Helicopters

A helicopter is an aircraft that can take off and land vertically. Also called a "rotary aircraft," it can hover and rotate in the air and can move sideways and backwards while aloft. It can change direction very quickly and can stop moving completely and begin hovering.

A helicopter flies by means of the thrust that is created by the rotation of the blades of a main rotor that is mounted on a shaft above the fuselage, or body, of the aircraft. As the blades rotate, airflow is created over them, resulting in lift. This raises the helicopter. A pilot maneuvers the helicopter by changing the pitch, or angle, of the rotor blades as they move through the air.

An engine is used to create the force needed to lift the aircraft and its passengers and cargo. Reciprocating gasoline and gas turbine engines are the most common types used on helicopters.



The Sikorsky CH-3E helicopter

All helicopters need a way to counteract the torque produced by the main rotor. If this were not done, the rotor would turn in one direction, and the fuselage would turn in the opposite direction. Usually, a small tail rotor is used to produce a sideways thrust that prevents the fuselage from rotating. By increasing or decreasing the thrust produced by the tail rotor, the pilot can steer the helicopter to the left or right. Another way to counteract thrust is with two main rotors that turn in opposite, or counter-rotating, directions. Each rotor cancels the torque produced by the other. No tail rotor is needed in this type of helicopter.



Components of a helicopter

The pilot controls the helicopter by using rudder pedals, which turn the helicopter to the right or left, a cyclic pitch stick that tilts that helicopter forward, backward, or sideways, and a collective pitch stick that allows the helicopter to climb and descend vertically.



A helicopter twin-bladed main rotor, mounted on a pylon (Robinson R44)

Rotor usually refers to the rotating part of a machine. Various devices, such as a <u>motor</u>, a <u>generator</u>, an <u>alternator</u>, a <u>pump</u>, or a <u>helicopter</u>, possess such elements. The part of the machine that does not rotate is called a <u>stator</u>.

General

- The flying part of a <u>helicopter</u> is called a <u>rotor</u>.
- In electrical engineering, the rotor of an electric motor or dynamo, is called an <u>armature</u>.
- In automotive mechanics, the disc in a <u>disc brake</u>. It can also connote a part in a <u>distributor</u>.
- Certain cipher machines, such as the German Enigma machine, made use of rotating wheels, see rotor machine in connection with these devices.

 In radio, a rotor is an <u>electric motor</u> designed to turn a receiving <u>antenna</u> to match the direction of the received signal.

Acronyms and code names

- the <u>ROTOR</u> radar project, the UK's 1st national air defence system following the Second World War, incorporating some Chain Home radar stations.
- <u>Rotor</u> is the code name for Microsoft's shared source implementation of the Common Language Infrastructure.

Entertainment

- The <u>SC Rotor Volgograd</u> is a Russian football club.
- "Rotor" is a fictional character from the Sonic the Hedgehog universe <u>Rotor (Sonic the</u> <u>Hedgehog)</u>.
- "THE ROTOR" is the trade name for an amusment ride.

Tail rotor

The tail rotor of a <u>helicopter</u> is mounted on the tail of a single-rotor helicopter, perpendicular to the main rotor. It is primarily used in order to counteract the <u>yaw</u> motion and the <u>torque</u> that a rapidly turning disk naturally produces.

In some more recent helicopter designs, the tail rotor has been mounted tangential to the furthest back point of the top rotor. That is to say that it looks much like an old propeller planes, only at the back of the helicopter instead of the front of a wing. In these new designs the rotor spins in a direction opposite to the top rotor (i.e. counter-clockwise if the rotor spins clockwise and vise-versa). This in effect, cancels the spin and has the added benifit of producing forward thrust.

Most, if not all, dual-rotary helicopters do not use tail rotors, instead, the design of the two main rotors is such that they spin in the opposite directions of each other, thus each cancels out the torque and yaw produced by the other.

See also

- Infra-red search and track
- night vision

Helicopter rotor



The simple rotor of a <u>Robinson R22</u> showing (from the top):

Definition

A rotor is the rotating part of a <u>helicopter</u> which generates <u>lift</u>, either vertically in the case of a main rotor, or horizontally in the case of a tail rotor.

Rotor Head Design

The rotor head is comprised of a robust hub with attachment points for the blades and mechanical linkages designed to control the pitch of the blades.

Description of parts and their functions

- Teeter hinge, allowing one blade to rise while the other falls
- Pitch hinges, allowing the blades to 'twist', ie change pitch. These are driven by the outer pitch link rods from the upper swashplate.
- Scissor link and counterweight, carries the main shaft rotation down to the upper swashplate
- Rubber covers protect moving and stationary shafts
- Swashplates, transmitting cyclic and collective pitch to the blades (the top one rotates)
- Three non-rotating control rods transmit pitch information to the lower swashplate
- Main mast leading down to main gearbox

History and Development

Prior to the development of powered helicopters in the mid 20th century, <u>Autogiro</u> pioneer <u>Juan de la</u> <u>Cierva</u> researched and developed many of the fundamentals of the rotor. Cierva is credited with successful development of multi-bladed, fully articulated rotor systems. This type of system is widely used today in many multi-bladed helicopters. In the 1930s, <u>Arthur Young</u> improved stability of two bladed rotor systems with the introduction of a stabilizer bar. This system was used in several <u>Bell</u> and Hiller helicopter models. It is also used in many remote control model helicopters.

Some modern military helicopters employ a rigid rotor design, in which flexible materials are used in place of hinges.

Swash plate

The pitch of main rotor blades is varied throughout it's rotation in order to control the magnitude and direction of the thrust <u>vector</u>. Collective pitch is used to increase or decrease rotor thrust perpendicular to the axis of rotation. Collective pitch controls the magnitude of the thrust vector. Blade pitch is varied during rotation to effectively tilt the rotor disk and control the direction of the thrust vector. These blade pitch variations are controlled by the swash plate.

The swash plate is essentially comprised of two concentric disks or plates, one plate rotates with the blades while the other does not rotate. The rotating plate is connected to 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 to some degree. Through shifting and tilting, the non-rotating plate controls the rototing plate, which in turn controls the individual blade pitch.

Fully articulated rotors

During the development of the <u>Autogiro</u>, <u>Juan de la Cierva</u> built scale models to test his designs. After promising results, he built full size models. Just prior to takeoff, his autogiro rolled unexpectedly and was destroyed. Believing this was the cause of wind gusts, Cierva rebuilt his autogiro only to suffer an almost identical fate. These setbacks caused Cierva to consider why his model autogiros flew successfully, while fill size aircraft did not.

Cierva realized that the advancing blade on one side created greater lift than on the retreating side. This is due to increased airspeed on the advancing side which creates a rolling force. The scale model was constructed with flexible materials, specifically <u>rattan</u>, so the rolling force was absorbed as the blades flapped and compensated for assymetry of lift. Cierva concluded that the full size steel rotor hub was far too rigid and introduced flapping hinges at the rotor hub.

Flapping hinges solved the rolling problem, but introduced lateral hub stresses as the blade center of mass moved as the blades flapped. Due to conservation of angular momentum, the bladed accelerate and decelerate as their center of mass moves inward and outward, like an twirling ice skater. Cierva added lag-lead, or delta hinges to reduce lateral stresses.

Two bladed rotors

Two bladed rotor systems are considerably simpler than fully articulated systems. The two blades can flap as a unit and therefore do not require lag-lead hinges. Two bladed systems require a single teetering hinge and two flapping hinges to permit modest coning of the rotor disk as thrust is increased.

Arthur Young found that stability could be increased significantly with the addition of a stabilizer bar perpendicular to the two blades. The stabilizer bar has weighted ends which cause it to stay relatively stable in the plane of rotation. The stabilizer bar is linked with the swash plate in such a manner as to reduce the pitch rate.

Tail rotors

Tail rotors are generally simpler than main rotors since they require only thrust control. A simplified swash plate is used to control collective pitch. Two bladed tail rotors include a teetering hinge to compensate for assymetry of lift.

Blade design

The blades of a helicopter are long, narrow <u>aerofoil</u> cross-sections with a high <u>aspect ratio</u>, a shape which minimises drag from tip vortices (see the wings of a <u>glider</u> for comparison). They generally contain a degree of <u>washout</u> to reduce the lift generated at the tips, where the airflow is fastest and <u>vortex</u> generation would be a significant problem.

Limitations and hazards

<u>Helicopters</u> with semi-rigid rotors, for example the two-bladed design seen on <u>Robinson</u> and some other light helicopters, must not be subjected to a <u>low-G condition</u>. Otherwise their <u>rotors</u> may move beyond the normal limits in a condition known as **mast bumping** which can cause the rotor droop stops to shear the mast and hence detach the whole system from the aircraft.

Why do helicopters not use ring-protected rotors?

There are serious dangers of rotor contact with a fixed object, the fuselage or people. Some people have asked if there is any reason that the rotors do not have some sort of ring fixed around the blades to protect them from contact-damage (or slicing someone in half)? Many radio-controlled model helicopters have this feature.

It has never been implemented in a full-size helicopter, even though blade strike accidents often have tragic consequences:

- A ring would add a significant amount of mass, and hence rotor inertia, where it isn't wanted at the blade tips
- A ring would prevent blades from flapping up and down as they face towards or away from the translational airflow
- A ring would prevent blades from leading and lagging, which is necessary on systems with more than two blades
- In order to provide a realistic degree of blade strike protection, such a ring would have to be massively strong and contribute a big weight penalty

Swashplate

The swashplate is the device that translates the pilot's (or autopilot's) commands via the <u>helicopter</u> <u>flight controls</u> into motion of the main rotor blades.

The two axis control of the cyclic and the single axis collective control of the helicopter need to be transmitted from the non-rotating fuselage to the rotating rotor hub and the mainblades, which necessitates a special joint called the swashplate. It consists of an outer non-rotating portion with push rods or hydraulic actuators that respond to the pilot controls and an inner rotating portion that is connected via pushrods to the rotor blade grips (or Bell / Hiller bars, if equipped).

The swashplate must be able to pitch forwards and backwards and roll left and right for the cyclic, as well as translate up and down for the collective. This requires the inner swash to slide on the mainshaft while being able to tilt freely. The inner swash also needs an anti-rotation link to prevent it from rotating independent of the blades, which would apply torque to the pushrods. The outer swash typically has an anti-rotation slider as well to prevent it from rotating.

If the aircraft does not have Bell / Hiller controls, the inputs from the swashplate will be out of phase with the blades and necessitate a phase angle correction via an offset arm. The specific phase angle depends on the rotational rate of the rotor, design of the rotorblades and other factors, and is typically fixed at time of manufacture. With Bell / Hiller controls the inputs to the rotor will always be 90 degress out of phase due to gyroscopic forces.

On most modern aircraft the swashplate is above the transmission and the pushrods are visible outside the fuselage, but a few early designs placed it underneath the transmission and enclosed the rotating pushrods inside the mainshaft. This reduces rotor hub drag since there are no exposed linkages.

Helicopter flight controls

Flight regimes

Helicopters can operate in several flight regimes.

Forward flight is when airspeed is greater than 15 mph, which is about the point of *effective translational lift* (ETL). At ETL, less engine power is required until about 40 mph airspeed when power requirements increase again.

Hover in <u>ground effect</u> is when the helicopter is flying within a half main rotor diameter above the ground and less than about 15 mph airspeed (ETL). This requires a significant amount of power, much more than in forward flight, but less then hover out of ground effect.

Hover out of ground effect is similar to hover in ground effect, but the altitude is greater than a half main rotor diameter. This requires the greatest amount of engine power and is also the most dangerous flight condition.

Autorotation is a descent with no engine power used. The engine can still be running, but a one-way <u>freewheel</u> disengages the engine from the <u>transmission</u>. Autorotation is used for emergency landing or high speed descent.

The following mnemonics are used to recall changes neccessary for speed-up and for slowing:

- Speed-Up: "L.L.F. Lift, Left, Forward" Lift Collective, Left Pedal and Forward Cyclic.
- Slow-Down: "R.R.A. Reduce, Right, Aft" Reduce (drop) Collective, Right Pedal and Aft Cyclic.

Note that left pedal is applied with increased collective for counterclockwise rotating main rotor (advancing from pilots right to left). This is common in most American made helicopters. For counterclockwise main rotors, right pedal is applied with increased collective.

The following is a table of **helicopter flight controls**.

Name	Directly controls	Primary effect	Secondary effect	Used in forward flight	Used in hover flight
<u>Cyclic</u> lateral	Varies main rotor blade pitch fore/aft	Tilts main rotor disk laterally via the <u>swashplate</u>	Increase descent rate	To turn the aircraft	To move sideways
<u>Cyclic</u> longitudinal	Varies main rotor blade pitch left/right	Tilts main rotor disk longitudinally via the <u>swashplate</u>	Increase descent rate	Control attitude	To move forwards/backwards
<u>Collective</u>	Collective angle of attack for the rotor main blades via the <u>swashplate</u>	Increase/decrease vertical thrust vector	Increase/decrease torque and engine <u>RPM</u>	To adjust vertical speed	To adjust skid height/vertical speed
Pedals	Collective pitch supplied to <u>tail rotor</u> blades	Yaw rate	Increase/decrease torque and engine <u>RPM</u> (less than collective)	Adjust slip angle	Control yaw rate/heading

Helicopter Pilotage

Helicopter Pilotage is the art of manipulating the flight controls of a <u>helicopter</u> in order to achieve controlled aerodynamic <u>flight</u>.

Flight Controls

A typical helicopter has three separate flight control inputs. These are the cyclic, the collective, and the anti-torque pedals. Depending on the complexity of the helicopter, the cyclic and collective may be linked together by a so-called *mixing unit*, a mechanical or hydraulic device that combines the inputs from both and then sends along the "mixed" input to the control surfaces to achieve the desired result.

Cyclic

The cyclic stick is usually located in between the pilot's legs. The cyclic is so-called, because it changes the <u>pitch</u> of the rotor blades cyclically, that is the pitch of a given blade will be different depending upon its position as it rotates about the rotor head. The result is to tilt the rotor disk in a particular direction, resulting in the helicopter moving in that direction.

Collective

The collective is usually located on the pilot's left side. The collective changes the pitch of the rotor blades collectively or all at the same time, regardless of their position. Therefore, if a collective input is made, all the blades change equally, and the result is the helicopter increasing or decreasing in altitude.

Anti-Torque Pedals

The anti-torque pedals are located in the same position as the <u>rudder</u> pedals in an airplane, and serve a similar purpose, namely to control the direction in which the nose of the aircraft is pointed. Application of the pedal in a given direction changes the pitch of the tail rotor blades, increasing or reducing the thrust produced by the tail rotor and causing the nose to <u>yaw</u> in the direction of the applied pedal.

Flight Conditions

There are two basic flight conditions which may be considered for a helicopter. These are hovering and forward <u>flight</u>.

Hovering

Hovering is the most challenging part of flying a helicopter. This is due to the fact that while in a hover, a helicopter generates its own gusty air which acts against the <u>fuselage</u> and flight control surfaces. The end result is constant control inputs and corrections by the pilot to keep the helicopter where he wants it. However, despite the actual complexity of the act itself, the control inputs themselves in a hover are quite simple. The cyclic is used to eliminate drift in the horizontal plane,

that is to control forward and back, right and left. The collective is used to maintain altitude. The pedals are used to control nose direction or <u>heading</u>. It is the interaction of these controls that makes hovering so difficult, since you cannot change one without having to change the other two, which will then require even more changes in a never-ending cycle of correction after correction.

Forward flight

For the purposes of this article, we will consider forward flight to be flight at <u>airspeeds</u> in excess of 40 KIAS, as it is at this airspeed at which most <u>pitot-static</u> airspeed systems become reliable. In forward flight a helicopter's flight controls behave more like that in a fixed-wing aircraft. Displacing the cyclic forward will cause the nose to pitch down, with a resultant increase in airspeed and loss of altitude. Aft cyclic will cause the nose to pitch up, slowing the helicopter and causing it to climb. The collective now becomes analogous to the throttle in an airplane. Increasing collective(power) while maintaining a constant airspeed will induce a climb while decreasing collective will cause a descent. Coordinating these two inputs, down collective + aft cyclic or up collective + forward cyclic, will result in airspeed changes while maintaining a constant altitude. The pedals serve the same function in both a helicopter and an airplane, and that is to maintain balanced flight. This is done by applying a pedal input in whichever direction is necessary to center the <u>balance ball</u>.

Collective pitch

Refers to the pitch (or angle) of blades of a <u>helicopter</u> to direct movement. There are three types of pitch:

- 1. <u>Cyclic pitch</u> is the individual angling of the blades on each revolution of the <u>rotor</u>. This affects the roll of the craft, moving the nose upward or downward or rolling the craft from side to side.
- 2. **Collective pitch** is the angling of all blades by an equal amount in unison. The pilot uses collective pitch control to rise vertically.
- 3. <u>Differential collective pitch</u> affects the <u>yaw</u> of the helicopter—the turning movement of the aircraft to the right or left. Differential collective pitch control allows the collective pitch of one rotor to be increased over the collective pitch of the other. This produces an increase in resistance, and more torque in one rotor than the other, turning the craft on its vertical axis.

Vortex ring

A vortex ring is a mass of moving <u>fluid</u> moving through the same or different fluid where the flow pattern takes on a <u>donut</u> shape. The movement of the fluid is about the poloidal or circular axis of the donut, in a twisting <u>vortex</u> motion.

Vortex ring formation and structure

One way a vortex ring may be formed is by pushing a spherical mass of fast moving fluid (**A**) into a mass of stationary fluid (**B**). **A** and **B** may chemically be the same fluid. As **B** hits the ball of **A** it pushes the outer layers of **A** with it. The inner layers are less affected. The main mass of **A** forms a 'shadow' of lower pressure behind it, and the layer peeled off by **B** begins to curve round back into the main mass of **A**. This inward curving flow initiates the vortex, and splits it into a donut shape. Now **B** flows past both the inner and outer circumferencii of the donut. The greater outer perimeter causes a net rolling the donut of **A**.

The leading edge of a <u>plume</u>, sometimes called the 'starting-plume', usually has a vortex-ring structure, as does a <u>smoke ring</u>. The motion of an isolated vortex ring and the interation of two or more vortices is discussed in eg <u>Batchelor</u>'s text book (ref 1)

For many purposes a ring vortex may be approximated as having a vortex-core of small crosssection. However a simple theoretical solution, called **Hill's spherical vortex**, is known in which the <u>vorticity</u> is distributed within a sphere (the internal symmetry of the flow is however still annular). Such a structure or an electromagnetic equivalent has been suggested as an explanation for the internal structure of <u>ball lightning</u>.

Vortex Ring effect in Helicopters



The curved arrows indicate airflow circulation about the rotor disc. The helicopter shown is the <u>RAH-66 Comanche</u>.

In typical flight, the rotor disc directs the airflow downwards, creating <u>lift</u>. A vortex ring state though involves a <u>toroid</u>-shaped path of airflow circumscribing the blade disc, as the airflow moves down through the disc, then outward, and then down through the top again. This circulation can negate much of the lifting force and cause a catastrophic loss of altitude.

A helicopter typically induces a vortex ring state by descending into its own downwash. This requires low airspeed and a moderate rate of descent with power applied, and can lead to an undesirable phase of flight known as <u>settling with power</u>. This condition can be corrected by lowering the collective, which controls the pitch angle of the rotor blade, slightly pitching nose down, and establishing forward flight. The aircraft will fly into "clean air", and will be able to regain lift.

Retreating blade stall

Retreating blade stall is a hazardous flight condition in <u>helicopters</u> and other rotary wing <u>aircraft</u>, where the blade rotating away from the direction flight stalls. The <u>stall</u> is due to low <u>airspeed</u> and excessive <u>angle of attack</u>.

Retreating blade stall occurs when the aircarft is travelling at high speed and is one of the factors limiting helicopter airspeed. Retreating blade stall is more likely to occur when the following conditions exist at high forward airspeed:

- High gross weight
- Low rotations per minute
- High density altitude
- Steep or abrupt turns
- Turbulent air

The stall reaction is rapid and violent resulting in pitch up and roll towards the retreating blade. In most cases recovery is not possible.

Settling with power

Definition

Settling With Power, is a hazardous <u>helicopter</u> flight condition in which the aircraft descends into its own downwash, and may not have enough power to stop the descent.

Settling with power is a result of entering a <u>Vortex Ring State</u>. A <u>standard procedure</u> exists to escape this condition.

Ground resonance

Ground resonance, in fully articulated multi-bladed <u>helicopters</u>, is a hazardous condition during <u>touchdown</u>. A series of shocks to the landing gear can pass through to the rotor disk and cause an imbalance in the rotor system. Under extreme conditions, the imbalance causes violent oscillations that quickly build and result in catastrophic damage of the entire airframe. In some cases, complete destruction occurs, e.g. body panels, fuel tanks, and engines are all ripped from their mountings.

The imbalance is possible because multi-bladed helicopters include <u>lag-lead hinges</u> at the <u>rotor hub</u> to reduce stresses in flight. Under normal conditions, all blades are spaced at equal angles. Shocks to the <u>rotor</u> shaft and hub can cause an imbalance if they are sufficiently violent. Note that two bladed helicopters are not susceptible to ground resonance because they do not require lag-lead hinges. Two-bladed rotors remain balanced through all flight conditions.

Recovery is possible in some cases. If sufficient rotor RPM exists, immediate takeoff can restore rotor balance. If rotor RPM is low, complete shutdown might be sufficient.

Low-G condition

Low-G condition is a phase of aerodynamic <u>flight</u> where the airframe is temporarily unloaded. The pilot - and the airframe - feels little or no <u>gravity</u> because the aircraft is in <u>free-fall</u> or decelerating vertically at the top of a climb. It may also occur during some horizontal turning manoeuvres.

This can have a disastrous effect on the aircraft, particularly in the case of helicopters, some of which need to 'feel' gravity all the time.

Effect on helicopters

<u>Helicopters</u> with semi-rigid rotors, for example the two-bladed design seen on <u>Robinson</u> and some other light helicopters, must not be subjected to a low-G condition. Otherwise their <u>rotors</u> may move beyond the normal limits in a condition known as <u>'mast bumping'</u> which can cause the rotor droop stops to shear the mast and hence detach the whole system from the aircraft.

Effect on fixed-wing aircraft

Low-G conditions can also affect fixed-wing aircraft by disturbing the airflow over the wings, making them difficult or impossible to control via the aerodynamic surfaces.

Autorotation

Autorotations are used in <u>helicopters</u> to perform power off landings from altitude in the event of an engine failure.

Autorotation is also used in *autogyro* aircraft as the main means of achieving <u>lift</u> during normal operation. See <u>autogyro</u> for more information.

Maneuver Description

An autorotation is used when the engine fails, or when a <u>tail rotor</u> failure requires the pilot to effectively shut down the engine. It is very similar to gliding in an <u>airplane</u>.

The entry

To enter the autorotation, the pilot lowers <u>collective</u> all the way down, simultaneously adding right pedal. Lowering the collective maintains <u>RPM</u> during the entry to autorotation, and keeps the AOA (<u>angle of attack</u>) at a normal value during the glide. Adding the right pedal is necessary because in autorotation there is no <u>torque</u>. During power-on flight, the pilot uses a lot of left pedal to counter the torque being produced by the engine. Once the helicopter is autorotating, the engine disengages and produces no more torque. While the collective is being lowered, the nose of the helicopter has a tendency to pitch down. The pilot needs to use <u>aft</u> cyclic to prevent this. Allowing the nose to pitch down creates two problems: it tends to reduce RPM because it decreases the amount of airflow through the rotor disk, and it tends to increase airspeed, usually far above the range you want to use while autorotating.

Establishing the glide

As the air starts flowing up through the rotor system, the RPM will start to increase, and depending on how the helicopter is rigged, the RPM may get too high. In this case, as RPM gets high the pilot can increase collective pitch to lower RPM. The pilot should set up a normal autorotational attitude in order to get a normal airspeed. Although helicopters will autorotate at zero airspeed and even at negative airspeed, normally the pilot will want to hold between 60-70 knots of airspeed during the glide.

Selecting a landing area

Within the first few seconds the pilot will establish autorotation and will have selected a landing area. The approach to the landing should almost always be into the wind, so the pilot needs to select a spot which will allow him to maneuver for an upwind approach. The spot should normally be flat, firm, and fairly level. One thing to quickly look for is poles which may have wires strung. The last thing the pilot needs on short final is trying to duck wires. Once the pilot has selected a landing area, it is recommended he visualize a standard traffic pattern imposed on the landing area and aligned with the wind. The pilot should figure out which leg he is currently on, and then fly the pattern so that he arrives on final approach at an altitude and airspeed which will allow him to land in the selected area. By flying a rectangular traffic pattern, the pilot can find himself on base leg, watching the angle to the landing area. When the angle is right, he simply turns final and will be very close to the desired spot. If the pilot starts to see the angle before he reaches the extended "centerline", he can simply turn final early. By cutting the corner he reduces the distance he has to fly, and makes it to the spot without ending up too low. If the pilot finds himself slightly high on base, he can simply fly through the extended centerline, and turn a little late onto final. The extra distance uses up some extra altitude, and he still makes it to his spot. A little overshoot is preferable to a little undershoot because it can be corrected easily still leaving sufficient energy. An undershoot normally requires going to best glide airspeed and dragging the rotor RPM down to the lowest allowable value. If the pilot is not careful, the result may be reaching the spot with low RPM. This is probably not a problem with a light inertia rotor system, but in a high inertia rotor system the RPM might not be recovered before touchdown.

The Flare

The pilot initiates the <u>flare</u> by using <u>aft cyclic</u>. No collective or pedal input is normally required. The height that the pilot should start to flare at depends on many factors, including the model of helicopter, the <u>descent rate</u>, the <u>airspeed</u>, the headwind component, and how rapidly the pilot is going to move the cyclic. The purpose of the flare is twofold. First, it slows the descent rate of the helicopter, from 1,000 or 2,000 feet per minute to much less, so that a soft touchdown can be made. It also reduces the forward ground speed to just a few knots so that sliding on the landing gear is minimized. The flare must be timed to not zero the descent rate, because the helicopter would be left hanging in the air bleeding RPM, but rather the flare should be timed to slow the descent rate so that the helicopter is approaching the ground at a manageable rate. The descent rate should be decreasing so that it either goes to zero just above the ground, or is low enough that a little collective pitch can bring it to zero.

The Landing

Touchdown is accomplished by (typically) putting the helicopter into a level attitude, and then using the collective to cushion the landing, just as in a hovering autorotation. The pedals are used to align the <u>landing gear</u> with the ground track.

Power Recovery

If the pilot is practicing an autorotation he may decide to recover to a hover, rather than touch down.

The procedure is to start raising collective while still in the flare, just as flare effectiveness starts to go away, before any increase in sink rate is experienced. By starting the recovery early, the engine is not trying to play catch-up, and the recovery can be made with the RPM in the green range at all times.

Common Mistakes

Failure to Lower Collective all the way down

If the pilot forgets to lower collective and this is a real engine failure, it's a fatal mistake. Lowering collective is the most important part of doing an autorotation. If you remember to do that, you will probably walk away from the landing. Some pilots only put the collective pitch part of the way down. They get to "know" where it belongs. The only problem with this is that the position the collective needs to go to depends on many factors such as <u>pitch link rigging</u>, gross weight, and density altitude. These things can change from day to day. This method also delays recovery of rotor RPM, and there is no good reason to do that. The best method is to lower collective all the way, and as RPM starts to build back up some collective should be raised to stop the RPM somewhere in the operating range.

Failure to trim with anti-torque pedals Pilots will either forget to push right pedal, or push too much, or even sometimes push the left pedal. In any case, the aircraft should be autorotated in trim, and the pilot can do this by putting in the correct amount of right pedal when the engine fails.

Allowing the nose to drop

Do not let the nose drop during the entry. Whatever attitude the helicopter is in, enter the autorotation in that attitude, and then after the autorotation is established the pilot can make any attitude adjustments required for proper airspeed. Allowing the nose to pitch down delays the recovery of RPM (it's like an anti-flare) plus it is not uncommon for pilots to overspeed the rotor by waiting until the airspeed builds to 80 knots or more, and then suddenly trying to fix it by yanking back on cyclic. The result is an almost instantaneous rotor overspeed.

Failure to control Rotor RPM with collective

Most helicopters are rigged so that at normal weights the collective will have to be raised somewhat to keep rotor RPM in the normal operating area. Common mistakes are either to leave the collective full down so long that a rotor overspeed occurs, or to overcontrol the collective, moving it up and down during the entire glide. The proper way to manipulate collective is to lower it full down during the entry to autorotation. Then, as RPM starts to increase toward the normal operating area raise enough collective to stop the RPM from changing. Wait a few seconds until it stabilizes, and make one final adjustment to place the RPM exactly where it is desired. Normally no further manipulation of the collective will be required during the glide. One exception is that during turns, especially at high speed, some collective may be required to prevent the RPM from climbing too high. Rolling out of the turn, the pilot should put the collective back to where it was before the turn was entered. By performing turns at lower airspeeds, little or no collective will be required.

Failure to maneuver to the point of intended landing

Many pilots get quite proficient at autorotating to the runway at their home airport, but have more trouble when trying to make a specific landing area in the off-airport environment. It is best to set up a (tight) traffic pattern to the landing area, just as is done at an airport. The pilot should figure out the wind, and therefore where "final" will be. Then the pilot should figure out where he currently is with respect to the traffic pattern (is he already on downwind, base, or final?). Once he knows what leg he is on, he can manipulate the length of the remaining legs to arrive on final at the proper altitude. A very short final is suggested. The longer final is, the bigger the chance is of over or undershooting,

with no easy way to correct once the under or overshoot is recognized. Instead, fly a very tight base and time your turn onto short final to give you the desired distance to the touchdown spot. If you are a little low, turn final slightly early. If you are a little high, delay the turn to final, overshoot the centerline somewhat, and use up the additional altitude on base. For gross errors, S-turns or zero (or negative) airspeed may be required. One final - never do a 360 degree turn. You lose track of your approach angle for too long. Instead, if you have massive amounts of altitude to lose, perform a figure-8 pattern on final. This way the spot is always visible, and you can turn back onto final when the angle begins to look right.

Flaring at the wrong altitude

Each helicopter has a range of altitudes it needs to be flared at. The altitude will change from flight to flight based on gross weight, density altitude, wind, and airspeed. Generally, aircraft with higher <u>disk</u> <u>loadings</u> require a higher flare. If the pilot flares too high, the helicopter will stop its descent too high above the ground to make a safe landing. If the pilot flares too low, he will be forced to level the helicopter (get rid of the flare) too early (to avoid hitting the tail on the ground). The result will be a high rate of descent (which he can probably fix by raising collective) and high forward ground speed (which he can't fix, so he'll slide hundreds of feet). Assuming a perfect flare cannot be made, which way the pilot should err depends on the surface being landed on. If the surface is firm and level, some slide probably won't hurt, and it would be best to be a little bit low to give a soft touchdown, followed by a little slide. If the surface does not appear to allow a slide (swamp or such which will cause the skids to dig in) the flare should probably be a little high to insure removal of all forward speed. The touchdown may be a little harder, but, by being more vertical, the chance of rolling over is reduced. One caveat is that human beings do not take vertical accelerations well, so to avoid back injuries, the flare should not be too high.

Flaring too aggressively or not aggressively enough

The speed with which the nose of the aircraft needs to be pitched up is related to gross weight, density altitude, wind, and airspeed. Generally if gross weight is high, a more aggressive flare will be required. If density altitude is high, a more aggressive flare is required. If wind is high, a less aggressive flare is required. And if airspeed is high, a less aggressive flare is required. Pilots can adjust for minor airspeed deviations by flaring at different altitudes, or with different amounts of aggressiveness. For instance, if the airspeed is 10 knots below optimal, a more aggressive flare will help to make up for this. Of course there are limits to the amount of correction that is possible.

Failure to level the aircraft

Some aircraft land in a slightly tail low attitude, but with many others it is critical to have the landing gear level before touchdown. Failure to do so can result in <u>tail boom</u> strikes and <u>porpoising</u> (where you hit on the heels, and then roll up onto the toes and flip over forward).

Failure to maintain heading during the slide

There are a couple reasons that heading might not be maintained during any ground slide. One is just that the pilot fails to manipulate the pedals correctly, the other is that if rotor RPM gets too low the tail rotor may lose effectiveness. Failure to maintain heading can cause a <u>skid gear</u> to catch and roll the aircraft over on its side. Most aircraft can perform fairly high speed slides if the skids are pointed in the direction the aircraft is moving.

Moving the cyclic aft during the slide

It's human nature to want to stop the slide as early as possible, but moving the cyclic aft has two problems. One is that the main rotor is probably not generating much thrust at this point, so it won't

help much anyway. The other is that flapping is at maximum because RPM is low, and moving the cyclic aft moves the rotor blades even closer to the tailboom. The rotor blades hitting the tailboom is a very real possibility.**Reference** <u>http://www.copters.com</u>



The Height-Velocity diagram or H/V curve is a graph relevant to helicopter pilots.

In the simplest explanation, the H/V curve is a diagram where the shaded areas should should be avoided, as the average pilot may be unable to complete an <u>autorotation</u> landing without damage. The H/V curve will usually contain a take-off profile, where the diagram can be traversed from 0 height and 0 speed to cruise, without entering the shaded areas. The portion in the upper left of this diagram demonstrates a flight profile which will likely not allow the pilot to successfully complete an autorotation. This is due to being on the "back side" of the power curve. The shaded area on the lower right is dangerous due to the airspeed and proximity to the ground resulting in dramatically reduced reaction time for the pilot in the case of mechanical failure, or other in-flight emergencies. This shaded area at the lower right is not portrayed in H/V curves for multiengine helicopters capable of safely hovering and flying with a single engine failure.

Trivia

The height-velocity curve is sometimes referred to as the **dead man's curve** by helicopter pilots, as operation outside the safe area of the chart can be fatal in the event of a power failure.

Anatomy of a helicopter



A Westland Lynx in the hover

- 1. <u>Rotor</u>
- 2. Engine
- 3. Transmission
- 4. Tail rotor
- 5. Battery compartment
- <u>Searchlight</u>
 <u>Landing light</u>
- 8. FLIR
- 9. Skids or wheels
- 10. Emergency floatation system
- 11. Strobe light





The instruments of a simpler aircraft, the Robinson R22

- 1 Vertical speed indicator
- 2 Attitude indicator, or Horizontal situation indicator
- 3 Airspeed indicator
- 4 Engine and rotor RPM guages
- 5 Altimeter
- 6 Heading indicator a gyroscopic compass
- 7 Slip ball
- 8 Manifold Pressure Guage shows engine power setting
- 9 Moving map display or GPS

Other cockpit equipment includes:

- <u>Cyclic</u>
- <u>Collective</u>
- Primary flight display
- Navigation display
- <u>Aircraft communication radios</u>
- <u>Aircraft navigation radios</u> for tuning <u>VORs</u>, <u>DMEs</u>, and <u>ILS</u>
- Automatic direction finder
- Transponder
- <u>GPS</u>
- Engine control panel
- Reconfiguration unit
- Overhead switch panel
- <u>Circuit breakers</u>

Forward looking infrared

A forward looking infrared (FLIR) system is a camera that takes pictures using the <u>infrared</u> portion of the <u>electromagnetic spectrum</u>. In Europe, these are typically called Thermal imagers. Often these contain sub-systems known as Thermal imaging common modules or TICM. FLIRs are often described as "<u>infrared cameras</u>". Since FLIRs use detection of <u>thermal energy</u> to create the "picture" assembled for the <u>video</u> output, they can be used to help <u>pilots</u> and drivers steer their vehicles at night, and in <u>fog</u>, or detect warm objects against a cold background when it is completely dark (such as a cloudy, moonless night). Note that a FLIR's wavelength range differs from a <u>night vision</u> camera, which detects <u>wavelengths</u> up to around 1-1.5 <u>micrometres</u> (slightly higher than the <u>human eye</u> can detect).

There are two basic ranges of <u>infrared</u>. 8-12 <u>micrometre</u> cameras (or "far infra-red" or LWIR) can see engine <u>exhaust</u>, or human <u>body heat</u> a few miles away, but longer distance viewing becomes blurred because the infra-red light is <u>absorbed</u>, <u>scattered</u> and <u>refracted</u> by the air.

3-5 <u>micrometre</u> <u>infrared</u> ("MWIR") cameras can see almost as well, and are far less absorbed by air, but generally require a much more expensive sensor array, and lower-<u>temperature</u> cooling.

Many FLIR systems use <u>digital image processing</u> to improve the image quality. FLIR sensor arrays often have inconsistent responses from <u>pixel</u> to pixel. To fix this, the response of each pixel is measured at the factory, and a transform, mostly linear, maps the measured <u>brightness</u>.

FLIRs are often used in naval vessels, fixed-wing <u>aircraft</u>, <u>helicopters</u>, and <u>armored fighting vehicles</u>. In warfare, they have three large advantages. First, the imager itself is difficult for the enemy to detect. Second, they see heat, which is hard to <u>camouflage</u>. Thirdly, FLIR systems can see through smoke, fog, haze, and other atmospheric obscurants better than a <u>visible light</u> camera.

Radio direction finder

A radio direction finder, or RDF, is a device for finding the direction to a radio source.

How it works

Due to radio's ability to travel very long distances "over the horizon", it makes a particularly good <u>navigation</u> system for ships and aircraft that might be flying at long distances from land. RDF's work by pointing a directional <u>antenna</u> in "various directions" and then listening for the direction in which the signal from a known station came through most strongly. This sort of system was widely used in the <u>1930s</u> and <u>1940s</u>. RDF antennas are particularly easy to spot on <u>German World War II</u> aircraft, as loops under the rear section of the fuselage, whereas most <u>US</u> aircraft enclosed the antenna in a small teardrop-shaped fairing.

In more recent times the task of finding the signal has been automated in the **automatic direction finder**, or **ADF**. In this system the antenna consists of a small cylinder of wire, a <u>solenoid</u> that is highly directional, which is spun by a motor. The electronics listen either for the repeated "peak" in the signal, or just as commonly, the "trough" when the signal drops to zero when the antenna is at right angles to the signal. A small lamp attached to a disk is timed to spin at the same speed as the

antenna, so when the peak or trough is detected the lamp flashes briefly. To the human eye it appears to be a single spot of light on top of a <u>compass rose</u>.

Usage in navigation

Signals are provided in the form of *radio beacons*, the radio version of a <u>lighthouse</u>. The signal is typically a simple <u>AM</u> broadcast of a <u>morse code</u> series of letters, which the RDF can tune in to see if the beacon is "on the air". Most modern detectors can also tune in any commercial radio stations, which is particularly useful due to their high power and location near major cities.

RDF was once the primary form of aircraft navigation, and strings of beacons were used to form "airways" from airport to airport. In the 1950s these systems were generally being replaced by the <u>VOR</u> system, in which the angle to the beacon can be measured from the signal itself, with no moving parts. Since the signal being broadcast in the RDF system is non-directional, these older beacons were referred to as <u>non-directional beacons</u>, or **NDB** in the aviation world.

Today all such systems are being generally removed in favour of the much more accurate and userfriendly <u>GPS</u> system. However the low cost of ADF systems today has meant something of a comeback, whereas the expensive VOR systems will likely all be switched off before <u>2010</u>.

Variometer



The vertical speed indicator from a Robinson R22

Definition

A variometer (also known as a rate-of-climb indicator, a vertical speed indicator (VSI), or a vertical velocity indicator (VVI)) is an <u>instrument</u> in an <u>aircraft</u> used to inform the <u>pilot</u> of the rate of descent or climb. It can be calibrated in feet per minute (ft/min), <u>knots</u> (nautical miles per hour) or metres per second (m/s), depending on country or type of aircraft.

In powered <u>flight</u> the pilot makes frequent use of the **VSI** to ascertain that level flight is being maintained, especially during turning manoeuvres. The instrument gives an instantaeous description of climbing or descent. But it is in <u>gliding</u> that the instrument really comes into its own.

Glider pilots call the instrument a variometer, while power pilots tend to call it a VSI.



Simple Variometer for <u>Paragliders</u>, <u>Hang Gliders</u> and <u>Ballooneers</u>



Panel mounted variometer for gliders

Description

In its simplest form, the instrument consists of an air bottle connected to the external atmosphere by a small tube. As the aircraft moves up or down in the atmosphere, the pressure inside the air bottle changes to equalise with the external air pressure. This causes air to move through the tube. The faster the aircraft is ascending (or descending), the faster the air flows. The variometer simply measures and displays the direction and speed of the airflow in the tube. This simple and effective instrument, known as an "uncompensated" variometer or vertical speed indicator, is used in most powered aircraft. The variometer has particular importance, however, for un-powered aircraft.

Purpose

Human beings, unlike birds, are not able directly to sense climb and sink rates. Before the invention of the variometer, <u>sailplane</u> pilots found it very hard to <u>soar</u>. Although they could readily detect abrupt *changes* in vertical speed ("in the seat of the pants"), their senses did not allow them to distinguish lift from sink, or strong lift from weak lift. The *actual* climb/sink rate could not even be guessed at, unless there was some clear fixed visual reference nearby. Being near a fixed reference means being near to a hillside, or to the ground. Except when hill-soaring (exploiting the lift close to the up-wind side of a hill), these are not generally very profitable positions for glider pilots to be in. The most useful forms of lift (<u>thermal</u> and wave lift) are found at higher altitudes and it is very hard for a pilot to detect or exploit them without the use of a variometer. The invention of the variometer (by <u>Max Kronfeld</u>) moved the sport of <u>gliding</u> into a whole new realm.

As the sport developed, however, it was found that these simple "uncompensated" instruments had their limitations. The information that glider pilots really need to enable them to soar is not the vertical speed of the glider itself, but the vertical speed of the air through which it is flying. When the pilot chooses to dive or to pull up, a simple variometer will faithfully indicate a corresponding change in climb or sink rate. This means that you can only use an uncompensated variometer to detect areas of atmospheric lift or sink when in level flight. Pulling up or diving makes the readings effectively meaningless.

The action of diving and/or pulling up a sailplane affects its velocity. You can exchange height for speed or speed for height. In energy terms this means exchanging <u>kinetic energy</u> for <u>potential energy</u> or vice versa. A sailplane pilot is mostly interested in the gain of potential energy provided by air currents, and far less interested in the gain of potential energy provided by the easy exchange

between potential and kinetic energies (speed for height). It is the change in the sailplane's *total* energy (potential + kinetic) which interests the pilot.

For this reason most modern sailplanes are equipped with a type of instrument known as the *total energy* or *compensated* variometer, which adjusts its measurement of the change of potential energy by subtracting the change of kinetic energy. This is achieved by the use of an additional tube which is connected at one end to the static side of the variometer and at the other to a <u>venturi</u>, an object shaped like two small funnels connected at their narrow ends. The geometry of a venturi is such that air flowing through it generates suction (reduced pressure) in the tube. With the venturi pointed into the airflow, if the pilot causes the sailplane to dive, the increase in air-speed causes a reduction in pressure in this tube which, when carefully set up, exactly cancels out the increase in the external static pressure. The net result is that there is no change to the reading on the variometer, and the influence of changing aircraft velocity is eliminated. To maximise the precision of this compensation effect, the venturi needs to be in airflow that is as far as possible undisturbed. Hence the "brunswick tube", the long cantilevered tube with a kink in the end that can be seen projecting from the leading edge of the fin on most modern sailplanes.

Very few powered aircraft have total energy variometers, so it is common for novice power pilots to "chase the needle", trying to establish a steady rate of descent or climb, or simply staying at zero. This usually results in the aircraft wandering up and down in altitude - a form of <u>pilot-induced</u> <u>oscillation</u> (PIO). More experienced power pilots using uncompensated variometers know to refer to the instrument only after establishing performance in some other manner. Generally, a pilot would set the appropriate power level and place the nose in the proper position relative to the horizon (or by using an <u>attitude indicator</u>). As the plane stabilizes its <u>airspeed</u> in the new configuration, the pilot will glance at the variometer and make any fine adjustments needed.

In modern gliders, electronic variometers generate a sound whose pitch and rhythm depends on the instrument reading. This allows the pilot to concentrate on the external view instead of having to watch the instruments, thus improving safety and also giving the pilot more opportunity to search for promising looking clouds and other signs of atmospheric lift.

Attitude indicator



Attitude indicator

The **attitude indicator** (AI), also often called the **artificial horizon**, is an <u>instrument</u> used in an <u>aircraft</u> to inform the pilot of the attitude of the plane - it indicates attitude in both pitch (fore and aft tilt) and roll (side to side tilt). The instrument is considered the most important for flight under the <u>instrument flight rules</u> (IFR), but has minimal application under the <u>visual flight rules</u> (VFR), except in emergencies, when the pilot may lose visual reference to the ground.

The first artificial horizons were used in maritime <u>navigation</u> where <u>latitude</u> is measured through the observation of celestial bodies in relation to the horizon. The horizon in this context is a fixed number of degrees below the actual tangent at the observation point. Various devices were developed (many relying on a liquid such as <u>mercury</u>) to indicate the level plane. Obviously fog and rain whilst obscuring the horizon might still allow the Sun's position to be clearly measured.

Als in aircraft works using a <u>gyroscope</u> to establish an <u>inertial platform</u>, geared to a display that has two degrees of freedom, simultaneously displaying pitch and roll. The display is coloured to indicate the horizon as the division between the two coloured segments, and as such is intended to be intuitive to use. The actual roll angle is also calibrated around the circumference of the instrument. The pitch angle is indicated by a series of calibration lines, each representing 10° of pitch. The pitch angle is relative to the ground, which is not as helpful as knowing the <u>angle of attack</u> of the aircraft, a much more critical measure of performance. The pilot must infer the total performance by using other instruments such as the <u>airspeed indicator</u> (ASI).

Under some circumstances, some types of AI may "tumble", which is, they lose the ability to display anything sensible, particularly if the aircraft is in an extreme or unusual attitude, or performing <u>aerobatics</u>. Some types are fitted with a "cage", which locks the gyroscope to prevent damage under these conditions.

Individual mechanical gyros are slowly being replaced by <u>Attitude and Heading Reference Systems</u> (AHRS), which use solid-state or miniature gyroscopes (<u>MEMS</u>) to supply aircraft orientation information, supplemented by <u>magnetometers</u> to supply heading information. Historically, heading information was supplied by a separate gyroscopic instrument known as a <u>directional gyro</u> (DG, or heading indicator). AHRS are able to provide 3-axis information that can be shared with multiple devices in the aircraft, such as "glass cockpit" primary flight displays (<u>PFDs</u>). AHRS have been proven to be highly reliable and are in wide use in commercial and business aircraft.

Altimeter



Aircraft altimeter as used in North America

An **altimeter** is an active instrument used to measure the <u>altitude</u> of an object above a fixed level. The traditional altimeter found in most aircraft works in measuring the <u>air pressure</u> from a <u>static port</u> in the <u>airplane</u>. Air pressure decreases with an increase of altitude - about one millibar (0.03 inches of mercury) per 27 feet (8.23 m) close to sea level. The altimeter is calibrated to show the pressure directly as altitude in accordance with a mathematical model defined by the <u>International Standard</u> <u>Atmosphere</u> (ISA).

The reference pressure can be adjusted by a setting knob. This is necessary since sea level air pressure varies with the weather. In pilot's jargon, the regional or local air pressure at mean <u>sea level</u> is called the <u>QNH</u>, and the pressure which will calibrate the altimeter to show the height above ground at a given airfield is called the <u>QFE</u> of the field. An altimeter cannot however be adjusted for variations in air temperature. Difference in temperature from the ISA model will therefore cause error in indicated altitude.

The calibration formula for an altimeter, up to 36,090 feet (11,000 m), can be written as:

$$h = \frac{(1 - (P_0/P_{ref})^{0.19026}) \times 288.15}{0.00198122}$$

where *h* is the indicated altitude in feet, P_0 is the static pressure and P_{ref} is the reference pressure (use same units for both).

Other types of altimeter are the <u>radar altimeter</u> that measures the altitude more exactly using the time taken for a radio signal to reflect from the surface back to the aircraft. The radar altimeter is used to measure the exact height during the landing procedure of commercial aircraft.

Mountaineers use wrist-mounted altimeters when on high-altitude expeditions, as do skydivers.

Scientific Uses

A number of satellites (See links) use exotic dual-band <u>radar</u> altimeters to measure height from a <u>spacecraft</u>. That measurement, coupled with <u>orbital</u> elements (possibly from <u>GPS</u>), enables determination of the <u>topography</u>. The two lengths of radio waves permit the altimeter to automatically correct for varying delays in the <u>ionosphere</u>.

Over water, detailed satellite altitude information has proven amazingly useful. Humps in the water indicate <u>gravitational</u> concentrations, permitting a computer program to construct a map of undersea features such as mountains. The altimeters can also measure wave heights, wave directions, and wave spectra. This information permits computer programs to measure the speed of ocean currents and produce detailed maps of wind speeds and directions at the surface, even in extremely stormy conditions.



Heading Indicator

The heading indicator from a Robinson R22

The **heading indicator** (or HI) is an <u>instrument</u> used in an <u>aircraft</u> to inform the <u>pilot</u> of his heading. It is sometimes referred to by its older name, the **directional gyro**, or (UK usage) **direction indicator** or DI. The primary means of establishing heading in most small aircraft is the magnetic <u>compass</u>, but that suffers from errors created by the 'dip' or downward slope of the earth's magnetic field. Dip error causes the magnetic compass to read incorrectly whenever the aircraft is in a bank, or during acceleration, making it difficult to use in any flight condition other than perfectly straight and level. To remedy this, the pilot will typically maneuver the airplane with reference to the heading indicator, as the gyroscopic heading indicator is unaffected by dip and acceleration errors. The pilot will periodically reset the HI to the heading shown on the magnetic compass.

The HI works using a <u>gyroscope</u> to establish an <u>inertial platform</u>, which will remain fixed in space. The HI is arranged so that only the horizontal axis is used to drive the display, which consists of a circular compass card calibrated in degrees. The gyroscope is spun either electrically, or using air from a <u>vacuum pump</u> (sometimes a pressure pump in high alititude aircraft) driven from the aircraft's <u>engine</u>. Because the earth rotates (15° per hour), and because of small accumulated errors caused by

friction, the HI will drift over time, and must be reset from the compass periodically. Normal procedure is to reset the heading indicator once each fifteen minutes of flight. Failure to do this is a common source of navigation errors among beginner pilots.

Some more expensive heading indicators are 'slaved' to a sensor (called a 'flux gate'). The flux gate continuously senses the earth's magnetic field, and a servo mechanism constantly corrects the heading indicator. These 'slaved gyros' reduce pilot workload by eliminating the need to be manually reset every fifteen minutes.



Airspeed indicator

Airspeed Indicator

The **airspeed indicator** is an instrument used in an <u>aircraft</u> to display the craft's <u>airspeed</u>, typically in <u>knots</u>, to the <u>pilot</u>.

Markings

A <u>redline</u> mark indicates V_{NE} , or *velocity (never exceed)*. This is the absolute maximum airspeed that the aircraft must not exceed under any circumstances. The red line is preceded by a yellow band which is the caution area, which runs from V_{NO} (*velocity maximum, normal operation*) to V_{NE} . A green band runs from V_{S1} to V_{NO} . V_{S1} is the <u>stall</u> speed with <u>flaps</u> and <u>landing gear</u> retracted. A white band runs from V_{S0} to V_{FE} . V_{S0} is the stall speed with <u>flaps</u> extended, and V_{FE} is the highest speed at which flaps can be extended. Airspeed indicators in multi-engine aircraft show a short red line near to the bottom of green arc for V_{mc} , the speed below which full rudder is insufficient to keep the aircraft from yawing at full power with the <u>critical engine</u> inoperative and a blue line for V_{YSE} , the speed for best rate of climb with the <u>critical engine</u> inoperative.

The green range is the normal range of operating speeds for the aircraft with the flaps up. The yellow range is the range in which the aircraft may be operated with caution to avoid turbulence or abrupt control inputs. The white range is the normal range of operating speeds for the aircraft with the flaps down.

At high <u>Density Altitude</u>, the airspeed indicator will show a far lower speed than the aircraft's <u>true</u> <u>airspeed</u> (TAS), but aerodynamically, the same indicated airspeeds apply. The airspeed indicator is especially important for monitoring <u>V-Speeds</u> while operating an aircraft. Modern aircraft employing <u>glass cockpit</u> instrument systems employ two airspeed indicators: an electronic indicator on the primary flight data panel and a traditional dial or "steam gauge" for use when the electronic panels fail.

Operation



Airspeed indicator construction

Along with the <u>altimeter</u> and <u>vertical speed indicator</u>, the airspeed indicator is a member of the <u>pitot</u><u>static</u> group of aviation instruments, so named because they operate by measuring pressure in the <u>pitot</u> and static circuits.

Airspeed indicators work by measuring the difference between <u>static pressure</u>, captured through one or more static port(s) and <u>dynamic pressure</u>, captured through a <u>pitot tube</u>. The static ports are located on the exterior of the aircraft, at a location chosen to detect the prevailing atmospheric pressure as accurately as possible, that is, without any disturbance from the passage of the aircraft. Some aircraft have static ports on both sides of the <u>fuselage</u> or <u>empennage</u>, in order to more accurately measure static pressure during slips and skids.

The pitot tube accumulates "ram air", that is, air forced against the opening of the tube by the passage of the aircraft. Pitot tubes face forward, in the direction of flight. <u>Ling</u> is a problem for pitot tubes when visible moisture is present in the atmosphere, as when flying through clouds or precipitation. Electrically heated pitots are used to prevent clogging with ice.

The airspeed indicator is rendered inoperative by blockage in the static system. To prevent this, most aircraft intented for use in <u>instrument meteorological conditions</u> are equipped with an alternate source of static air. This is usually less accurate, but is still workable.

Use

The primary use of the airspeed indicator is to provide guidance during climb, descent and landing, so that an appropriately slow airspeed is maintained while still operating safely above <u>stall speed</u> and without entering <u>slow flight</u>. During approach and landing, the aircraft is typically operated at airspeeds specified by <u>air traffic control</u> or the aircraft's operating handbook depending on conditions and the phase of the approach. The airspeed indicator is also important for ensuring that structural speeds are not exceeded, beyond which the airframe may be stressed and damaged.

During <u>instrument flight</u>, the airspeed indicator is the primary instrument of reference for pitch control during climbs and descents, and a secondary instrument of reference for pitch control during cruise and turns.

The airspeed indicator is also used in <u>dead reckoning</u>, where time, speed, and bearing are used for navigation.

Alternatives

The "lift reserve indicator", or LRI, has been proposed but poorly received as an alternative to the airspeed indicator for use during critical stages of flight. The LRI shows the margin of speed above stall speed. Since indicated stall speed varies with conditions (particularly gross weight), the LRI is simpler to use.

Some aircraft are equipped with a ground speed display, which is calculated by radionavigation equipment.

Types of airspeed measurements

Most aircraft exhibit a difference between (theoretical) <u>calibrated airspeed</u> (CAS) and the airspeed actually shown on the instrument (indicated airspeed, or IAS). This *position error* is mainly due to inaccurate static pressure. It is usually not possible to find locations for the static ports which accurately sense static pressure at all speeds and angles of attack.

Because <u>Bernoulli's principle</u> states that total pressure is constant along a streamline, a <u>pitot tube</u> that is away from the <u>boundary layer</u> and approximately aligned with the local airflow should not cause much position error.

Position error is typically small (a few percent), and, for small planes, the IAS will be lower than CAS at slow speeds and higher than CAS at high speeds. A calibration chart is usually provided but rarely used.

The true airspeed (TAS) can be calculated as a function of local air density, or of temperature and pressure altitude (which determine density). Some airspeed indicators incorporate a <u>slide rule</u> mechanism to perform this calculation. Otherwise, it can be performed with a calculator such as the <u>E6B</u> handheld circular <u>slide rule</u>.