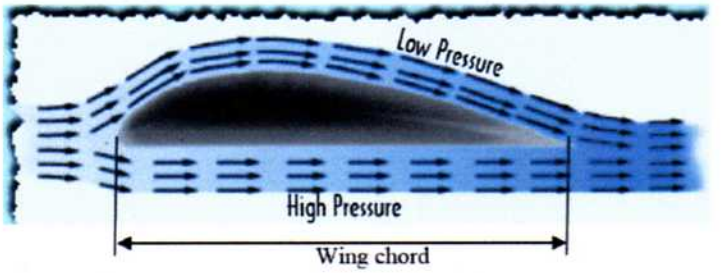
Basic Aerodynamics

The Bernoulli Principle

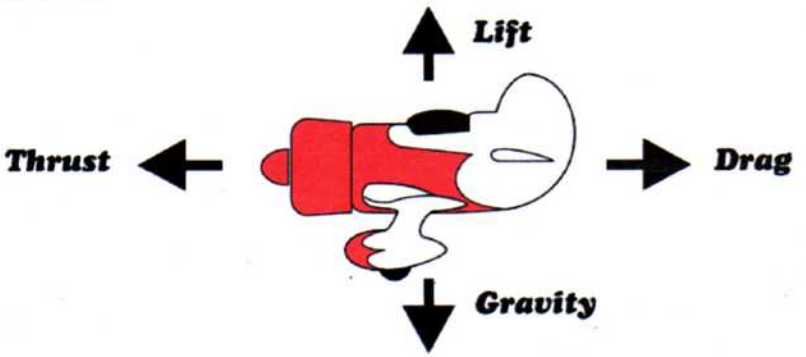
Airplanes fly when the movement of air across their wings creates an upward force on the wings (and thus the rest of the plane) that is greater than the force of gravity pulling the plane toward the earth.

The physics behind this phenomenon was first described by Daniel Bernoulli, an 18th century Swiss mathematician and scientist who studied the movement of fluids. Bernoulli discovered that the pressure exerted by a moving fluid is inversely proportional to the speed of the fluid. In other words, fluid pressure decreases as fluid speed increases, and vice versa.



The same principle applies to moving air. The faster that air moves through a space, the lower the air pressure; and the slower it moves, the higher the pressure. Aircraft wings are designed to take advantage of that fact and create the lift force necessary to get airplanes off the ground. The underside of wings are more-or- less flat, while their tops are curved. In addition, wings are slanted slightly downward from front to back, so air moving around a wing has a longer way to travel over the top than it does underneath. The air going over the top moves faster than the air going underneath, and the air pressure above the wing thus is lower than it is under the wing, where slower moving air molecules bunch together. The pressure differential creates lift, and the faster the wing moves through the air, the greater the lift becomes, eventually overcoming the force of gravity upon the aircraft.

Forces on an aircraft:



Lift

[In the following, you may skip the math, if you wish]

As the air passes over the wing towards the trailing edge, the air flows not only rearward but downward as well. This flow is called downwash. At the same time, the airflow passing under the wing is deflected downward by the bottom surface of the wing. Think of a water ski or

surfboard planing over the water. In exerting a downward force upon the air, the wing receives an upward counterforce. Remember Newton's Third Law, for every action there is an equal and opposite reaction. Therefore, the more air deflected downward, the more lift is created. The reaction produced by the downwash is therefore significant.

Dynamic pressure is produced by a body moving through the air. It is a product of two quantities: air density and velocity. *[Mathematically, dynamic pressure is denoted as "Q", and is defined by the formula*

$$Q = \frac{1}{2}\rho V^2$$

where ρ ("rho") is the atmospheric density and V is the velocity of air moving over the vehicle. RC airplanes stay within a narrow altitude range, so the air density is constant. Note that dynamic pressure increases with the square of velocity.

Aerodynamic lift is the product of dynamic pressure, the wing area, and the lift coefficient, C_L

$$L = QAC_L$$

The lift coefficient is a number determined by the shape of the airfoil and the angle between the wind vector and the chord line of the airfoil.] This angle is called the "angle of attack" or the "angle of incidence." The latter term refers to the angle between the fuselage centerline and the wing chord line. Therefore, lift is a product of dynamic pressure, wing area, and the angle of attack. Lift increases as the angle of attack increases, up to a certain point, typically around 10 degrees, depending on the airfoil. At this point, a sudden loss of lift may occur, resulting in a stall.

The phenomenon defined by Bernoulli's Principle also has an effect in the production of lift by the wing moving through the air. Scientist Daniel Bernoulli discovered that the total energy in any system remains constant. In other words, if one element of an energy system is increased, another decreases to counter balance it. Take the example of water flowing through a venturi tube. Being incompressible, the water must speed up to pass through the constricted space of the venturi. The moving water has energy in the form of both pressure and speed. Within the venturi tube, pressure is sacrificed (decreased) to accelerate the speed of the flow.

Air is a fluid, just like water, and can be assumed incompressible as far as low speed aerodynamics is concerned. As such, it acts exactly the same way as water in a venturi tube. Air flowing over the wing's upper surface accelerates as it passes through the constricted area just as it does in the venturi tube. The result is a decrease in pressure on the upper surface of the wing that results in the phenomenon known as lift.

Gravity

Gravity is simple. It is the force which the earth pulls all objects towards its core at the rate of 32 ft/sec^2.

Thrust

Thrust is the force that provides the forward motion of the airplane through the air. For most model aircraft, there are two ways to produce this force: jets or propellers. They both depend on the principle of pushing air backward with the object of causing a reaction, or thrust, in the forward direction. The effect is the same whether the thrust is produced by a propeller moving a large mass of air backward at a relatively slow speed or by a jet moving a small mass of air backward at a relatively high speed.

Drag

Drag is the air resistance. The faster the aircraft is moving, the greater the force of drag applied to the airframe. The aerodynamic drag is defined in the same way as lift, except that the drag coefficient, C_D, is used instead of the lift coefficient. *[The formula is* $D = QAC_D$, *where the drag coefficient is usually determined experimentally, based on the entire aircraft shape. Notice that both lift and drag forces are dependent on dynamic pressure, Q, which is proportional to the square of velocity.]*

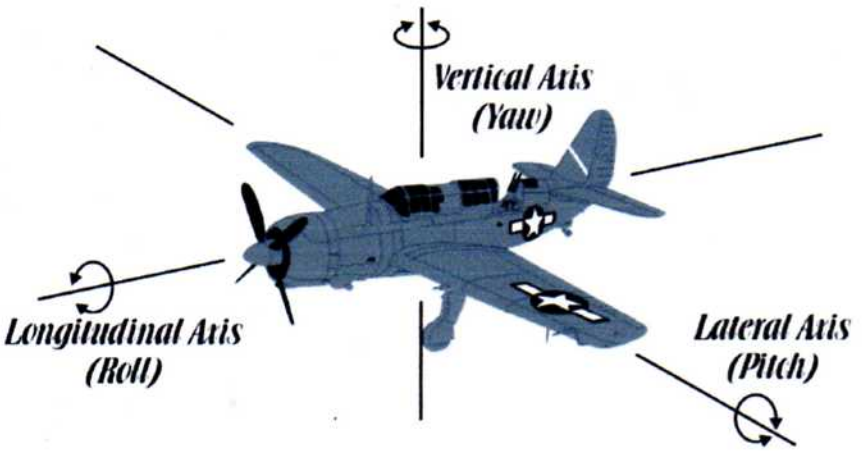
Balance of Forces

If Lift = Gravity, the aircraft is not climbing or descending. If Lift is decreased (as in a stall, or because the velocity is reduced), Gravity > Lift, and therefore, the aircraft will descend.

This is also true with Thrust and Drag. Imagine your aircraft at the end of the runway about to take off. You go to full throttle, and the aircraft accelerates. This is because the Thrust exceeds Drag. Eventually, the aircraft will come to its top speed. At that point, Thrust = Drag. The aircraft does not accelerate nor decelerate.

Flight Control Axes

Aircraft fly in three dimensions, and they move in directions other than straight and level. In order to examine these other directions, we have to take another look at our aircraft. In addition to moving forward, an aircraft in flight may move about three axes. See the Figure below and you will understand what we mean. The simplest way to understand the axes is to think of them as long rods passing through the aircraft where each will intersect the other two. At this point of intersection, called the center of gravity, each of these axes is also perpendicular to the other two.



The axis that extends lengthwise (nose through tail) is called the longitudinal axis, and rotation about this axis is called roll. The axis that extends crosswise (wingtip through wingtip) is called the lateral axis, and rotation about this axis is called pitch. The axis that passes vertically through the center of gravity (when the aircraft is in level flight) is called the vertical or yaw axis, and rotation about this axis is called yaw.

If you hold a model in your hand in a straight and level manner and roll it so as to dip a wing, you are demonstrating roll around the longitudinal axis. If you hold it level and move the nose up and down, you are demonstrating movement around the lateral axis—that is, you are changing pitch. If you hold the model straight, and move it through the air while turning the nose to one side or the other, you have it yawing on its vertical axis; in other words, it is not moving forward in the direction in which the nose is pointing. An aircraft may move about one or all of these axes at the same time. With various types of turns and maneuvers, all three may be used.

As you begin to perceive, the axes of rotation control an aircraft's maneuverability. Still holding your model airplane, try the same movements again, but carry them further. Dip a wing and roll 180 degrees and you are flying upside down. Roll another 180 degrees and you are again straight and level. Your aircraft has executed an axial roll.

The Longitudinal Axis

Running from the nose to the tail of an aircraft is the longitudinal axis. This axis can be thought of as a skewer which runs the length of the fuselage, and movement around the longitudinal axis is called roll.

The cause of movement or **roll** about the axis is the action of the **ailerons**. Ailerons are attached to the wing and are connected in a way that ensures one aileron will deflect downward when the other is deflected upward. How is it that deflecting an aileron causes the wing to move? Very simply, when an aileron is not in perfect alignment with the total wing, it changes the wing's lift characteristics. To make a wing move upward, the aileron on that wing must move downward. When this happens, the total lift being produced by that wing is increased. At the same time, the aileron on the opposite side moves upward, reducing the lift and causing that wing to move downward. This causes the aircraft to roll.

The Lateral Axis

Another name for the lateral axis is the **pitch** axis. This name makes sense because the airplane is actually caused to pitch its nose upward or downward around the lateral axis which runs from wingtip to wingtip. What causes this pitching movement? It is the **elevator** which is attached to the horizontal stabilizer. The elevator can be deflected up or down as the pilot moves the elevator stick backward or forward. Since this motion is around the lateral axis, as the tail moves (pitches) downward, the nose moves (pitches) upward and the aircraft climbs.

The Vertical or **Yaw** Axis

The third axis which passes through the meeting point of the longitudinal and lateral axes from the top of the aircraft to the bottom is called the vertical or **yaw** axis. The aircraft's nose moves about this axis in a side-to-side direction. In other words, the airplane's nose is made to point in a different direction when the airplane turns about this particular axis.

The airplane's **rudder**, which is moved by the left stick, is responsible for movement about this axis. The rudder is a movable control surface attached to the vertical fin of the tail assembly. When the pilot pushes the rudder stick to the left, he or she then sets the rudder so that it deflects the relative air to the left. This then creates a force on the tail, causing it to move to the right and the nose of the aircraft to yaw to the left.