with accurate positioning of the aircraft on the deck; once on deck locking beams close on the probe, locking the aircraft to the flight deck. This device was pioneered by the Royal Canadian Navy and was called "Beartrap". The U.S. Navy implementation of this device, based on Beartrap, is called the "RAST" system (for Recovery Assist, Secure and Traverse) and is an integral part of the LAMPS MK III (SH-60B) weapons system. A secondary purpose of the haul-down device is to equalize electrostatic potential between the helicopter and ship. The whirling rotor blades of a helicopter can cause large charges to build up on the airframe, large enough to cause injury to shipboard personnel should they touch any part of the helicopter as it approaches the deck.

Hazards of helicopter flight

As with any moving vehicle, operation outside of safe regimes could result in loss of control, structural damage, or fatality. For helicopters the hazards are particularly acute since they are flying at relatively low altitude, with little time to react to a sudden event. The following is a list of some of the potential hazards:

- Retreating blade stall
- Settling with power
- Ground resonance
- Low-G condition
- Operating within the shaded area of the height-velocity diagram
- Vortex ring state, a problem the V-22 Osprey was associated with

Each of these conditions is potentially fatal and recovery might not be possible. For this reason, good pilotage demands operation within safe flight regimes and avoiding hazardous conditions at all costs.

Helicopter models and identification

Kamov Ka-50 helicopter with contra-rotating co-axial rotors.

In identifying conventional helicopters during flight it is helpful to know that when viewed from below, the rotor of a French, Russian, Soviet or Ukrainian designed helicopter rotates counter-clockwise, whilst that of a helicopter built in Italy, the UK or the USA rotates clockwise.

Further information: List of helicopter models

Some companies, notably Schweizer in the USA, are developing remotely-controlled variants of light helicopters for use in future battlefields. Rotomotion is currently selling a line of small (less than 50 kg) rotorcraft UAVs, including an all electric helicopter.

Hybrid types that combine features of helicopters and fixed wing designs include the experimental Fairey Rotodyne of the 1950s and the Bell Boeing Osprey, which is on order by the U.S. Marine Corps and will be the first mass produced tilt-rotor aircraft to enter service.

A helicopter should not be mistaken for an autogyro, which is a historical predecessor of the helicopter that gains lift from an unpowered rotor.

Some common nicknames for helicopters are "copter", "chopper", "whirlybird", "windmill", "helo" (common U.S. Navy usage) or "paraffin budgie" (the latter term being mostly used in the UK offshore oil industry).

See also

- Anatomy of a helicopter
- Helicopter flight controls
- Aeronautical engineering

- U.S. Patent 1848389 : "Aircraft, especially aircraft of the direct lift amphibian type and means of construction and operating the same"
- Helicopter history
- Helicopter history
- Image of a Chinese flying top
- Helicopter development in the early 20th century
- Description of a helicopter
- Helicopter pictures and videos (in German)
- Sikorsky MH-53J/M PAVE LOW helicopter