How Helicopters Work

Helicopters are the most versatile flying machines in existence today. This versatility gives the pilot complete access to **three-dimensional** space in a way that no airplane can. If you have ever flown in a helicopter you know that its abilities are exhilarating!

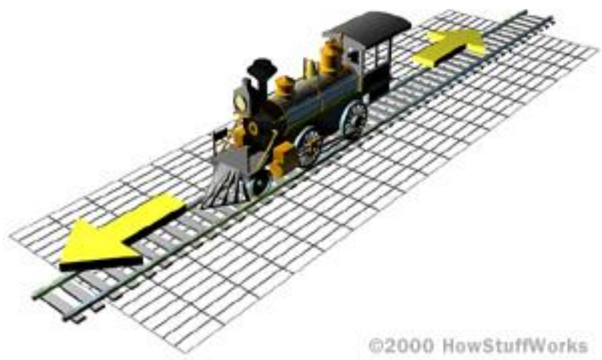
The amazing flexibility of helicopters means that they can fly almost anywhere. However, it also means that flying the machines is complicated. The pilot has to think in three dimensions and must use both arms and both legs constantly to keep a helicopter in the air! Piloting a helicopter requires a great deal of training and skill, as well as continuous attention to the machine.

In this article, you will learn about all of a helicopter's different capabilities and how it's able to do such amazing things!

Comparing Modes of Transport

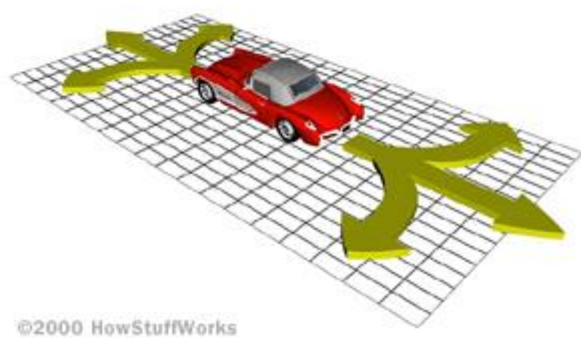
To understand how helicopters work and also why they are so complicated to fly, it is helpful to compare the abilities of a helicopter with those of trains, cars and airplanes. By looking at these different modes of transportation, you can come to understand why helicopters are so versatile!

If you have ever been inside of the cab of a locomotive, you know that trains are fairly simple to drive. After all, there are only two directions that a train can travel in -- forward and reverse. There is a brake to stop the train's travel in either direction, but there is no steering mechanism of any kind on a train. The tracks take the train where it needs to go.



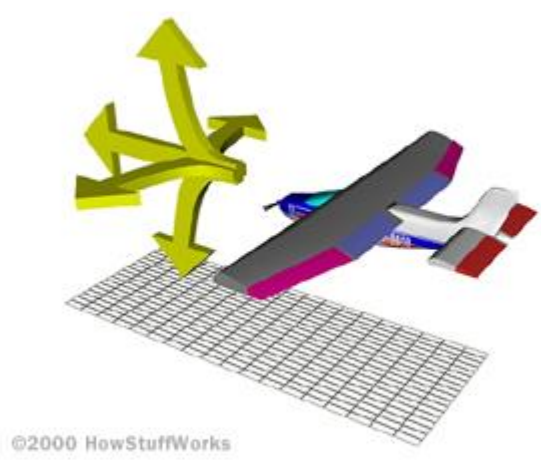
Because a train has only two directions in which it can travel, you can drive a train with one hand.

A car, of course, can go forward and backward like a train. While you are traveling in either direction you can also turn left or right:



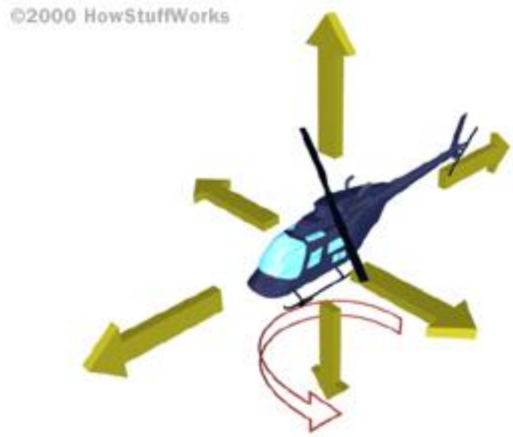
To handle the steering, a car uses a steering wheel that the driver can turn clockwise or counterclockwise. It is possible to drive a car with one hand and one foot.

Anyone who has taken pilot lessons or looked inside the cockpit while boarding a jumbo jet knows that planes are a lot more complicated to fly than a car is to drive. However, a plane is really only one step away from a car:



A plane can move forward and turn left or right. It also adds the ability to go up and down. However, it loses the ability to reverse. So a plane can move in five different directions instead of a car's four directions. The ability to go up and down adds a whole new dimension to a plane, and this dimension is one of the things that makes airplanes different from a car. To control the upward and downward motion of the plane, either a joystick replaces the steering wheel or the steering wheel gains the ability to move in and out (in addition to turning clockwise and counterclockwise). In most planes (but not all), the pilot also has access to two pedals to control the rudder. Therefore, a pilot could fly a plane with one hand and two feet.

A helicopter can do three things that an airplane cannot:



- A helicopter can **fly backwards**.
- The entire aircraft can **rotate in the air**.
- A helicopter can **hover** motionless in the air.

In a car or a plane, the vehicle must be moving in order to turn. In a helicopter, you can move **laterally** in any direction or you can **rotate 360 degrees**. These extra degrees of freedom and the skill you must have to master them is what makes helicopters so exciting, but it also makes them complex.

To control a helicopter, one hand grasps a control called the **cyclic**, which controls the lateral direction of the helicopter (including forward, backward, left and right). The other hand grasps a control called the **collective**, which controls the up and down motion of the helicopter (and also controls engine speed). The pilot's feet rest on pedals that control the tail rotor, which allows the helicopter to rotate in either direction on its axis. It takes both hands and both feet to fly a helicopter!

Special Capabilities of Helicopters

Helicopters have a number of unique abilities that airplanes do not have. Several of these capabilities are shown in the following videos (if you have a high-speed Internet connection, these videos are quick and fun to watch!).

The signature of a helicopter is its ability to **hover** over one point on the ground. While hovering, a helicopter can also spin on its axis so that the pilot can look in any direction.

Click here to download the 30-second video showing a helicopter hovering over a point and rotating. (2.0 MB)

Another unique feature of a helicopter is its ability to **fly backwards**. A helicopter can also fly **sideways** just as easily.

Click here to download the 25-second video showing a helicopter flying in reverse. (1.6 MB)

Since a helicopter can fly backwards and sideways, it can do a number of interesting tricks. The following video shows a helicopter performing a **pirouette**, in which it rotates 360 degrees while it travels down a straight line relative to the ground:

Click here to download the 40-second video showing a helicopter doing a pirouette (turning about its axis while flying down a straight path). (2.7 MB)

A helicopter that is flying forward can also **stop in mid-air** and begin hovering very quickly, as demonstrated in this video:

Click here to download the 15-second video showing a helicopter stopping quickly in mid-air. (0.9 MB)

All of these maneuvers are impossible in an airplane, which must fly forward at all times in order to develop lift from its wings (see How Airplanes Work for details).

How Helicopters Fly

You can begin to understand how a helicopter flies by thinking about the abilities displayed in the previous section. Let's walk through the different abilities and see how they affect the design and the controls of a helicopter.

Imagine that we would like to create a machine that can simply fly straight upward. Let's not even worry about getting back down for the moment -- up is all that matters. If you are going to provide the upward force with a wing, then the wing has to be in motion in order to create **lift**. Wings create lift by deflecting air downward and benefiting from the equal and opposite reaction that results (see How Airplanes Work for details -- the article contains a complete explanation of how wings produce lift).

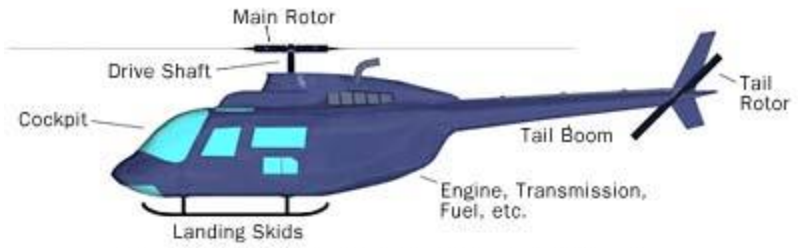
Thanks to Raleigh Helicopters!
I would like to express my gratitude to Glenn Brown, the president of Raleigh Helicopters, and Ellen Turcio, my pilot and the star of the videos shown in this article. Both were extremely helpful and went out of their way to assist me with this article. If you are in the Raleigh, NC, area and need helicopter services or instruction, you can reach Raleigh Helicopters at (919) 497-1870.

A **rotary motion** is the easiest way to keep a wing in continuous motion. So you can mount two or more wings on a central shaft and spin the shaft, much like the blades on a ceiling fan. The rotating wings of a helicopter are shaped just like the airfoils of an airplane wing, but generally the wings on a helicopter's rotor are narrow and thin because they must spin so quickly. The helicopter's rotating wing assembly is normally called the **main rotor**. If you give the main rotor wings a slight angle of attack on the shaft and spin the shaft, the wings start to develop lift.

In order to spin the shaft with enough force to lift a human being and the vehicle, you need an engine of some sort. Reciprocating gasoline engines and gas turbine engines are the most common types. The engine's driveshaft can connect through a transmission to the main rotor shaft. This arrangement works really well until the moment the vehicle leaves the ground. At that moment, there is nothing to keep the engine (and therefore the body of the vehicle) from spinning just like the main rotor does. So, in the absence of anything to stop it, the body will spin in an opposite direction to the main rotor. To keep the body from spinning, you need to apply a force to it.

The usual way to provide a force to the body of the vehicle is to attach another set of rotating wings to a long boom. These wings are known as the **tail rotor**. The tail rotor produces **thrust** just like an airplane's propeller does. By producing thrust in a sideways direction, counteracting the engine's desire to spin the body, the tail rotor keeps the body of the helicopter from spinning. Normally, the tail rotor is driven by a long drive shaft that runs from the main rotor's transmission back through the tail boom to a small transmission at the tail rotor.

What you end up with is a vehicle that looks something like this:



The Fundamental Parts of any Helicopter

The helicopter shown in the previous videos has all of the parts labeled in the diagram above.

In order to actually control the machine, both the main rotor and the tail rotor need to be **adjustable**. The following two sections explain how the adjustability works.

The Tail Rotor

The adjustability of the tail rotor is straightforward -- what you want is the ability to change the **angle of attack** on the tail rotor wings so that you can use the tail rotor to rotate the helicopter on the drive shaft's axis.

The pilot has two foot pedals that control the angle of attack. These two videos let you take a look at the pedals and see how they affect the tail rotor:

Click here to download the 15-second video showing the helicopter's pedals. (1.1 MB)

Click here to download the 10-second video showing the tail rotor's movements in relation to the foot pedals. (0.7 MB)

You can see the pedals in this shot of the cockpit

The blades of the tail rotor are only about 2 feet (61 cm) long.


The tail rotor's hub allows the pilot to change the angle of attack of the rotor's wings.

The Main Rotor

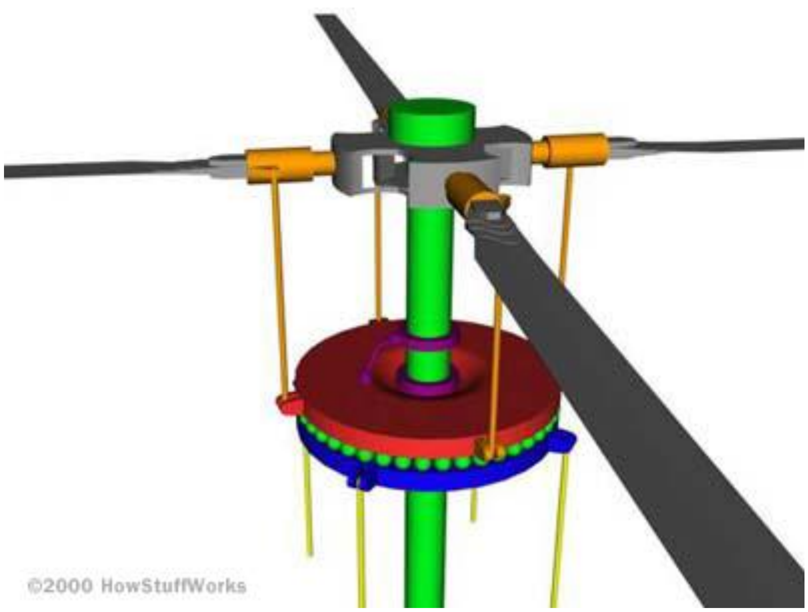
A helicopter's **main rotor** is the most important part of the vehicle. It provides the **lift** that allows the helicopter to fly, as well as the **control** that allows the helicopter to move laterally, make turns and change altitude.

To handle all of these tasks, the rotor must first be incredibly strong. It must also be able to adjust the angle of the rotor blades with each revolution of the hub. The adjustability is provided by a device called the **swash plate assembly**, as shown in this photograph:

The main rotor hub, where the rotor's drive shaft and blades connect, has to be extremely strong as well as highly adjustable. The swash plate assembly is the component that provides the adjustability.

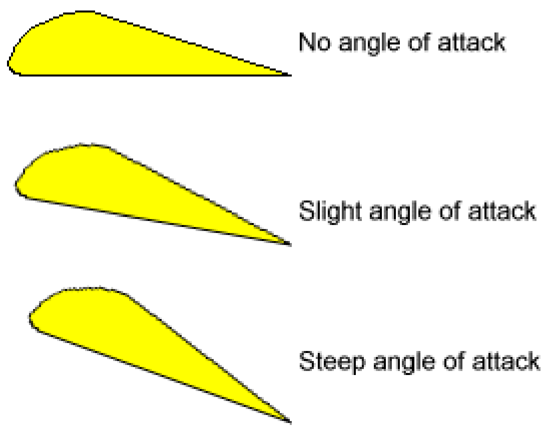
The swash plate assembly has two primary roles:

- Under the direction of the **collective** control, the swash plate assembly can change the angle of both blades simultaneously. Doing this increases or decreases the lift that the main rotor supplies to the vehicle, allowing the helicopter to gain or lose altitude.
- Under the direction of the **cyclic** control, the swash plate assembly can change the angle of the blades individually as they revolve. This allows the helicopter to move in any direction around a 360-degree circle, including forward, backward, left and right.



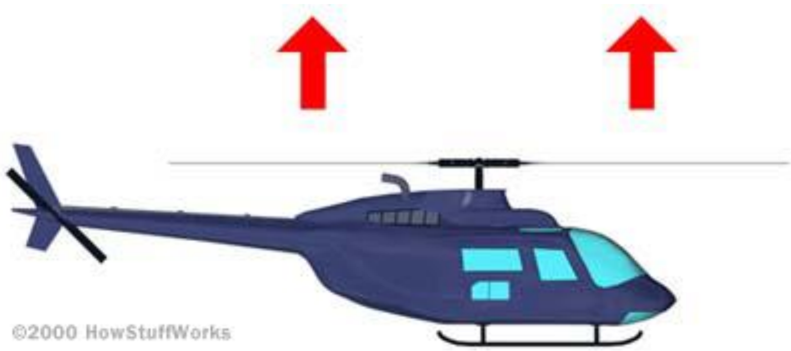
The swash plate assembly consists of two plates -- the **fixed** and the **rotating** swash plates -- shown above in blue and red, respectively.

- The **rotating swash plate** rotates with the drive shaft (green) and the rotor's blades (gray) because of the links (purple) that connect the rotating plate to the drive shaft.
- The **pitch control rods** (orange) allow the rotating swash plate to change the pitch of the rotor blades.
- The angle of the **fixed swash plate** is changed by the control rods (yellow) attached to the fixed swash plate.
- The fixed plate's control rods are affected by the pilot's input to the **cyclic and collective controls**.
- The fixed and rotating swash plates are connected with a set of **bearings** between the two plates. These bearings allow the rotating swash plate to spin on top of the fixed swash plate.



The swash plate assembly changes the angle of attack of the main rotor's wings as the wings revolve. A steep angle of attack provides more lift than a shallow angle of attack.

The collective control changes the angle of attack on both blades simultaneously:



The collective lets you change the angle of attack of the main rotor simultaneously on both blades.

The cyclic control tilts the swash plate assembly so that the angle of attack on one side of the helicopter is greater than it is on the other, like this:

The cyclic changes the angle of attack of the main rotor's wings unevenly by tilting the swash plate assembly. On one side of the helicopter, the angle of attack (and therefore the lift) is greater.

Hovering in a helicopter requires experience and skill. The pilot adjusts the cyclic to maintain the helicopter's position over a point on the ground. The pilot adjusts the collective to maintain a fixed altitude (especially important when close to the ground, as shown in the videos). The pilot adjusts the foot pedals to maintain the direction that the helicopter is pointing. You can imagine that windy conditions can make hovering a real challenge!

Relating the Controls and the Swash Plate

The following videos help you understand the relationship between the cyclic and collective controls and the swash plate assembly. In general:

- The **collective control** raises the entire swash plate assembly as a unit. This has the effect of changing the pitch of both blades simultaneously.
- The **cyclic control** pushes one side of the swash plate assembly upward or downward. This has the effect of changing the pitch of the blades unevenly depending on where they are in the rotation. The result of the cyclic control is that the rotor's wings have a greater angle of attack (and therefore more lift) on one side of the helicopter and a lesser angle of attack (and less lift) on the opposite side. The unbalanced lift causes the helicopter to tip and move laterally.

Click here to download the 25-second video showing the helicopter's fixed and rotating swash plates. (1.5 MB)

Click here to download the 55-second video showing the helicopter's cyclic control. (3.6 MB)

Click here to download the 20-second video showing how the swash plate assembly reacts to changes in the cyclic control. (1.5 MB)

Click here to download the 20-second video showing the effect of precession on the helicopter's blades. The precession here is the same precession discussed in How Gyroscopes Work. (1.2 MB)

Click here to download the 10-second video showing the helicopter's collective control. (0.8 MB)

Click here to download the 15-second video showing the swash plate assembly's reaction to the collective control. (1.0 MB)

Other Important Components

Click here to download the 150-second video explaining the main instrument panel. (10.2 MB)

Click here to download the 25-second video explaining the engine instrument panel. (1.6 MB)

Click here to download the 30-second video explaining the engine main drive pulley system. (2.0 MB)

Click here to download the 50-second video showing the helicopter's engine and cooling system. (3.4 MB)

Lots More Information

Related HowStuffWorks Articles

- How Airplanes Work

- How Apache Helicopters Work
- How the V-22 Osprey Works
- How Personal Jetpacks Will Work
- How Hoverboards Will Work
- How Blimps Work
- How Boomerangs Work
- How Gliders Work

More Great Links

Click here to add your site to this list

- The Helicopter Page
- Robinson Helicopter Company
- Helicopter History Site
- PRA Rotocraft Directory