# Flight (lift)

Air New Zealand 747 taking off

An airplane flies due to the aerodynamic reactions that happen when air passes at high speed over the wing.

If you look at a cross-section of an airplane wing, you will see that the top of the wing is curved, while the bottom of the wing is straight -- or at least curved less than the top. This shape -- called an airfoil -- is what creates lift when a wing travels through the air.

In air (or comparably in any fluid), lift is created as an airstream passes by an airfoil and is deflected downward. The force created by this deflection of the air creates an equal and opposite force upward on an airfoil according to Newton's third law of motion. The deflection of airflow downward during the creation of lift is known as downwash.

It is important to note that the acceleration of the air does not just involve the air molecules "bouncing off" the bottom of the airfoil. Rather, air molecules closely follow both the top and bottom surfaces of the airfoil, and so the airflow is deflected downward. In fact, the acceleration of the air during the creation of lift can also be described as a "turning" of the airflow.

Nearly any shape will produce lift if curved or tilted with respect to the air flow direction. However, most shapes will be very inefficient and create a great deal of drag. One of the primary goals of airfoil design is to devise a shape that produces the most lift while producing the least lift-induced drag.

Many readers new to this topic may be looking for the explanation that is commonly put forward in many mainstream books, and even in scientific exhibitions which touch on flight and aerodynamic principles. Known as the "equal transit-time" explanation, it states that the parcels of air which are divided by an airfoil must rejoin again; because of the greater curvature (and hence longer path) of the upper surface of an aerofoil, the air going over the top must go faster in order to "catch up" with the air flowing around the bottom. Therefore, because of its higher speed the pressure of the air above the airfoil must be lower. Despite the fact that this "explanation" is probably the most common of all, it must be made clear that it is false. It has recently been dubbed the "Equal transit-time fallacy." There is no requirement that divided parcels of air rejoin again, and in fact they do not do so. Such an explanation would predict that an aircraft could not fly inverted, which is demonstrably not the case. The explanation also fails to account for aerofoils which are fully symmetrical yet still develop significant lift.

# Rudder

A **rudder** is a device used to steer a ship or other watercraft. In its simplest form, a rudder is a flat sheet of material attached with hinges to the ship's stern. A tiller - basically, a stick or pole - is attached to the top of the rudder to allow it to be turned in different directions.

### Invention of the rudder

Oars mounted on the side of ships for steering are documented from the 3rd millennium BCE in Ancient Egypt in the form of artworks, wooden models, and even remains of actual boats. These evolved into quarter rudders, which were used in Antiquity until the end of the Middle Ages in Europe. As the size of ships and the height of the freeboards increased, quarter-rudders became less satisfactory and were replaced in Europe by the more sturdy stern-mounted rudders with pintle and gudgeon attachment from the 12th century. The West's oldest known depiction of a stern-mounted rudder can be found on church carvings dating to around 1180.

The world's oldest known depiction of a stern-mounted rudder can be seen on a pottery model of a Chinese junk dating from the 1st century CE, predating their introduction in the West by a thousand years. The Chinese stern-mounted rudder is hung from the stern and held in place and controlled with a rope mechanism. The invention of the stern-mounted rudder in the West may have been independent, as its technical specifications certainly differ, although the idea may have been transmited through trade exchanges with the East. Detailed descriptions of Chinese junks during the Middle Ages are known from various travellers to China, such as Ibn Battuta and Marco Polo.

Also, many junks incorporated "fenestrated rudders" (rudder with holes in them, allowing for better control), an innovation adopted in the West in 1901 to increase the manoeuvrability of torpedo boats.

### Aircraft rudders

The tail of a KC135 Stratotanker, with the rudder marked

On an aircraft, the **rudder** is a control surface, usually attached to the fin (or vertical stabiliser) which allows the pilot to control the aircraft in the yaw axis. It is not used to effect turns—the ailerons are used for that—but the rudder is necessary to correctly balance the various acting forces in a turn. By convention, the rudder is controlled with foot pedals, usually coupled to bell cranks on the rudder via wire cables. In some (rare) aircraft, such as the American-designed Ercoupe of the 1940s, there are no rudder pedals, as the rudder is controlled with springs associated with the roll control. In some designs, an all-moveable fin is used instead of a rudder.

# Aileron


Aileron location on a Piper PA-28. The aileron in this picture is slightly drooped

**Ailerons** are hinged flaps attached to the trailing edge of an airplane wing. They are used to control the aircraft in roll. The two ailerons are interconnected so that one goes down when the other goes up: the downgoing aileron increases the lift on its wing while the upgoing aileron reduces the lift on the other wing, producing a rolling moment about the aircraft's longitudinal axis. The word *aileron* is French for "little wing."

An unwanted side-effect of aileron operation is adverse yaw - a yawing moment in the opposite direction to the turn generated by the ailerons. In other words, using the ailerons to roll an aircraft to the right would produce a yawing motion to the left.

Modern airliners tend to have a second set of inboard ailerons much closer to the fuselage, which are used at high speeds. Some aircraft use spoilers to achieve the same effect as ailerons.

The device was developed independently by the Aerial Experiment Association, headed by Alexander Graham Bell, and by Robert Esnault-Pelterie, a French airplane builder. Ailerons superseded the earlier wing warping technique, developed by the Wright Brothers.

Another control surface that combines an **aileron** and flap is called a flaperon. A single surface on each wing serves both purposes: used as an aileron, the flaperons left and right are actuated differentially; when used as a flap, both flaperons are actuated downwards. As a example of an aircraft using flaperons, see this RJ.03 IBIS experimental aircraft. Please note that when a flaperon is actuated downwards (i.e. used as a flap) there is enough freedom of movement left to be able to still use the aileron function.

# **Elevator (aircraft)**.


The surface immediately behind the final A of the registration G-ASBA is the horizontal stabilizer. The drooped surface hinged to it, nearly touching the grass, is the **elevator**. The aircraft is a 1966 Currie Wot


The tail of a Lufthansa Airbus A319 in flight, showing the **elevator** (Stab. means Stabiliser)

Pre-installed elevators for a small Airbus. The elevator is the silver surface on the right hand side of the picture, immediately below the red pipes on the factory wall

**Elevators** are control surfaces, usually at the rear of an aircraft, which control the aircraft's orientation by changing the pitch of the aircraft, and so also the angle of attack of the wing. An increased angle of attack will cause a greater lift to be produced by the profile of the wing, and (if no power is added or available), a slowing of the aircraft. A decreased angle of attack will produce an increase in speed (a dive). There may be separate elevators on each side, operating in unison. The elevator or elevators may be the only pitch control surface present, or may be hinged to a fixed or adjustable surface called a stabilizer.

In some aircraft the elevator is in the front, ahead of the wing; this type of configuration is called a canard, the French word for duck. The Wright Brothers' early aircraft were of this type. The canard type is more efficient, since the forward surface produces upward lift. The main wing is also less likely to stall, as the forward control surface is configured to stall before the wing, causing a pitch down and reducing the angle of attack of the wing.

## Flight controls

Aircraft **flight controls** allow a pilot to guide a plane to a destination. This article describes controls used on a fixed wing aircraft of conventional design. Other fixed wing aircraft configurations may use different control surfaces but the basic principles remain. The controls for rotary wing aircraft (helicopter or autogyro) are completely different.

**Axes of motion**


Rotation around the three axes

An aircraft is free to rotate around three axes which are perpendicular to each other and intersect at the plane's center of gravity (CG). To control position and direction a pilot must be able to control rotation about each of them.

- Vertical - The vertical axis passes through the plane from top to bottom. Rotation about this axis is called **yaw**. Yaw changes the direction the aircraft's nose is pointing, left or right. The primary control of yaw is with the rudder. Ailerons also have a secondary effect on yaw.

- Longitudinal - The longitudinal axis passes through the plane from nose to tail. Rotation about this axis is called **bank** or **roll**. Bank changes the orientation of the aircraft's wings with respect to the downward force of gravity. The pilot changes bank angle by increasing the lift on one wing and decreasing it on the other. This differential lift causes bank rotation around the longitudinal axis. The ailerons are the primary control of bank. The rudder also has a secondary effect on bank.

- Lateral - The lateral axis passes through the plane from wingtip to wingtip. Rotation about this axis is called **pitch**. Pitch changes the vertical direction the aircraft's nose is pointing. The elevators are the primary control of pitch.

It is important to note that these axes move with the aircraft, and change relative to the earth as the aircraft moves. For example, for an aircraft whose left wing is pointing straight down, its "vertical" axis is parallel with the ground, while its "lateral" axis is perpendicular to the ground.

**Main Control Surfaces**

The main control surfaces are attached to the airframe on hinges so they may move and thus deflect the air stream passing over them. This redirection of the air stream generates an unbalanced force to rotate the plane about the associated axis.

- Ailerons - Ailerons are mounted on the back edge of each wing near the wingtips, and move in opposite directions. When the pilot moves the stick left, or turns the wheel counter-clockwise, the left aileron goes up and the right aileron goes down. A raised aileron reduces lift on that wing and a lowered one increases lift, so moving the stick left causes the left wing to drop and the right wing to rise. This causes the plane to bank left and begin to turn to the left. Centering the stick returns the ailerons to neutral maintaining the bank angle. The plane will continue to turn until opposite aileron motion returns the bank angle to zero to fly straight.

- Elevators - An elevator is mounted on the back edge of the horizontal stabilizer on each side of the fin in the tail. They move up and down together. When the pilot pulls the stick backward, the elevators go up. Pushing the stick forward causes the elevators to go down. Raised elevators push down on the tail and cause the nose to pitch up. This makes the wings fly at a higher angle of attack which generates more lift and more drag. Centering the stick returns the elevators to neutral and stops the change of pitch.

- Rudder - The rudder is mounted on the back edge of the fin in the tail. When the pilot pushes the left pedal, the rudder deflects left. Pushing the right pedal causes the rudder to deflect right. Deflecting the rudder right pushes the tail left and causes the nose to yaw right. Centering the rudder pedals returns the rudder to neutral and stops the yaw.

## Flaperon

A flaperon is a type of control surface that combines aspects of both flaps and ailerons. In addition to controlling the roll or bank of an airplane like conventional ailerons, both flaperons can be lowered together to function much the same as a dedicated set of flaps would. The pilot still has separate controls for ailerons and flaps at his disposal. A mixer is used to combine the separate pilot input into this single set of control surfaces called flaperons. The use of flaperons instead of separate ailerons and flaps can reduce the weight of an aircraft. The complexity is transfered from having a double set of control surfaces (flaps & ailerons) to the mixer.

An aircraft that uses flaperons is the RJ.03 IBIS, an experimental two-seater aircraft. The following link shows how the IBIS design implements the aileron/flap mixer.


BMI Airbus A320, showing position of aileron, flap and slat **flight controls**. Click on the picture to read the labels more clearly


The tail of a Lufthansa Airbus A319, showing **flight controls** (Stab. means Stabiliser)

**Secondary effects of controls**

- Ailerons: The ailerons primarily control bank. Whenever lift is increased, induced drag is also increased. When the stick is moved left to bank the airplane to the left, the right aileron is lowered which increases lift on the right wing and therefore increases drag on the right wing. Using ailerons causes adverse yaw, meaning the nose of the aircraft yaws in a direction opposite to the aileron application. When moving the stick to the left to bank the wings, adverse yaw moves the nose of the airplane to the *right*. Adverse yaw is more pronounced for light aircraft with long wings, such as gliders. It is counteracted by the pilot with the rudder.

- Rudder: Using the rudder causes one wing to move forward faster than the other. Increased speed means increased lift, and hence rudder use causes a small roll effect. For this reason ailerons and rudder are generally used together on light aircraft. When turning to the left, the stick is moved left and left rudder is applied.

**Turning the aircraft**

Unlike a boat, turning an aircraft is not normally carried out with the rudder. Instead the ailerons are used to bank the aircraft. The forces on the plane cause the aircraft to turn in the same direction as the bank, with a steeper bank causing a faster turn. While this is happening the nose of the aircraft has a tendency to drop, and the aircraft may also yaw, so the nose is not pointing in the direction it is flying. The elevators are used to counteract the first, and the rudder to counteract the second.

**Alternate main control surfaces**

Some aircraft configurations have non-standard primary controls. For example instead of elevators at the back of the stabilizers, the entire tailplane may change angle. Most supersonic aircraft will have a fully-moving tail. Some aircraft have a tail in the shape of a V, and the moving parts at the back of those combine the functions of elevators and rudder. Delta wing aircraft may have "elevons" at the back of the wing, which combine the functions of elevators and ailerons.

**Secondary control surfaces**

**Trimming**

Trimming controls allow a pilot to balance the lift and drag being produced by the wings and control surfaces over a wide range of load and airspeed. This reduces the effort required to adjust or maintain a desired flight attitude.

- Trim Tabs - Trim tabs are used to adjust the position of an associated main control surface. They are often hinged to the back edge of the control surface with a control in the cockpit. Some trim tabs on light aircraft are fixed sheets of metal that can be bent while the aircraft is on the ground but cannot be controlled in flight. Both types function by redirecting the air stream to generate a force which holds the main control surface in the desired position. Because they are furthest from the pivot point of the main control surface, their small aerodynamic effects are magnified by leverage to achieve the deflection of the main surface.

- Trimming Tail Plane - Except for very light aircraft, trim tabs on elevators are unable to provide the force and range of motion desired. To provide the appropriate trim force the entire horizontal tail plane is made adjustable in pitch. This allows the pilot to select exactly the right amount of positive or negative lift from the tail plane while reducing drag from the elevators.

- Control Horn - A control horn is a section of control surface which projects ahead of the pivot point. It generates a force which tends to increase the surface's deflection thus reducing the control pressure experienced by the pilot. Control horns may also incorporate a counterweight which helps to balance the control and prevent it from "fluttering" in the airstream. Some designs feature separate anti-flutter weights.

In the simplest cases trimming is done by a mechanical spring which adds appropriate force to the pilot's control.

### Other Controls

KLM Fokker 70, showing position of flap and airbrake/spoiler **flight controls**.The airbrakes/spoilers are the lifted cream-coloured panels on the wing upper surface (in this picture there are five on the right wing). The flaps are the large drooped surfaces on the trailing edge of the wing

- Spoilers - On very high lift/low drag aircraft like sailplanes, spoilers are used to disrupt airflow over the wing and greatly reduce the amount of lift. This allows a glider pilot to lose altitude without gaining excessive airpeed. Spoilers are sometimes called "lift dumpers". Spoilers, that can be used asymmetrically are called spoilerons and are able to effect an aircraft's roll.

- Flaps - Flaps are mounted on the back edge of each wing near the wing roots. They are deflected down to increase the effective curvature of the wing and produce additional lift, and also reduce the stalling speed of the wing. They are used during low speed, high angle of attack flight like descent for landing. Some aircraft use flaperons instead, which can also be used for roll control.

- Slats are extensions to the front of a wing for lift augmentation, and are intended to reduce the stalling speed by altering the airflow over the wing. Slats may be fixed or retractable - fixed slats (e.g. as on the Fieseler Storch) give excellent slow speed and STOL capabilities, but compromise higher speed performance. Retractable slats, as on most airliners, allow higher lift on take off, but retract for cruising.

- Air brakes - these are used on high speed aircraft and are intended to increase the drag of an aircraft without altering the amount of lift. Airbrakes and spoilers are sometimes the same device - on most airliners for example, the combined spoiler/airbrakes act to simultaneously remove lift and to slow the aircraft's forward motion. Ground spoilers, which are a combination of airbrakes/flight spoilers along with additonal panels are deployed upon touchdown to assist braking the aircraft by applying positive downward forces which also ensures that the aircraft remains planted firmly on the ground.

Mechanical braking of the wheels is assisted by both functions - the weight of the aircraft carried by its wings is transferred to the undercarriage when the lift is dumped, so there is less chance of a skid, and the airbrake effect increases the form drag of the aircraft.

## Aircraft engine controls

**Aircraft engine controls** provide a means for the pilot to control and monitor the operation of his aircraft's powerplant. This article describes controls used with a basic internal-combustion engine driving a propeller. Some optional or more advanced configurations are described at the end of the article. Jet turbine engines use different operating principles and have their own sets of controls and sensors.

**Basic Controls and Indicators**

- Master Switch - Most often actually two separate switches, the Battery Master and the Alternator Master. The Battery Master activates a relay (sometimes called the battery contactor) which connects the output of the battery to the aircraft's main electrical bus. The alternator master activates the alternator by applying power to the alternator field circuit. These two switches provide electrical power to all the systems in the aircraft.
- Throttle - Sets the desired engine power level. The Throttle controls the volume of fuel/air mixture delivered to the cylinders.
- Pitch Control - Adjusts the Constant Speed Unit, which turn adjusts the propeller pitch & regulates the engine load as necessary to maintain the set R.P.M.
- Mixture Control - Sets the amount of fuel added to the intake airflow. At higher altitudes the air pressure (and therefor the oxygen level) declines so the fuel volume must also be reduced to give the correct air/fuel mixture. This process is known as "leaning".
- Ignition Switch - Activates the magnetos by opening the grounding or 'p-lead' circuit; with the p-lead ungrounded the magneto is free to send its high-voltage output to the spark plugs. In most aircraft the ignition switch also applies power to the starter motor during engine start. In piston aircraft engines, the battery does not generate the spark for combustion. This is accomplished using devices called magnetos. Magnetos are connected to the engine by gearing. When the crankshaft turns, it turns the magnetos which mechanically generate voltage for spark. In the event of an electrical failure, the engine will continue to run. The Ignition Switch has the following positions:
    1. Off - Both magnetos are connected to electrical ground.
    2. Left - The left magneto is connected to its spark plugs. The right magneto is grounded.
    3. Right - The right magneto is connected to its spark plugs. The left magneto is grounded.
    4. Both - Both magnetos are connected to their spark plugs. This is the normal operating configuration.
    5. Start - The pinion gear on the starter motor is engaged with the flywheel and the starter motor runs to turn the engine over.
- Tachometer - A gauge to indicate engine speed in revolutions per minute (R.P.M.). It is a measure of engine power in aircraft with “fixed pitch” propellers.
- Manifold Pressure Gauge – Used to measure the pressure in the induction manifold. It is a measure of engine power in aircraft using a controllable pitch propeller.
- Oil Temperature Gauge - Indicates the operating temperature of the engine.

- Oil Pressure Gauge - Indicates the supply pressure of the engine lubricant.
- Exaust Gas Temperature Gauge – Indicates the temperature of the exaust gas just after compustion. Used to set the air/fuel mixture (leaning) correctly.
- Carburetor Heat Control - Controls the application of heat to the carburetor venturii area to remove or prevent the formation of ice in the throat of the carburetor. Fuel injected engines do not have this control as there is no carburetor.

**Fuel**

- Fuel Primer Pump - A manual pump to add a small amount of fuel at the cylinder intakes to assist in starting a cold engine. Fuel injected engines do not have this control. For fuel injected engines, a fuel boost pump is used to prime the engine prior to start.
- Fuel Quantity Gauge - Indicates the amount of fuel remaining in the identified tank. One per fuel tank.
- Fuel Select Valve - Connects the fuel flow from the selected tank to the engine.

If the aircraft is equipped with a fuel pump:

- Fuel Pressure Gauge - Indicates the supply pressure of fuel to the carburetor (or in the case of a fuel injected engine, to the fuel controller.)
- Fuel Boost Pump Switch - Controls the operation of the auxiliary electric fuel pump to provide fuel to the engine before it starts or in case of failure of the engine powered fuel pump.

**Propeller**

If the aircraft is equipped with adjustable-pitch (constant-speed) propeller:

- Propeller Control - Sets the desired R.P.M. of the propeller governor, which turn regulates the engine load as necessary to maintain the set R.P.M. Once the R.P.M. is set by the pilot, the governor adjusts engine load by increasing or decreasing propeller pitch by using engine oil pressure to move a piston in the propeller hub.
- Manifold Pressure Gauge - Indicates the absolute pressure in the engine intake manifold, between the throttle and the cylinders. **Cowl:**

If the aircraft is equipped with adjustable Cowl Flaps:

- Cowl Flap Position Control - Cowl Flaps are opened during high power/low airspeed operations like takeoff to maximize the volume of cooling airflow over the engine's cooling fins. They are closed during normal cruise flight to maintain normal engine operating temperature and minimize drag.
- Cylinder Head Temperature Gauge - Indicates the temperature of the cylinder with the least cooling airflow. A Cylinder Head Temperature Gauge has a much shorter response time than the oil temperature gauge, so it can alert the pilot to a developing cooling issue more quickly. Engine overheating may be caused by:
    1. Running too long at a high power setting.
    2. Running too lean on the fuel mixture.
    3. Restricting the volume of cooling airflow too much.
    4. Insufficient delivery of lubricating oil to the engine's moving parts.