Introduction

Aerodynamics is the study of forces and motion of objects through the air.

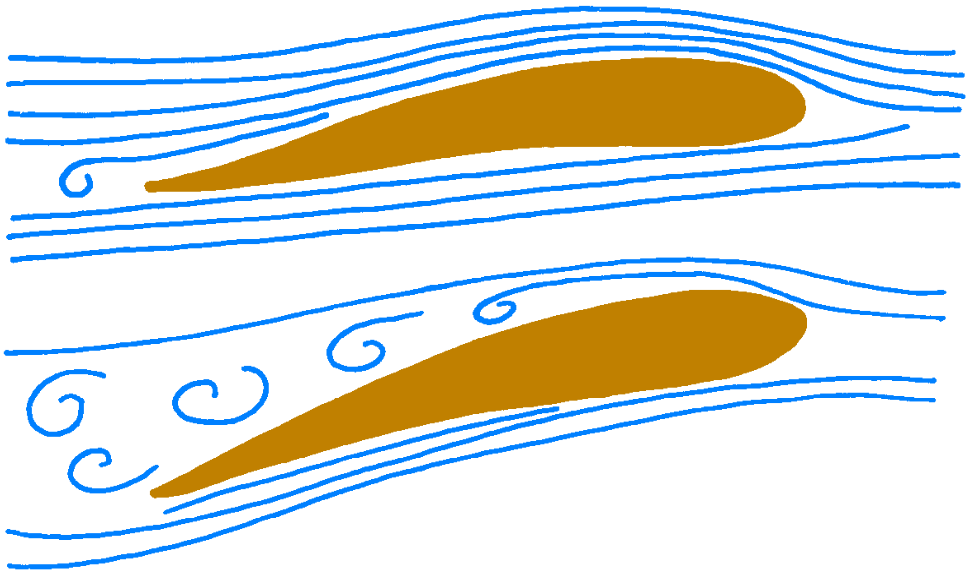
Basic knowledge of the aerodynamic principles is highly recommended before getting involved in building and/or flying model aircraft.
A model aircraft that is hanging still in air during strong winds may be subject to the same aerodynamic forces as a model aircraft that is flying fast during calm weather.

The aerodynamic forces depend much on the air density.

For example, if a glider glides 25 meters from a given altitude during low atmospheric pressure, it may glide 40 meters during high pressure.
The air density depends on the atmospheric pressure and on the air temperature.

The air density **decreases** with increasing of the air temperature and/or with decreasing of the atmospheric pressure.
The air density **increases** with decreasing of the air temperature and/or with increasing of the atmospheric pressure.
A flying aircraft is subject to a pressure depending on the airspeed and the air density.
This pressure increases exponentially with increasing of the airspeed.
The aircraft's resistance to the airflow (drag) depends on the shape of the fuselage and flying surfaces.
An aircraft that is intended to fly fast has a thinner and different wing profile than one that is intended to fly slower.
That's why many aircraft change their wing profile's on landing approach by lowering the flaps located at the wings' trailing edge and the slats at the leading edge in order to keep a resonable lifting force during the much lower landing speed.
The wings' profile of a slower aircraft is usually **asymmetric**, this causes the air on the wings upper side to accelerate downwards, making the pressure on the upper side lower than the underside, thereby a lift force is created.

The lift force of a **symmetric** profile, is based on the airspeed and on a positive angle of attack to the on-coming flow.
The following picture shows the airflow through two wing profiles.



The uppermost profile has a lower angle of attack than the lowest one.
When the air flows evenly through the surface is called a laminar flow.
A too high angle of attack causes turbulence on the upper surface and dramatically increases the air resistance (drag) this may result in an abrut loss of lift, which is known as **stall**.
<u>Summarising:</u>
The aircraft generates lift by moving through the air.
The wings have airfoil shaped profiles that create a pressure difference between upper and lower wing surfaces, with a high pressure region underneath and a low pressure region on top.
The lift produced will be proportional to the size of the wings, the square of airspeed, the density of the surrounding air and the wing's angle of attack to on-coming flow before reaching the stall angle.
How does a glider generate the velocity needed for flight?
The simple answer is that a glider trades altitude for velocity.
It trades the potential energy difference from a higher altitude to a lower altitude to produce kinetic energy, which means velocity.
Gliders are always descending relative to the air in which they are flying.
How do gliders stay aloft for hours if they constantly descend?
The gliders are designed to descend very slowly.
If the pilot can locate a pocket of air that is rising faster than the glider is descending, the glider can actually gain altitude, increasing its potential energy.

Pockets of rising air are called **updrafts**.
Updrafts are found when the wind blowing at a hill or mountain rises to climb over it. (However, there may be a **downdraft** on the other side!)
Updrafts can also be found over dark land masses that absorb more heat from the sun than light land masses.
The heat from the ground heats the surrounding air, which causes the

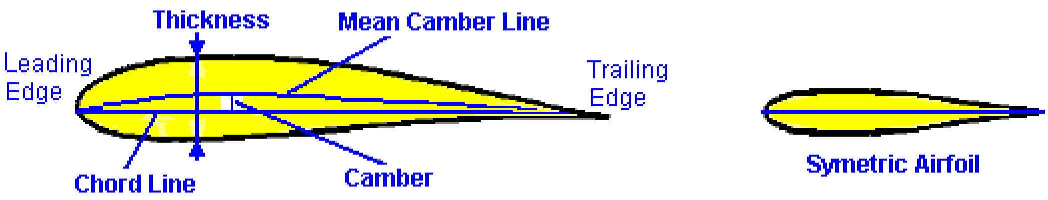
air to rise. The rising pockets of hot air are called **thermals**.

Large gliding birds, such as owls and hawks, are often seen circling inside a thermal to gain altitude without flapping their wings.
Gliders can do exactly the same thing.

Aerodynamics

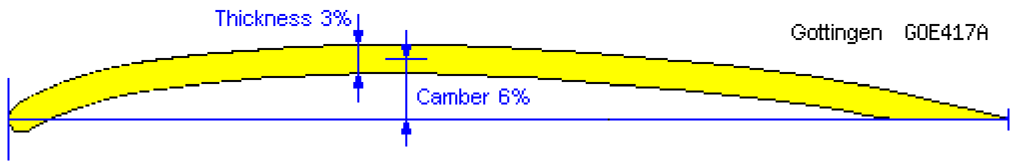
- **Wing Geometry Definitions**
  A vertical cut through the wing parallel to flight's direction (plan view) will show the cross-section of the wing.
  This side view (profile) is called **Airfoil**, and it has some geometry definitions of its own as shown on the picture below.

Wing's Side View



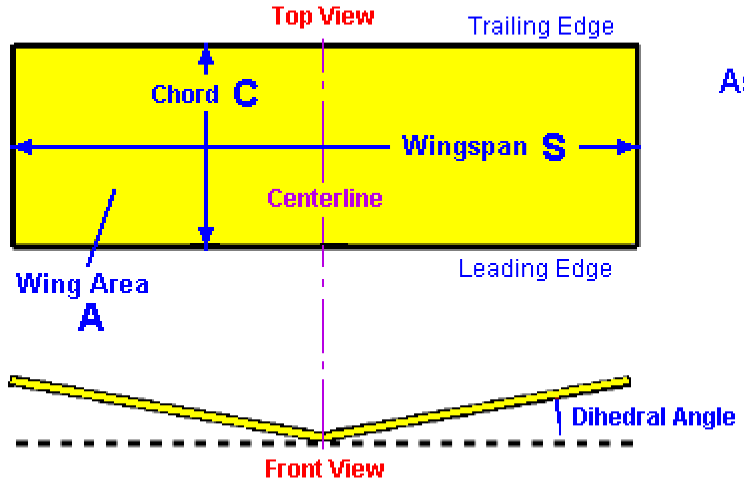
The longest straight line that can be drawn from the Airfoil's leading edge to trailing edge is called the **Chord Line**.
The Chord Line cuts the airfoil into an upper surface and a lower surface.
If we plot the points that lie halfway between the upper and lower surfaces, we obtain a curve called the **Mean Camber Line**.

For a symmetric airfoil (upper surface the same shape as the lower surface) the Mean Camber Line will fall on top of the Chord Line. But in most cases, these are two separate lines.
The maximum distance between these two lines is called the **Camber**, which is a measure of the curvature of the airfoil (high camber means high curvature).
The maximum distance between the upper and lower surfaces is called the **Thickness**.
Both the Thickness and the Camber are expressed as a percentage of Chord.



Airfoils can come with all kinds of combinations of camber and thickness distributions. NACA (the precursor of NASA) established a method of designating classes of airfoils and then wind tunnel tested the airfoils in order to provide lift coefficients and drag coefficients for designers.

Aspect Ratio is a measure of how long and slender a wing is from tip to tip. The Aspect Ratio of a wing is defined to be the square of the span divided by the wing area and is given the symbol **AR**.
The formula is simplified for a rectangular wing, as being the ratio of the span to the chord length as shown on the figure below.



Aspect Ratio = AR

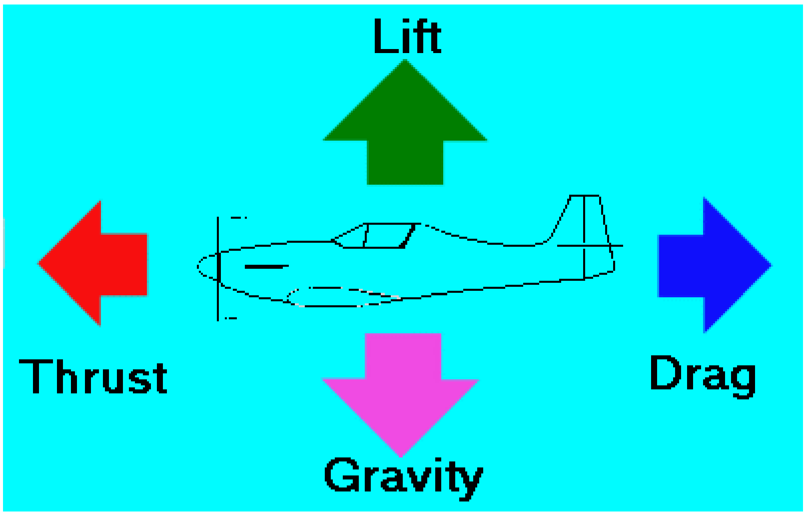
$$AR = \frac{S^2}{A} = \frac{S}{C}$$

Wing **Dihedral** refers to the angle of wing panels as seen in the aircraft's front view.
Dihedral is added to the wings for roll stability; a wing with some Dihedral will naturally return to its original position if it is subject to a briefly slight roll displacement.
Most large airliner wings are designed with Dihedral.
On the contrary the highly maneuverable fighter planes have no Dihedral.
In fact, some fighter aircraft have the wing tips lower than the roots, giving the aircraft a high roll rate.
A negative Dihedral angle is called Anhedral.

Aerodynamics

Forces in Flight

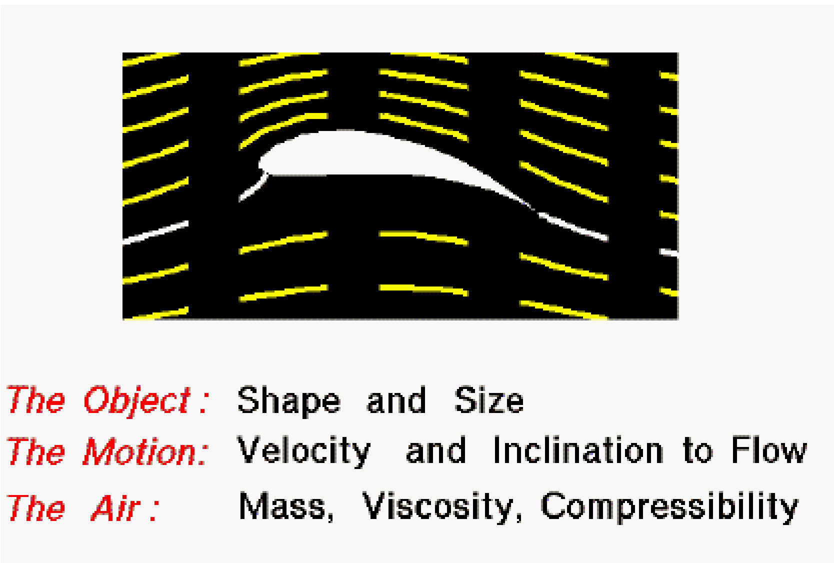
Gravity, Lift, Thrust and Drag.



Gravity is a force that is always directed toward the centre of the earth. The magnitude of the force depends on the mass of all the aircraft parts. The gravity is also called weight and is distributed throughout the aircraft. But we can think of it as collected and acting through a single point called the **centre of gravity**.
In flight, the aircraft rotates about its centre of gravity, but the direction of the weight force always remains toward the centre of the earth.

Lift is the force generated in order to overcome the weight, which makes the aircraft fly.
This force is obtained by the motion of the aircraft through the air.

Factors that affect lift:



Thrust is the force generated by some kind of propulsion system.
The magnitude of the thrust depends on many factors associated with the propulsion system used:

- type of engine
- number of engines

- throttle setting
- speed

The direction of the force depends on how the engines are attached to the aircraft.

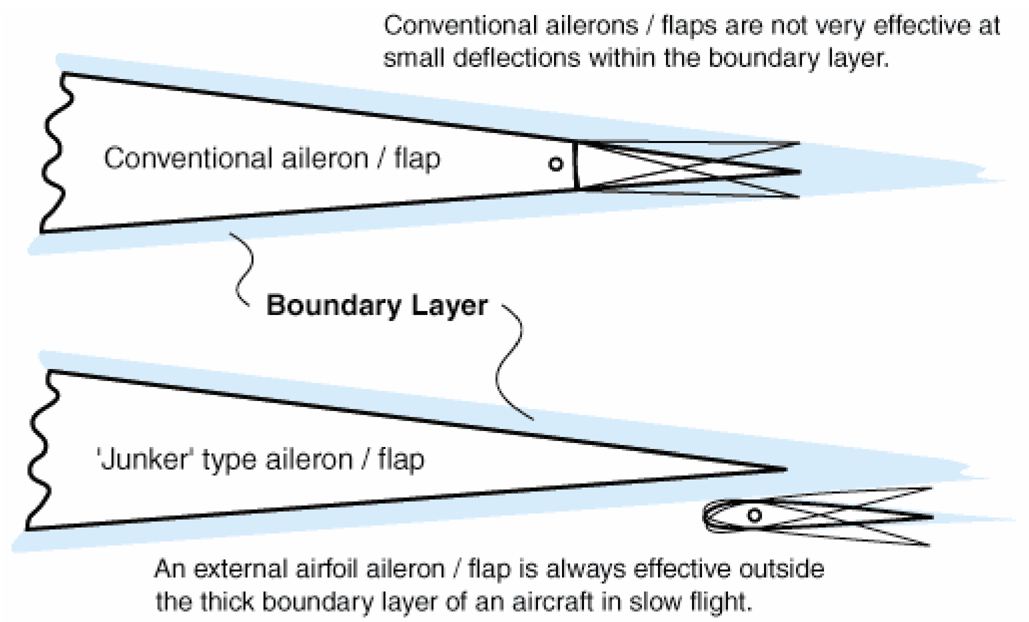
The glider, however, has no engine to generate thrust. It uses the potential energy difference from a higher altitude to a lower altitude to produce kinetic energy, which means velocity.
Gliders are always descending relative to the air in which they are flying.

Drag is the aerodynamic force that opposes an aircraft's motion through the air.

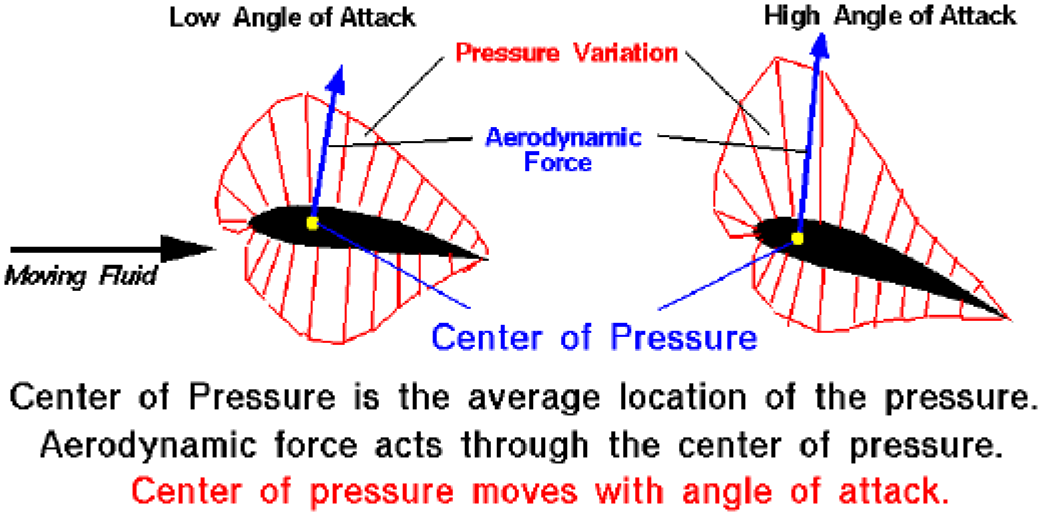
Drag is generated by every part of the aircraft (even the engines).

There are several sources of drag:

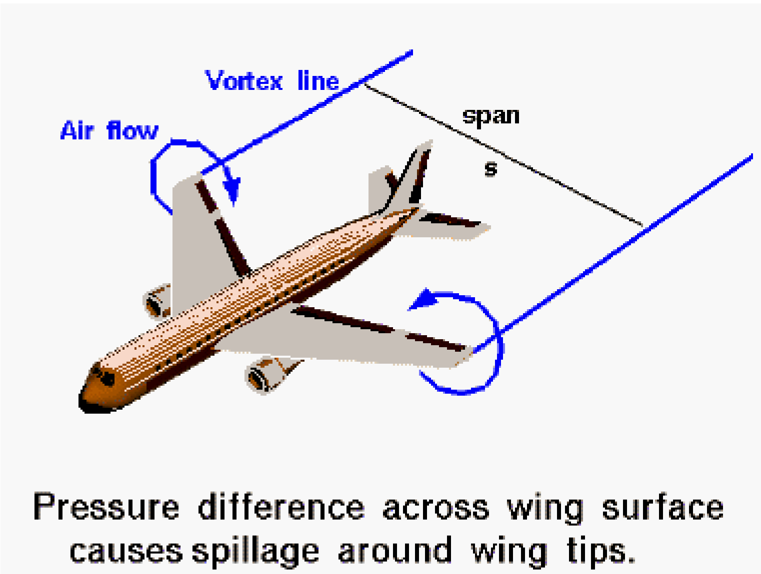
One of them is the **skin friction** between the molecules of the air and the surface of the aircraft.
The skin friction causes the air near the wing's surface to slow down.
This slowed down layer of air is called the **boundary layer**.
The boundary layer builds up thicker when moving from the front of the airfoil toward the wing trailing edge.
Another factor is called the Reynolds effect, which means that the slower we fly, the thicker the boundary layer becomes.



Form drag is another source of drag.
This one depends on the shape of the aircraft.
As the air flows around the surfaces, the local velocity and pressure changes.
The component of the aerodynamic force on the wings that is opposed to the motion is the wing's drag, while the component perpendicular to the motion is the wing's lift.
Both the lift and drag force act through the **centre of pressure** of the wing.



Induced drag is a further sort of drag caused by the wing's generation of lift. This drag occurs because the flow near the wing tips is distorted as a result of the pressure difference between the top and the bottom of the wing, which results in swirling vortices being formed at the wing tips.
The induced drag is an indication of the amount of energy lost to the tip vortices. The swirling vortices cause downwash near the wing tips, which reduces the overall lift coefficient of the wing.
The magnitude of induced drag depends on the amount of lift being generated by the wing and on the wing geometry.

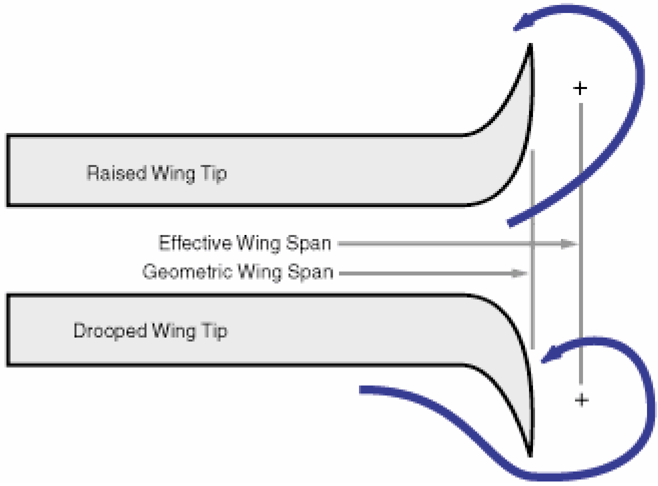


Long wing with a small chord (high aspect ratio) has low induced drag, whereas a short wing with a large chord has high-induced drag.

The picture below shows the downwash caused by an aircraft.

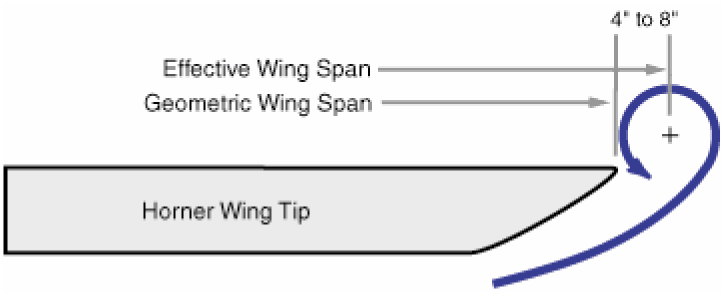
The Cessna Citation has just flown through a cloud.
The downwash from the wing has pushed a trough into the cloud deck.
The swirling flow from the tip vortices is also evident.

In order to minimise tip vortices some aircraft designers design a special shape for the wing tips.
With drooped or raised wing tips, the vortex is forced further out.



However this method causes an increase in weight since they need to be added to the wing tip.

An easier and lighter method is by cutting the wing tip at 45-degrees.
With a small radius at the bottom and a relatively sharp top corner, the air from the secondary flow travels around the rounded bottom but can't go around the sharp top corner and is pushed outward.



There's also the **Interference drag**, which is generated by the mixing of streamlines between one or more components, it accounts for 5 to 10% of the drag on an airplane.
It can be reduced by proper fairing and filleting which allows the streamlines to meet gradually rather than abruptly.

All drag that is not associated with the production of lift is defined as Parasite drag.

Aerodynamics

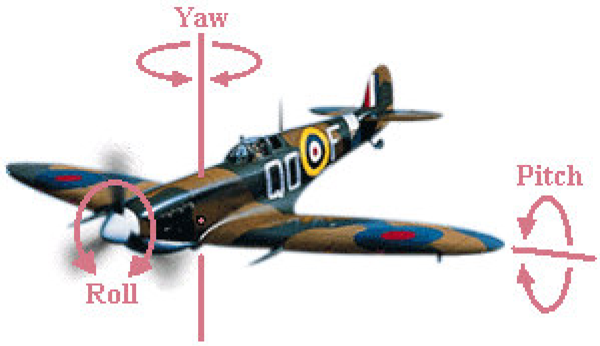
Stability Concepts

The aircraft's response to momentary disturbance is associated with its inherent degree of stability built in by the designer, in each of the three axes, and occurring without any reaction from the pilot.

There is another condition affecting flight, which is the aircraft's state of trim or equilibrium (where the net sum of all forces equals zero).
Some aircraft can be trimmed by the pilot to fly 'hands off' for straight and level flight, for climb or for descent.

Free flight models generally have to rely on the state of trim built in by the designer and adjusted by the rigger, while the remote controlled models have some form of trim devices which are adjustable during the flight.

An aircraft's stability is expressed in relation to each axis:
lateral stability (stability in roll), **directional stability** (stability in yaw) and **longitudinal stability** (stability in pitch).
Lateral and directional stability are inter-dependent.



Stability may be defined as follows:
- Positive stability - tends to return to original condition after a disturbance.
- Negative stability - tends to increase the disturbance.
- Neutral stability - remains at the new condition.
- Static stability - refers to the aircraft's **initial** response to a disturbance.
- Dynamic stability - refers to the aircraft response **over time** to a disturbance.

A totally stable aircraft will return, more or less immediately, to its trimmed state without pilot intervention.
However, such an aircraft is rare and not much desirable. We usually want an aircraft just to be reasonably stable so it is easy to fly.
If it is too stable, it tends to be sluggish in manoeuvring, exhibiting too slow response on the controls.

Too much instability is also an undesirable characteristic, except where an extremely manoeuvrable aircraft is needed and the instability can be continually corrected by on-board 'fly-by-wire' computers rather than the pilot, such as a supersonic air superiority fighter.

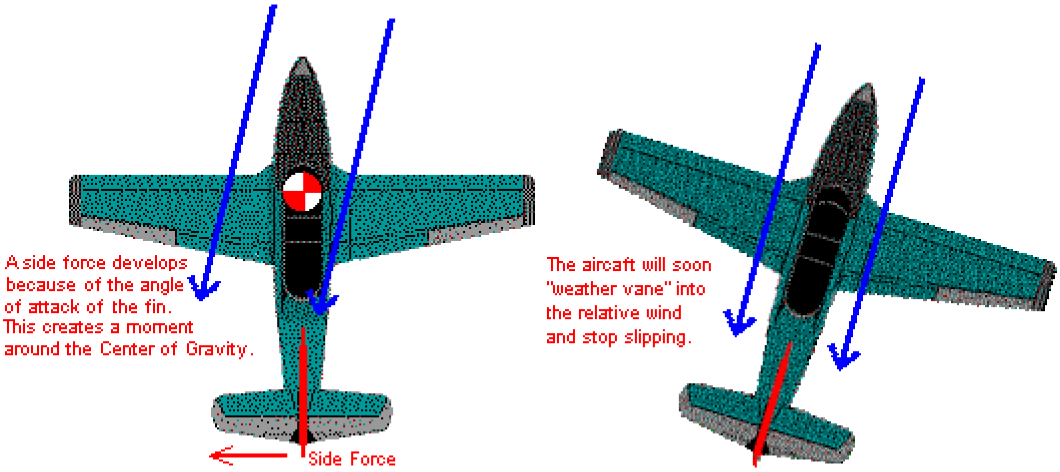
Lateral stability is achieved through dihedral, sweepback, keel effect and proper distribution of weight.
The dihedral angle is the angle that each wing makes with the horizontal (see Wing Geometry).
If a disturbance causes one wing to drop, the lower wing will receive more lift and the aircraft will roll back into the horizontal level.

A sweptback wing is one in which the leading edge slopes backward.
When a disturbance causes an aircraft with sweepback to slip or drop a wing, the low wing presents its leading edge at an angle more perpendicular to the relative airflow. As a result, the low wing acquires more lift and rises, restoring the aircraft to its original flight attitude.

The keel effect occurs with high wing aircraft. These are laterally stable simply because the wings are attached in a high position on the fuselage, making the fuselage behave like a keel.
When the aircraft is disturbed and one wing dips, the fuselage weight acts like a pendulum returning the aircraft to the horizontal level.

The tail fin determines the **directional stability**.

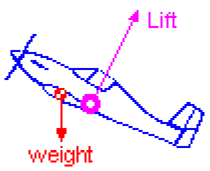
If a gust of wind strikes the aircraft from the right it will be in a slip and the fin will get an angle of attack causing the aircraft to yaw until the slip is eliminated.



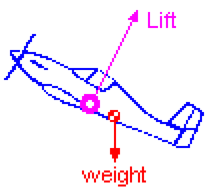
Longitudinal stability depends on the location of the centre of gravity, the stabiliser area and how far the stabiliser is placed from the main wing.
Most aircraft would be completely unstable without the horizontal stabiliser.
The stabiliser provides the same function in longitudinal stability as the fin does in directional stability.

It is of crucial importance that the aircraft's **Centre of Gravity (CG)** is located at the right point, so that a stable and controllable flight can be achieved.
In order to achieve a good longitudinal stability, the CG should be ahead of the **Neutral Point (NP)**, which is the Aerodynamic Centre of the whole aircraft.
NP is the position through which all the net lift increments act for a change in angle of attack.
The major contributors are the main wing, stabiliser surfaces and fuselage.

The bigger the stabiliser area in relationship to the wing area and the longer the tail moment arm relative to the wing chord, the farther aft the NP will be and the farther aft the CG may be, provided it's kept ahead of the NP for stability.



When the CG is ahead of NP the weight tends to correct the upset = Stable



When the CG is behind NP the weight worsens the uppset = Unstable

The angle of the fuselage to the direction of flight affects its drag, but has little effect on the pitch trim unless both the projected area of the fuselage and its angle to the direction of flight are quite large.

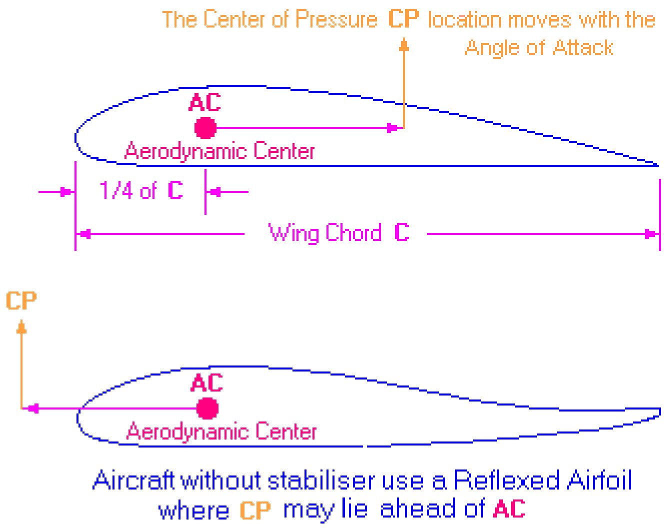
A **tail-heavy** aircraft will be more unstable and susceptible to stall at low speed

e. g. during the landing approach.
A **nose-heavy** aircraft will be more difficult to takeoff from the ground and to gain altitude and will tend to drop its nose when the throttle is reduced. It also requires higher speed in order to land safely.

The angle between the wing chord line and the stabiliser chord line is called the **Longitudinal Dihedral (LD)** or decalage.
For a given centre of gravity, there is a LD angle that results in a certain trimmed flight speed and pitch attitude.
If the LD angle is increased the plane will take on a more nose up pitch attitude, whereas with a decreased LD angle the plane will take on a more nose down pitch attitude.
There is also the **Angle of Incidence**, which is the angle of a flying surface related to a common reference line drawn by the designer along the fuselage.
The designer might want this reference line to be level when the plane is flying at level flight or when the fuselage is in it's lowest drag position.
The purpose of the reference line is to make it easier to set up the relationships among the thrust, the wing and the stabiliser incidence angles.
Thus, the Longitudinal Dihedral and the Angle of Incidence are interdependent.

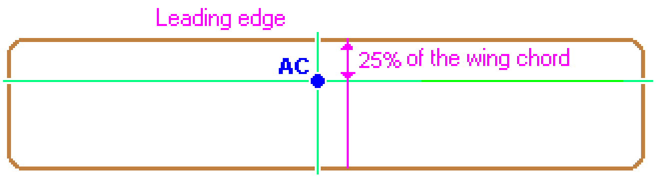
Longitudinal stability is also improved if the stabiliser is situated so that it lies outside the influence of the main wing downwash.
Stabilisers are therefore often staggered and mounted at a different height in order to improve their stabilising effectiveness.

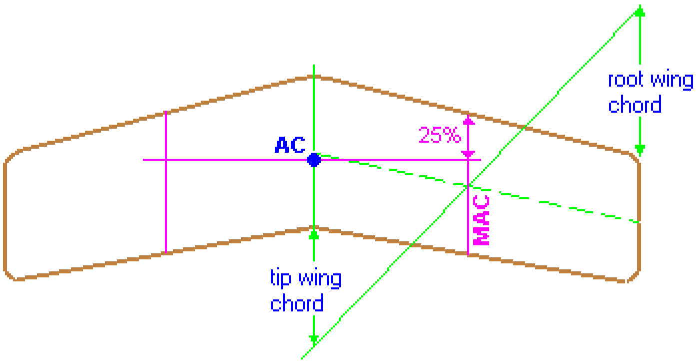
It has been found both experimentally and theoretically that, if the aerodynamic force is applied at a location 1/4 from the leading edge of a rectangular wing at subsonic speed, the magnitude of the aerodynamic moment remains nearly constant even when the angle of attack changes.
This location is called the wing's **Aerodynamic Centre AC**.
(At supersonic speed, the aerodynamic centre is near 1/2 of the chord).

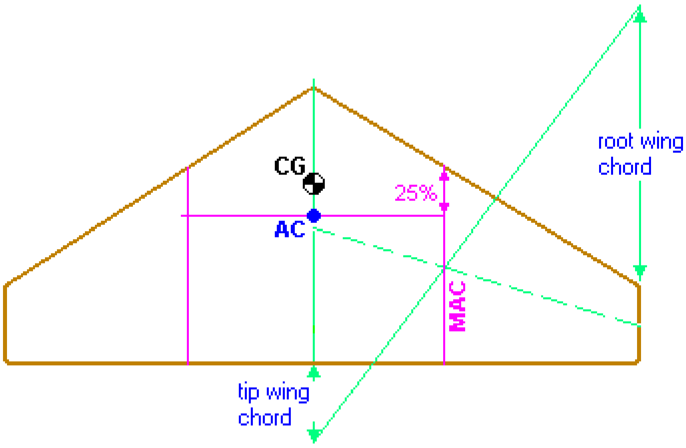


In order to obtain a good Longitudinal Stability the **Centre of Gravity CG** should be close to the main wings' **Aerodynamic Centre AC**.

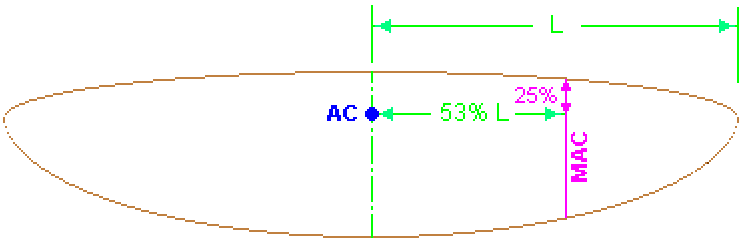
For wings with other than rectangular form (such as triangular, trapezoidal, compound, etc.) we have to find the **Mean Aerodynamic Chord MAC**, which is the average for the whole wing. See the drawings below:





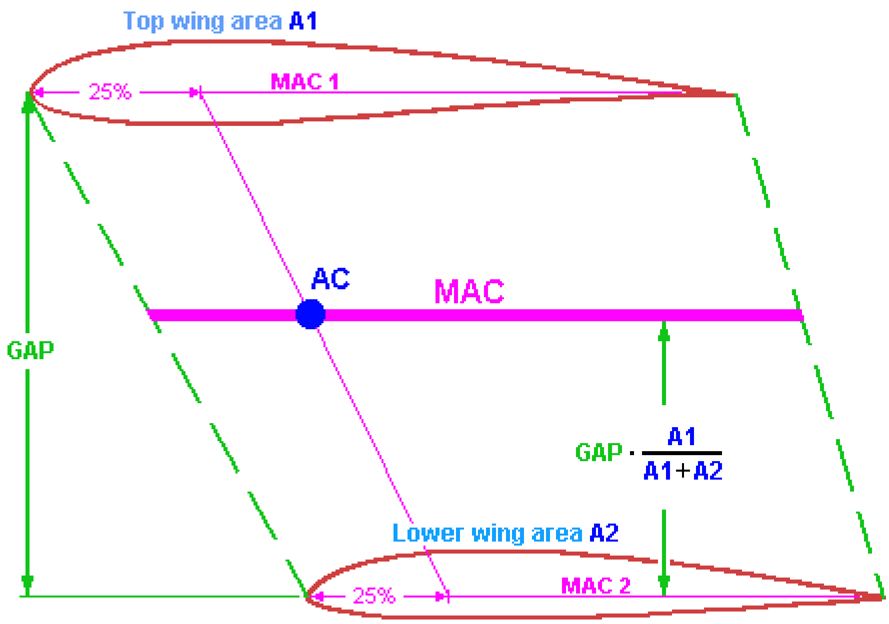


For a delta wing the **CG** should be located 10% ahead of the geometricaly calculated **AC** point as shown above.



The MAC of an elliptical wing is 85% of the root chord and is located at 53% of the half wingspan from the root chord.

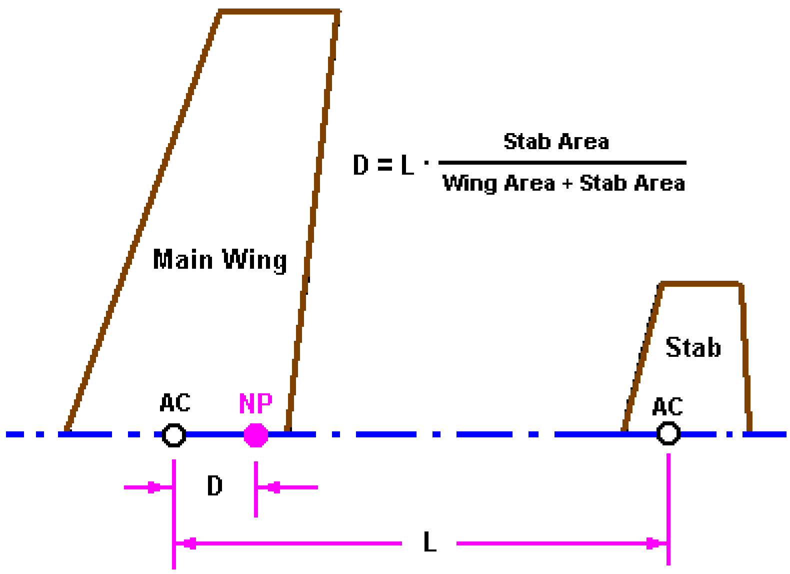
The **AC** location for biplanes with positive stagger (top wing ahead of the bottom wing), is found according to the drawing below.



For conventional designs (with main wing and horizontal stab) the **CG** location range is usually between 28% and 33% from the leading edge of the main wing's MAC, which means between about 5% and 15% ahead of the aircraft's Neutral Point NP.
This is called the **Static Margin**, which is expressed as a percentage of MAC. When the static margin is zero (CG coincident with NP) the aircraft is considered "neutrally stable".
However, for conventional designs the static margin should be between 5% and 15% of the MAC ahead of the NP.

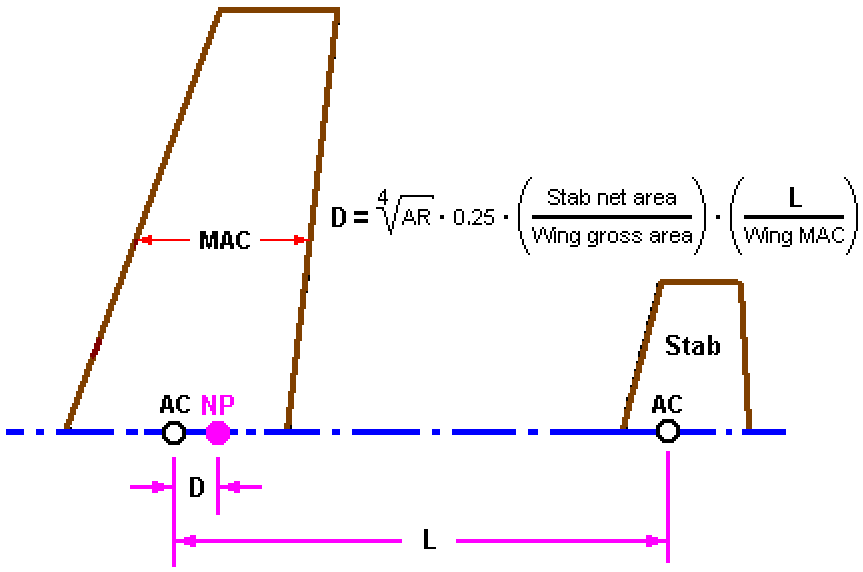
The CG location as described above is pretty close to the wing's Aerodynamic Center AC because the lift due to the horizontal stab has only a slightly effect on the conventional R/C models.

However, those figures may vary with other designs, as the NP location depends on the size of the main wing vs. the stab size and the distance between the main wing's AC and the stab's AC.
The simplest way of locating the aircraft's NP is by using the areas of the two horizontal lifting surfaces (main wing and stab) and locate the NP proportionately along the distance between the main wing's AC point and the stab's AC point.
For example, the NP distance to the main wing's AC point would be:
D = L · (stab area) / (main wing area + stab area) as shown on the picture below:



There are other factors, however, that make the simple formula above inaccurate. In case the two wings have different aspect ratios (different dCL/d-alpha) the NP will be closer to the one that has higher aspect ratio.
Also, since the stab operates in disturbed air, the NP will be more forward than the simple formula predicts.

The figure below shows a somewhat more complex formula to locate the NP but would give a more accurate result using the so called Tail Volume Ratio, **Vbar**. This formula gives the NP position as a percentage (%) of the wing's MAC aft of the wing's AC point.



For those who are not so keen on formulas and calculations there is the Aircraft Center of Gravity Calculator, which automatically calculates the CG location as well as other usuful parameters based on the formula above.

For Canards check the link below:

Canard Center of Gravity Calculator

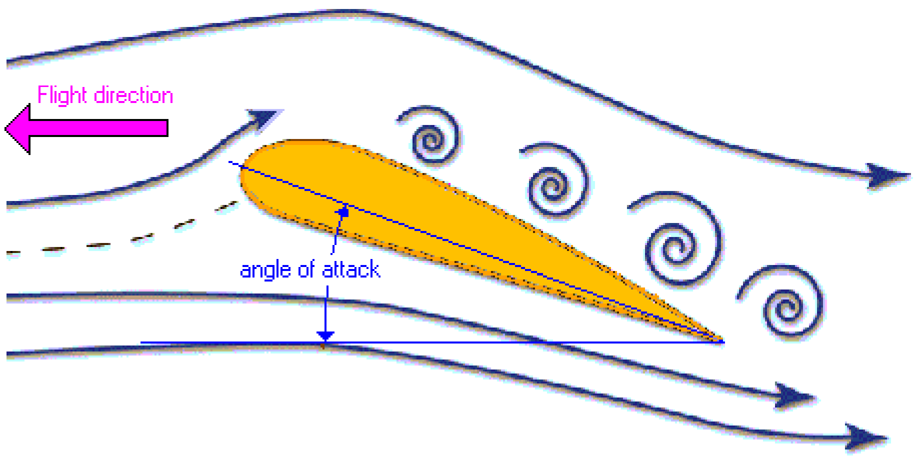
For further equations on how to find the proper CG location with different wing shapes and design configurations including Canards, check here.

Aerodynamics

Stall and Spin

One of the first questions a pilot might ask, when converting to a new aircraft type, is "What's the stall speed?"
The reason for the enquiry is that usually, but not always, the approach speed chosen for landing is 1.3 times the stall speed.
Stall is an undesirable phenomenon in which the aircraft wings produce an increased air resistance and decreased lift, which may cause an aircraft to crash.

The stall of the wing occurs when the airflow no longer can go around the airfoil's nose (leading edge) and separates from the upper wing surface.
It happens when a plane is under too great an angle of attack (the angle of attack is the angle between the airfoil chord line and the direction of flight).
For light aircraft, without high-lift devices, is this critical angle usually around 16°.
The picture below shows a stalled airfoil:



The stall may occur during take-off or landing, just when the flight speed is low: At low speed the aerodynamic forces are smaller and, if a non-experienced pilot tries to lift the aircraft at a too low speed, it may exceed the critical angle of attack and stall occurs.
The rapid reduction in speed after passing the critical angle of attack means the wing is now unable to provide sufficient lift to totally balance weight and, in a normal stall, the aircraft starts to sink, but if one wing stalls before the other, that wing will drop, the plane falls out of the air. The ground waits below.

Stalls may also occur at high airspeeds. If at max airspeed and full throttle the

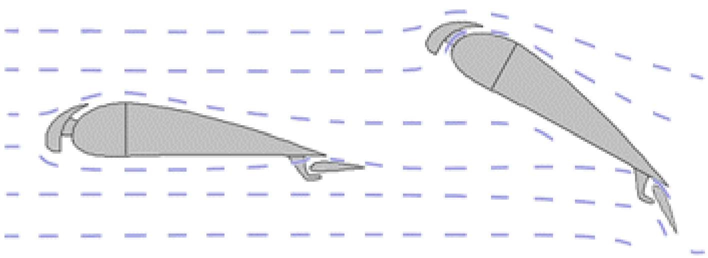
pilot suddenly applies excessive up elevator, the aircraft will rotate upwards, however, due to aircraft's inertia, it may continue flying in the same direction but with the wings at an angle of attack that may exceed the stall angle.
See an example here

Stalling at high-speed gives a more dramatic effect than at low speed.
This because the strong propeller wash causes one of the wings to stall first that combined with the high speed produces a snaproll followed by a spiral dive.
This happens very fast causing the aircraft to dive at full throttle and unless there's enough height for recovery, the crash will be inevitable.

An aircraft with relatively low **wing loading** has a lower stall speed (wing loading is the aircraft's weight divided by the wing area).
The airfoil also affects the stall speed and the max angle of attack.
Many aircraft are equipped with flaps (on the wing trailing edge), and a few designs use slats (on the wing leading edge), which further lowers the stall speed and allow higher angle of attack.

Another factor that affects the aircraft's stall characteristics is the location of its centre of gravity **CG**.
A tail-heavy aircraft is likely to stall at higher airspeed than one with the CG at the right location.

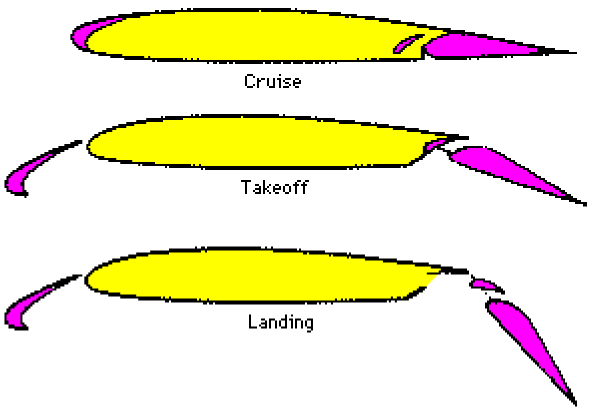
Aircraft that are designed for Short Take-Off and Landing (STOL) use slots on the wing's leading edge together with flaps on the trailing edge, which gives high lift coefficient and remarkable slow flying capabilities by allowing greater angle of attack without stalling.



Cruise Climb

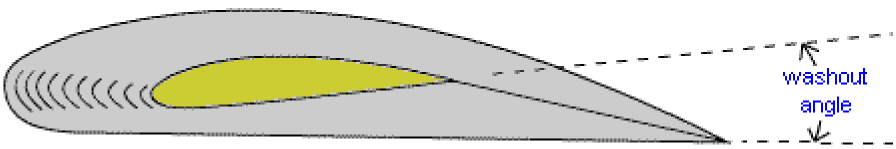
The leading edge slots prevent the stall up to approximately 30 degrees angle of attack by picking up a lot of air from below, accelerating the air in the funnel shaped slot (venturi effect) and forcing the air around the leading edge onto the upper wing surface.

The disadvantage of the slots and flaps is that they produce higher drag. Since the high lift is only needed when flying slowly (take-off, initial climb, and final approach and landing) some designers use retractable devices, which closes at higher speeds to reduce drag.



Such devices are seldom used in model aircraft (especially the smaller ones), mainly due to its complexity and also the increasing of wing loading, which may counter-act the increased lift obtained.

Another method to improve an aircraft's stall characteristics is by using wing **washout**, which refers to wings designed so that the outboard sections have a lower angle of attack than the inboard sections in all flight conditions.



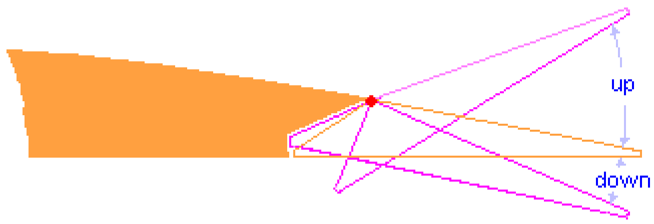
The outboard sections (toward the wing tips) will reach the stalling angle after the inboard sections, thus allowing effective aileron control as the stall progresses. This is usually achieved by building a twist into the wing structure or by using a different airfoil in the outboard section.
A similar effect is achieved by the use of flaps.

The **aileron drag** is a further factor that may cause an aircraft to stall.
When the pilot applies aileron to roll upright during low speed, the downward movement of the aileron on the lower wing might take an angle on that part of the wing past the critical stall angle. Thus that section of wing, rather than increasing lift and making the wing rise, will stall, lose lift and the aircraft instead of straightening up, will roll into a steeper bank and descend quickly.

Also the wing with the down aileron often produces a larger drag, which may create a yaw motion in the opposite direction of the roll.
This yaw motion partially counteracts the desired roll motion and is called the **adverse yaw**.

Following configurations are often used to reduce aileron drag:
- Differential ailerons where the down-going aileron moves through a smaller angle than the up-going.
- Frise ailerons, where the leading edge of the up-going aileron protrudes below the wing's under surface, increasing the drag on the down-going wing.
- And the wing washout.

Stall due to aileron drag is more likely to occur with flat bottom wings.
Since differential ailerons will have the opposite effect when flying inverted, some aircraft with symmetrical airfoils designed for aerobatics don't use this system.
The picture below illustrates an example of a Frise aileron combined with differential up/down movement.



Recovering from a stall:

In order to recover from a stall, the pilot has to reduce the angle of attack back to a low value. Despite the aircraft is already falling toward the ground, the pilot has to push the stick forward to get the nose even further down.
This reduces the angle of attack and the drag, which increases the speed.

After the aircraft gained speed and the airflow incidence on the wing becomes favourable, the pilot may pull back on his stick to increase the angle of attack again (within allowable range) restoring the lift.
Since recovering from a stall involves some loss of height, the stall is most dangerous at low altitudes.

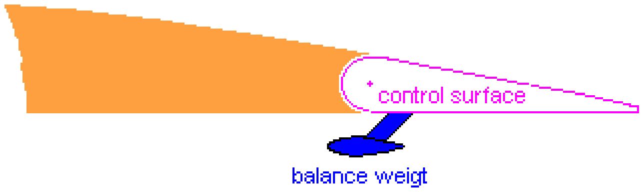
Engine power can help reduce the loss of height, by increasing the velocity more quickly and also by helping to reattach the flow over the wing.
How difficult it is to recover from a stall depends on the plane. Some full-size aircraft that are difficult to recover have stick shakers: the shaking stick alerts the pilot that a stall is imminent.

Spin

A worse version of a stall is called spin, in which the plane spirals down.
A stall can develop into a spin through the exertion of a sidewise moment.
Depending on the plane, (and where its CG is located) it may be more difficult or impossible to recover from a spin.
Recovery requires good efficiency from the tail surfaces of the plane; typically recovery involves the use of the rudder to stop the spinning motion, in addition to the elevator to break the stall. However the wings might block the airflow to the tail.
If the centre of gravity of the plane is too far back, it tends to make recovery much more difficult.

Another circumstance that may cause loss of control is when a hinged control surface starts to **flutter**.
Such flutter is harmless if it just vibrates slightly at certain airspeed (possibly

giving a kind of buzzing sound), but ceases as soon as the airspeed drops.
In some cases however, the flutter increases rapidly so that the model is no longer controllable.
The pilot may not be aware of the cause and suspect radio interference instead.
To reduce the flutter, the control linkages should not be loosely fitted and the push rods should be stiff.
Long unbraced push rods can create flutter as vibration whips them around.
In some difficult cases the control surface has to be balanced, so that its centre of mass (gravity) is ahead of the hinge line. It should be located at about 60-65% of the length of the control surface from its inner end:



Beginners' Guide

First Model

Some people consider a glider as the obvious choice for the first model.
Although a glider normally flies slower and is supposed to be more forgiving,
I think that's just a matter of taste.
Being a skilled glider pilot doesn't necessarily mean being also a skilled powered aircraft pilot and vice-versa.

Assuming that a powered model was chosen, the beginner is advised to start with a so-called trainer.
This type is usually a high wing aircraft model with nearly flat bottom airfoil that produces high lift, permitting slow landing speeds without stalling.
It also has some dihedral angle to give a good lateral stability.

However, a flat bottom high wing with dihedral is more sensitive to crosswind gusts, so the first flights should be done during calm weather.

A beginner should avoid wings with too sharp leading edges, as it will worsen the stall characteristics.

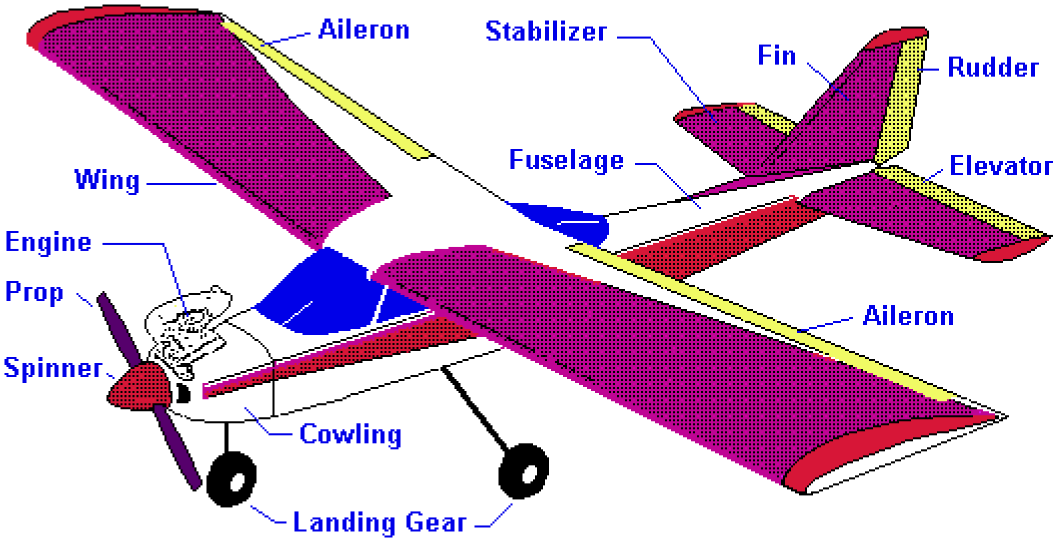
A well-rounded leading edge is therefore preferable, as it better conveys the airflow onto the upper wing surface allowing higher angle of attack at low speed.

A trainer model should not be too small, as it would be difficult to assemble and maintain and would be more sensitive to strong winds.

It should not be too large either, as it would be difficult to transport, require a larger flying field and would be more expensive.

A reasonable size is about 150cm wingspan (60 in) with a high aspect ratio, which means the wingspan being about 5.5 times the wing chord.
A square wing is advisable, as it distributes the weight of the aircraft evenly over the entire surface of the wing.
In order to allow a reasonable low landing speed without stalling, the wing loading should not be greater than about 60g/sq.dm (19-oz/sq. ft).
Wing loading is the aircraft's weight divided by the wing area.
Some degree of wing washout also improves the stall characteristics.

The basic parts of a trainer model:



Engine - provides the power to rotate the propeller.
Propeller - (also Prop) is attached to the engine's shaft to convert rotational motion into thrust and speed, which depends on the Prop's diameter, pitch and the Engine's power.
Spinner - streamlined part that covers the end of the Prop shaft.
Fin - (also Vertical Stabiliser) provides directional stability (stability in yaw).
Rudder - moveable part fitted to the Fin's trailing edge, is used to change the aircraft's direction.
Stabiliser - (also Horizontal Stabiliser or Stab) provides longitudinal stability (stability in pitch).
Elevator - moveable part fitted to the Horizontal Stabiliser's trailing edge, is used to make the aircraft climb or dive.
Ailerons - movable parts on both sides of the wing, are used to make the aircraft roll about its fore - aft axis. When one aileron moves up the other moves down.
Wing - provides the aircraft's main lifting force.

One may build a model aircraft based on drawings (plans). This requires some building skills and also time and effort to find out and gather the materials needed for the construction.

An easier approach (albeit more expensive) is buying a kit of parts.
There are many kits on the market with different levels of prefabrication depending on their price.
The cheaper kits have most of parts included, but some pieces come either pre - cut or printed on sheets of wood, so the builder is expected to do some extensive job, such as to cut out the fuselage formers and wing ribs, glue the parts together, apply the covering material, etc.
For those who are not so keen on construction, there are almost ready to fly (**ARF**) kits with an extensive prefabrication, requiring one or two evenings to assemble.
There are also ready to fly (**RTF**), which normally come complete with the power plant and some of them even with the radio preinstalled.

First Flight

It's highly recommended to have an experienced instructor beside you during your first flight, however, it is not impossible to get succeed by doing it alone.

Check the CG location with empty fuel tank by supporting the model with your fingertips underneath the wings. Find the position where the fuselage gets level or its nose is pointed slightly downwards.

Transmission range check should be performed on the ground before the flight.
This is usually done with the Transmitter aerial collapsed. The control surfaces should respond without glitch at a distance of about 80 meters (263ft).
This distance is only an approximately guide line, as the actual range may vary depending on the environment.
The effective range may only be half of this value if located at mountain bowl site or close to a public radio transmitter, radar station or similar.
The range may suffer adverse effects if the receiver aerial is close to metal parts or model components reinforced with carbon fibre.
Some transmitters allow the aerial to be totally collapsed inside a metal case, which also may reduce the radiation.
In this case the lower section of the aerial should be extended during the test.
The check should be repeated with the power system running, alternating the throttle setting between idle and full-throttle.

The range will be much higher when the model is in the air, normally about 1Km or as far as one can see the model.

Take-off:

If you hand launch your model, throw it against the wind horizontally and straight ahead, not up.
If you take-off from the ground, taxi the model towards the wind and let the model gain ground speed before applying elevator.
Once in the air try to climb at a very small angle, not abruptly upward, which would cause loss of airspeed and stall.

The model is more sensitive to the motor torque effect during the relatively low take-off speed and may begin to turn left (or right). Use the rudder or ailerons to prevent the model from turning during the climb stage, otherwise the model may initiate a spiral dive.

Don't try any turns until the model has gained speed and reached a "safe altitude". Be very gentle with the controls and practice gentle turns high in the air before you try to land.
To prevent losing altitude when turning the model, just give little up elevator at same time you make a turn.

Try to keep the model in sight and do not fly too high or too far away.
You may reduce the throttle while high in the air so you may get an idea how the model behaves at low speed.

To prevent getting confused about which way to turn when the model flies towards you, turn your back to the model slightly while keeping watching it, so you can imagine "right" and "left" from the model's point of view.

Some trimming may be needed in order to reduce or eliminate roll, bank and/or pitch tendencies.
A flat bottom wing often tends to "balloon" up into the sky, keeping climbing when full throttle is applied. This may be reduced during the flight by adjusting the elevator trim or by reducing the throttle.
In worst cases it may be needed to increase the motor's down-thrust angle and/or decrease the main wings incidence angle.

Landing:

Reduce throttle to about half so you have to slightly pull up the elevator to keep the altitude.
Turn the model towards the wind and let the model sink gradually towards the landing area by easing the elevator.

During the last fifteen to twenty meters (45 to 60 feet) of descent, (which depends on the model's characteristics) you should idle the throttle.
The model will start sinking at a higher rate now. Try to keep the model in a shallow dive and don't use the elevator to gain altitude or to prolong the flight at this stage, otherwise stall is likely to occur.
Just keep a slightly downward attitude throughout the final approach in order to maintain the airspeed.
The higher the wing loading, the steeper the approaching angle may be however, it is not recommended approaching angles greater than 45 degrees.
If you notice that the model is sinking too fast or is too low to reach the landing field - just increase the throttle first before applying elevator to maintain or gain altitude to prolong the flight or to repeat the landing approach.
Pull up the elevator slightly about 30-60cm (1-2 ft) before the touch-down so that the propeller or nose gear don't hit the ground.
Be prepared to repeat unsuccessful landings several times, since it's often a matter of trial and error before one gets used with how the model behaves.

Don't try to land in a specific spot, avoid turns when the model is flying low or at low speed. Just let your model glide into the ground straight-ahead.

Avoid the proximity of buildings, roads and electric power lines.
Don't fly close to or towards people and animals.
The bigger the field for your first flight, the greater will be your chances for success.

- Good luck.

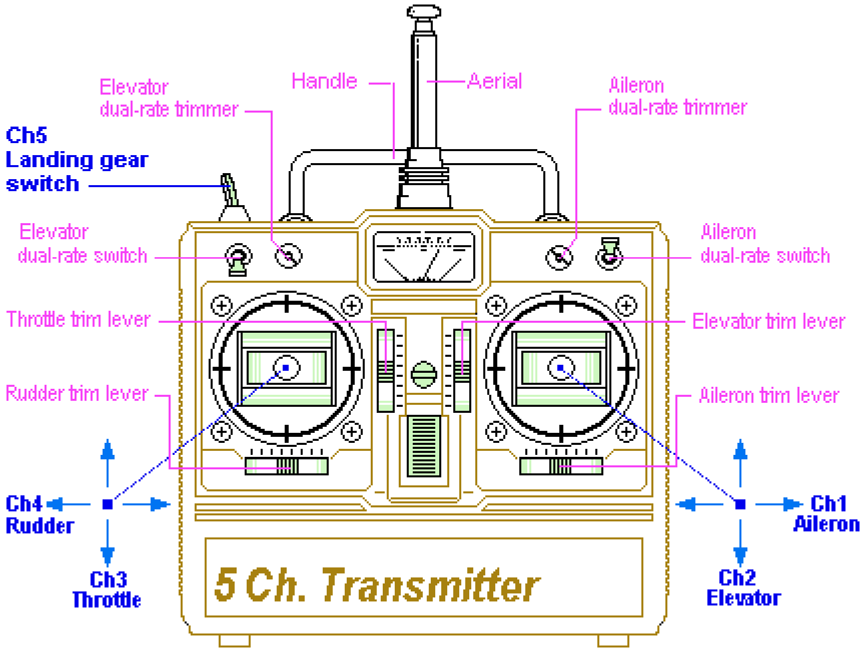
It's also advisable to join the nearest model aircraft club there you may meet experienced flyers who can provide lots of useful tips and hints.

Radio Control

The R/C pilot controls the model by a radio link, which means by using electromagnetic radiation.
Basically the R/C equipment consists of a Transmitter operated by the pilot and the airborne units consisting in a Receiver together with one or more Servos depending on the number of channels used and a Battery pack.

The picture shows a four channel Transmitter, Receiver, 4 Servos, Battery pack and Switch.

A typical Transmitter has about 4 to 6 channels with at least 4 of them being proportional, which means the controlled surfaces or devices will move proportionally to the movements of the control sticks.
Additional channels may function only in "on-off" manner like a switch, and are usually used to actuate retractable landing gears, airbrakes, lamps, etc.



The example above shows a five channel Transmitter with two joysticks (left/right and up/down movement) enabling four proportional channels, while the fifth channel is of switch type (on/off).
The example shows the **mode two** configuration (most common) having the elevator control on the right joystick and the motor throttle on the left one.
The right joystick self centres in the both axis, whereas the left joystick only self centres in left/right axis and "clicks" in the up/down axis in order to allow the throttle setting.
The **mode one** configuration has the elevator control on the left joystick and the throttle on the right one.

Most modern Transmitters have "dual-rate" facility, which means the pilot may change the max throw angle of the control surfaces during the flight, e.g. the max throw may be reduced when flying fast and increased when flying slow.
The possibility to choose exponential movement may be featured in some types.
Many Transmitters have a servo-reversing feature, which facilitates the servo linkage assembly.
Other feature such as channel mixing enables V-tail configuration and flaperons.
Some Transmitters include a microprocessor and memory, enabling the user to save different model configurations and settings.

Another facility is the so-called buddy box, which allows two compatible transmitters being connected by a cable. This is used for training purposes where a transmitter is held by the instructor and the other by the student.
The student may control the model as long as the instructor holds down a push-button on his/her own transmitter.
Should the student get in trouble, the instructor releases the push-button, and quickly takes over the control.

The Transmitter sends data to the Receiver by generating a modulated radio frequency (**RF**) carrier, while the Receiver is tuned to detect the Transmitter's

carrier frequency.
The accuracy of sending and receiving frequencies are usually achieved by the use of crystals.
The Receiver detects data from the modulated carrier, decodes and deliveries it to the respective Servo.

There are several Frequency Bands allocated for Radio Control depending on the country. Each Frequency Band is divided in several Channels.
In USA the Frequency Band for Model Aircraft is 72MHz, Channels 11 to 60 with 20KHz separation. And for surface models (Cars, Boats, Robots etc) is 75MHz, Channels 61 to 90.
In most European countries the Frequency Band for Model Aircraft is 35MHz, Channels 55 to 90. And for surface models is 40MHz (from 40.665 to 40.995).
For a more detailed information about each country's frequencies check here

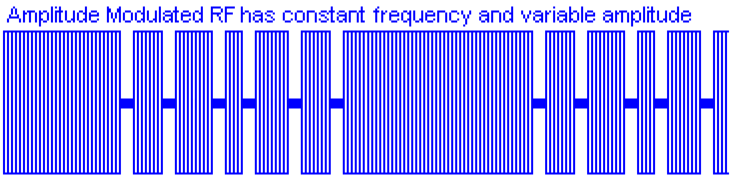
Channel identification on 35MHz Band is done by an orange flag with a white channel numeral.

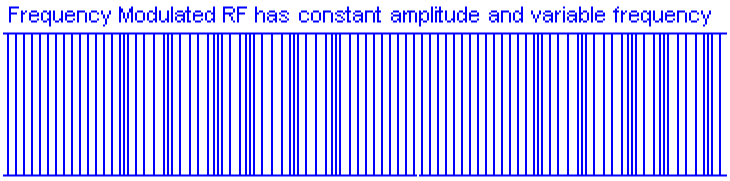
Ch an	Freq uenc	Ch an	Freq uenc	Ch an	Freq uenc
55	34.95	67	35.07	79	35.19
56	34.96	68	35.08	80	35.20
57	34.97	69	35.09	81	35.21
58	34.98	70	35.10	82	35.22
59	34.99	71	35.11	83	35.23
60	35.00	72	35.12	84	35.24
61	35.01	73	35.13	85	35.25

62	35.02	74	35.14	86	35.26
63	35.03	75	35.15	87	35.27
64	35.04	76	35.16	88	35.28
65	35.05	77	35.17	89	35.29
66	35.06	78	35.18	90	35.30

It's possible to change the Frequency Channel by changing the transmitter and receiver crystals. However, it is advisable to change only to a channel close to the original transmitter frequency, which was tuned by the manufacturer, otherwise significant reduction in range may occur.
This problem is eliminated if the transmitter has a changeable RF power module. The drawback is that the RF modules are more expensive than the crystals. Some manufacturers offer synthesised radios, which enable change of channels at the field without the need to remove modules or crystals. They are likely to be rather expensive though.

Most R/C systems today use frequency modulation (**FM**) as it better rejects interference than the earlier amplitude modulation (**AM**).





Frequency Modulation means that the Transmitter sends data by changing its carrier frequency with a deviation of for ex. +/- 1.5KHz from its nominal value.

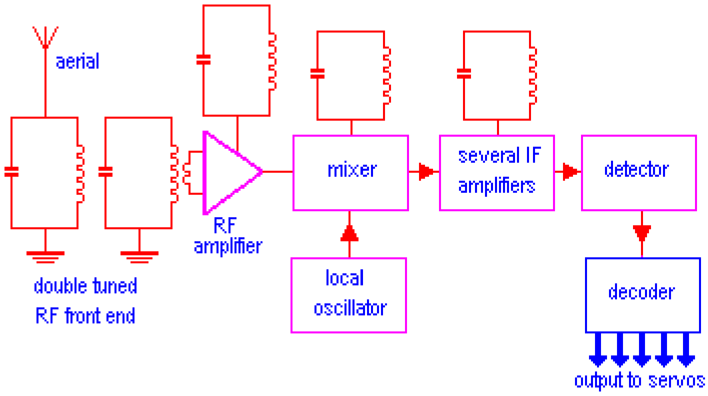
The Transmitter RF power output combined with the Receiver sensitivity and selectivity are the main factors that influence the transmitting quality and the range limit of a particular outfit.

The Transmitter aerial is part of the final **RF** amplifier stage tuned circuit.
The aerial has a natural frequency resonance dependent upon its length.
Since at 35MHz the physical length corresponding to a wavelength is 8.6 meters, the designers choose alternatives of 1/2 or 1/4 wavelength aerials in order to be more practical for a hand held transmitter, despite the small reduction in radiation efficiency.
Aerial efficiency may be improved if the designer fits a loading coil to increase the effective length. The coil may either be located at base of the aerial inside the transmitter case or outside, part away along the aerial length.

The latter is more efficient but makes aerial replacement more difficult since re-tuning is needed.

There's a null in the radiation at the tip of a straight vertical rod aerial, so the pilot should avoid pointing the aerial tip towards the model when flying at a greater distance.

In order to achieve a good selectivity the Receiver design is often based on Superheterodyne principle. There are two types:
The Single Conversion and the Double Conversion.
The block diagram below shows a typical Single Conversion Superhet. Receiver.



The Receiver's **RF** stage is tuned to the transmitter's frequency and also may or not include a RF tuned amplifier.
A local crystal controlled oscillator operates at frequency usually 455kHz below the incoming RF signal.
The local oscillator's frequency is mixed with the incoming RF signal at the mixer stage and the difference of these two frequencies is amplified by several tuned Intermediate Frequency circuits **IF**.
In case of an **AM** receiver it is required an Automatic Gain Control (AGC) for the IF stage.
The data received is detected at detector stage and send to the decoder, which in turn delivers it to each Servo.

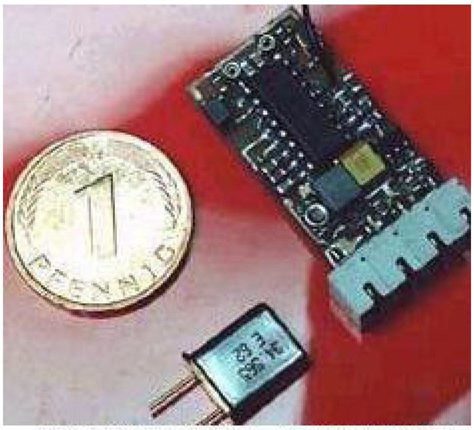
However, the Single Conversion Superht. Receiver has some drawbacks that may cause problems in model control applications.
The mixer stage produces a 455kHz output from both the incoming RF signal and also from a signal 455kHz below the local oscillator frequency. This signal is called the "image" and will cause interference if it enters the receiver.
There are also a number of other signal combinations that may cause the generation of 455kHz IF such as, Second, Third, Fourth etc. harmonics of the operating frequency and similar harmonics of the local oscillator plus and minus 455kHz may also cause problems.

Many of these drawbacks can be overcome by using a Double Conversion Superhet. Receiver. This concept uses two Intermediate Frequencies (IF) and two crystal controlled oscillators.
The first Intermediate Frequency is higher than 455kHz, typically 10.7MHz.
Signals that could cause spurious responses are now beyond the passband of the RF stage.

A second mixer reduces the 10.7MHz to 455kHz to obtain a good selectivity.
Due to its complexity, increased costs and added weight, such a design is not widespread among the manufactured VHF equipment, but under some severe operating conditions it may give the only solution to reliable performance.

Receivers are available in different shapes, sizes and weights.

Multiplex Pico receiver weights 6.9g and is designed for indoor flight models — has a range of 300m

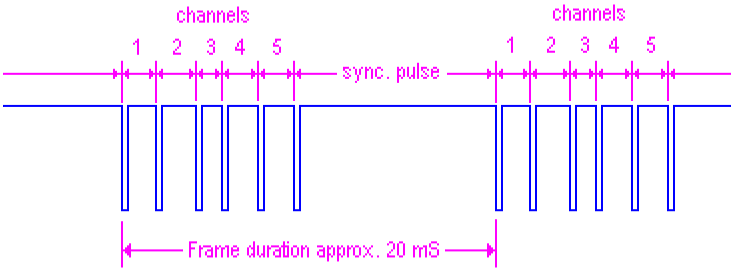


JMP RX5 weights 2.3g - range about 150m

PPM System

There are several data encoding/decoding systems on the market today.
The older one is PPM (Pulse Position Modulation).
That's just the way the data is encoded/decoded, since the RF carrier is often FM modulated on all systems.

The PPM encoding system consists of a data frame containing a synchronising pulse followed by a number of shorter pulses equal to the number of channels.
The frame duration is about 20mS, which means the data is being send at a frequency of about 50Hz.



The transmitter encoder circuit reads each control potentiometer's value and switch's position sequentially, converting each value to a pulse width.
The width of each pulse corresponds to the respective Servo position.
A control in neutral position gives a pulse of 1.5mS and in the end position may be either 1 or 2mS depending on which way the control has been moved.

PCM System

PCM stands for Pulse Code Modulation.
The position of joy-sticks, switches and pots, originally analogue voltages are digitised by an A/D converter to a 8 to 10 bits (256 to 1024 decimal) word.
For eight to ten servos means 80 -100 bits. With a further 16-32 bit checksum per frame, synchronisation sequences and failsafe values, and a bit number of 100 -160 becomes necessary for a complete frame.

A bit length of 0.3mS (JR/Graupner and Futaba/Robbe) will produce a 30-48mS frame time, considerably longer than about 20mS the PPM uses.
If even more secure bit lengths and 12 channels are used, this time is increased to 55mS, e.g. Simprop (System 90), where only 6 channels are proportional and 6 are switched channels.

Actual PCM uses two systems to synchronise the transfer: an extra long starting pulse made up of so many "1" or "0" bits, that it can never be mistaken for data, or the so called half bit pulse, e.g. 2,5 bits, equally impossibly mistaken for data.
Usually this is followed by a synchronisation sequence, setting the receive-clock.
This is the clock that scans the middle of the bits upon reception.
This explains why, at the limits of the transmission range with PPM the servos start to glitch, as noise causes the pulse flanks to vary (up to+/-30 us), while PCM keeps them quiet, having half a bit (150 us) to play with.

The checksum in the shape of a 16 bit long CRC (Cyclic Redundancy Check) provides an effective way to detect bit errors, but **in no way corrects them**.
This in turn means that, even if only one single bit error has crept in the ca. 100 - 160 bits total frame length, the checksum fails and the whole message is rejected.
The servos remain in their last correctly received position until the arrival of new, correct data. If this takes too long (0.25-1 Sec), failsafe will take place, and depending on the predefined settings, a chosen (and defined in the transmitter) failsafe position or the last correctly received position will be activated.

To reduce the failure time, JR/Graupner (S-PCM) and Futaba/Robbe (PCM1024) subdivided the frame using separate CRC checks.
This allows rejecting only a part of the faulty frame.

PCM advantages:
Servo movements without glitch, even if the model is far way.
Holding of the servo position during short glitches (Hold).
Moving the servo to a predefined position in case of a longer disturbance or even complete failure of the transmitter (Fail-Safe).
Fast transmission if S-PCM20 or PCM 1024 is used, similar to PPM.
Servos are not damaged by pulses that are too long/short, which could happen with PPM.

PCM disadvantages:
More expensive.
Sensitivity to adjacent channels is usually worse comparing with PPM receivers.
Care has to be taken when flying near to a transmitter from an adjacent channel.

Due to different protocols, only receivers from the same brand or even type of the transmitter can be used.
Checking the transmission quality can be difficult, because the hold-mode smoothes out small glitches.
The lack of early warning signs often causes trouble.
Control problems that build up gradually, e.g. of a technical nature, get noticed only when the connection fails completely, which may lead to a crash.

PPM advantages:
The PPM system is cheaper.
There should be no problems using different brands of receivers with different transmitter manufacturers.
Transmission is fast enough to operate even the quickest of servos.
With PPM, the end of the transmission range is shown by the servos starting to glitch. When the pilot notices this, he/she can probably still get the model back home safely.

PPM disadvantages:
Due to its simplicity, PPM system cannot detect errors, the receiver does not see the difference between valid and invalid servo pulses. When the range boundaries are reached, pulses get slightly longer or shorter because of noise. Servos start to glitch. This may happen when antenna orientation is not optimal, when the projection of the receiver antenna is nearly down to a single point, the signal breaks down and the servos get false pulses.
These short glitches go unnoticed most of the time because they are smoothed out by the servo's and the model's inertia (response time).

Improvements can still be expected in the PPM sector, like the IPD system by Multiplex, Scan-PLL by ACT or Scan2000 by Simprop.
Using a microprocessor in the receiver makes checking RC-pulses a possibility.
Failsafe and Hold, exclusive advantages of PCM so far, are now also possible with PPM.

IPD System

IPD stands for Intelligent Pulse Decoding, and the receiver incorporates a processor, which analyses the incoming signal for validity.
Like a PCM system, IPD filters out invalid signals.
The difference between the systems is that the IPD receiver does not "switch off" the "dirty" signal as field strength declines, but instead widens its tolerance.
This means that control becomes less precise as field strength falls away or the transmission quality deteriorates, but remains usable for longer time and greater range.
The result is that you can notice the approaching limit of range from the model's behaviour, whereas PCM suddenly robs you of control.
When the signal is insufficient for the receiver to interpret, a fail-safe condition occurs, thereby driving the servos to pre-selected safe positions.

The IPD receiver only considers a signal valid as long as its length lies within

the range 890 µsec to 2350 µsec. These are limit values, which cater for most radio control transmitters.
The receiver analyses the signal, and adjusts it automatically in accordance with the current reception quality, or field strength. Powerful signals are passed on to the servos directly, but weaker signals are "post-processed".
This means that the IPD receiver calculates the nominal servo position from the last "good" signals, which it picks up. This greatly reduces the effect of any interference, but - in contrast to PCM - the pilot is made aware that there is a problem during a longer period of time.
In this way the pilot receives a warning that all is not well and has more time to respond appropriately.

The IPD receiver can operate with usual PPM formats, which means that all standard FM PPM transmitters can be used in conjunction with these receivers.
IPD is faster than PCM because there are no check cycles.

DSR System

DSR stands for Digital Signature Recognition and is used by FMA's FS5 and FS8 dual conversion FM receivers.
It's claimed to provide the ultimate protection against crashes when used along with FMA's Co-Pilot Flight Stabilisation System.
The DSR receivers block the interference by memorising the actual transmitter's unique signal frame and rejecting all the others, even if they are in the same frequency...!

For further safety the receivers' Pre-flight Interference Check detects and warns the pilot if there's another transmitter on the same frequency.

When turned-on these receivers analyse the data stream and automatically checks for:
-positive or negative shift
-valid number of pulses (and stores this)
-valid frame length
-valid pulse widths

If a frame is damaged, the system invokes three levels of error correction to attempt to restore the data. If the data fails to be restored for 50 consecutive frames, the failsafe mode is enabled which sets the servos to either the "last good frame" or the pre-set positions depending on the pilot's choice.
The Co-Pilot will hold the wings and nose level enabling the model to fly in a stable and predictable flight path, giving the pilot time to find the problem and/or to warn the spectators.

These receivers also include extensive flight data reporting capabilities via PC while the most critical data can be read directly from the receiver.

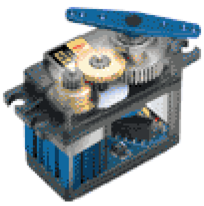
The DSR receivers work with any standard FM - PPM transmitter.
For further information on DSR receivers click here.

The **Co-Pilot** monitors an aircraft's relationship to the earth's horizon by using four infrared temperature sensors.
In the infrared spectrum, the earth is warm below the horizon, while the sky is cold above the horizon.
During the flight, the Co-Pilot senses changes in the aircraft's attitude relative to the horizon and sends corrective signals to the aileron and elevator servos in order to keep the aircraft level.
If an extra channel is available, the pilot may turn the Co-Pilot on and off, and adjust its sensitivity from the ground.

Servos

Servos are the end units in a radio control chain.
They are used to move the aircraft's control surfaces, the motor throttle and to actuate other devices such as retractable landing gears.

A servo consists basically in a motor, gearbox, feedback potentiometer and an electronic board inside a plastic case.
Outside are the servo arm and the servo cable and plug.

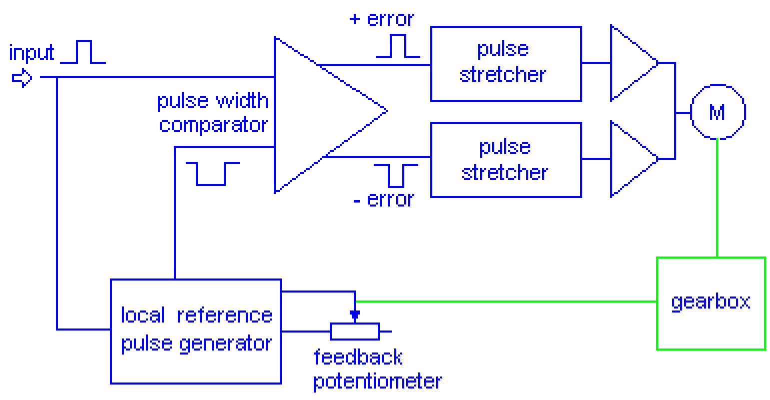


The servo arm is often a plastic piece with holes on it for attaching push rods or other mechanical linkages.

There are linear and rotary servos, but the most widespread today are the rotary servos whose arm rotates about 45 degrees left and right from its centre point.

The picture on right shows some servo hardware, such as mounting screws, rubber pads, and different sorts of servo arms.

The servo has an electronic circuit that compares the incoming control pulse with a local generated one whose width corresponds to the servo arm's actual position.
The servo's internal pulse width is determined by its feedback potentiometer whose slider moves together with the servo's arm.
When the width of the incoming control pulse is different from the local generated, the servo motor will rotate until the both pulses' width are equal.
The direction of rotation depends on whether the incoming pulse is wider or shorter than the local pulse.



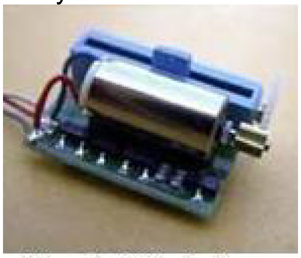
There are two operating concepts: the conventional servo and the digital servo.
The conventional servo circuit uses a pulse stretcher to widen the pulse difference between the incoming pulse and the locally generated.
Thereby a 1% pulse difference produces a 50% duty cycle for motor drive.
A continuous drive signal will be obtained when the pulse difference is over 10%.
Also a small dead band is provided to prevent the servo being in continuous state of motion when insignificant pulse differences occur.

The difference between the conventional and the digital servo is that the pulse drive to the motor occurs every 20mS with the conventional, whereas with the digital occurs (for example) every 3.3mS, which means that the digital servo sends pulses to the motor at a much higher frequency.
Digital servo incorporates a microprocessor, which receives the input pulse signal and generates power pulses to the servomotor based on preset values.
Some brands offer the possibility to program certain parameters such as Dead-Band Width, Direction of Rotation, Neutral Point, Servo Arm Throw and End Point.
The digital servo is supposed to have constant torque throughout the servo travel, faster control response and more accurate positioning, but at the expense of greater power consumption.

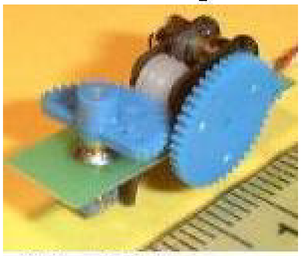
Servos are available in different shapes, sizes, weights and output torque.
Typically they may be sorted as follows:

Giant - weights around 100gr (3.5oz)
Standard - 45gr (1.6oz)
Mini - 20gr (.70oz)
Micro - 8gr (.28oz)
Pico - 5.5gr (.18oz)
Wes Technik - 2.1gr (.08oz)
Falcon Servo - 1.7 gr

Some of the smallest servos on the market today:



Wes-Technik 2g Servo



Falcon 1.7g Servo

Further lighter systems use a coil/magnet concept, and may weight less than 1gr (.035oz). However, they need a special tailored receiver.
A more detailed description about the coil/magnet system may be found here.

Batteries

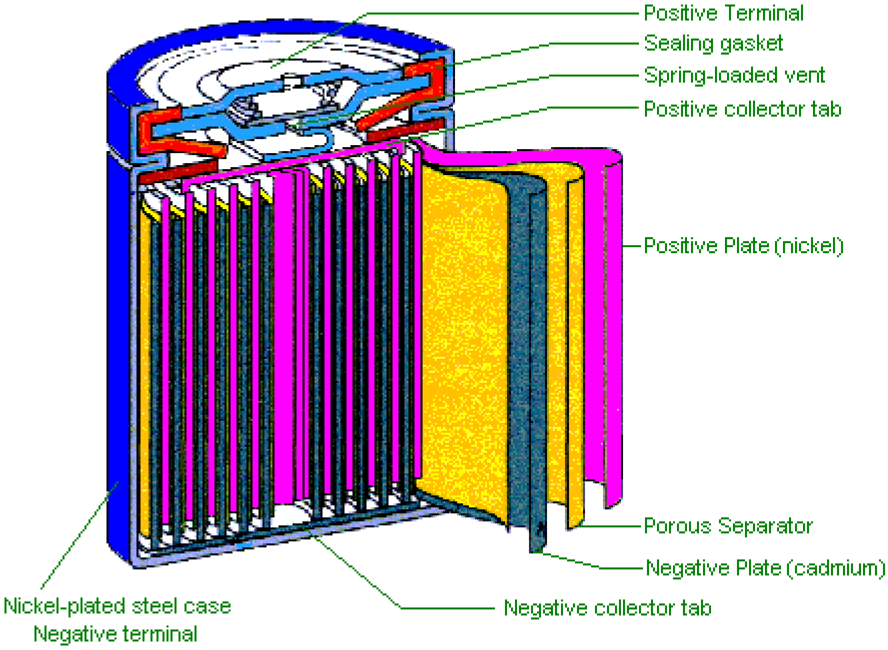
Batteries are available in different sizes, weights and capacities **C**, which refer to their stored energy expressed either in amps-hour **Ah** or milliamps-hour **mAh**. For example, a battery with a capacity of 500mAh should deliver 500mA during one hour before it gets totaly discharged (flat).

The radio control sytems are usually powered by rechargeable batteries.
There are two main rechargeable battery
types available on the market today:
The NiCads (nickel - cadmium) and the
NiMH (nickel - metal hydride) batteries.
Even Lead-Acid batteries are also used
as ground power source.

Normally the NiCads stand more "abuse" which means that they may be charged at higher rate (normally 2 - 4C) and have the ability to deliver higher current, i.e. discharge rates up to 2C continuous or 8 to 10C during 4 - 5 minutes and even up to 100C during very short time.
They have some designations such as the Sanyo AE for high capacity and AR or

SCR for quick charge/discharge.

A NiCad cell consists basically in a positive plate foil of nickel metal with nickel oxide/hydroxide, a negative plate foil of cadmium metal with cadmium hydroxide and an isolating porous separator film moistened with an electrolyte of potassium hydroxide (caustic potash).
The two plates are sandwiched between the isolating porous separator films, rolled up and enclosed in a nickel-plated steel can.
A spring-loaded vent is fitted at the positive terminal end in order to release the electrolyte and/or gasses, in case overpressure occurs due to overcharge.
See picture below.



The NiMH have higher capacity/weight compared with the NiCads but are more sensitive to high charge rates (max recommended 1C) and normally it is not recommended to discharge the NiMH batteries at higher rates than 3 - 5C.

The NiMH self-discharge rate is also about 50% higher than the NiCads.
However, the NiMH are more environment-friendly.

A new type of NiMH battery known as HeCell has recently been developed, which is claimed to allow higher discharge rates than the conventional ones (about 12 - 16C).

Both battery types lose their stored charge due to internal chemical action, even when not in use.
Normally the NiCads lose around 10% of its charge in the first 24 hours after been charged and keep losing it by 10% per month.

The rate of self-discharge doubles for a rise in temperature of 10 degrees C.
Some NiCads can discharge themselves completely in a period of six months.

The best way to keep batteries which are not in use for a long time, is by having them stored in the refrigerator (not in the freezer).
Just allow the battery to reach the ambient temperature before using/recharging.

Some manufacturers claim that these battery types are able to stand at least 1000 charges/discharges during their lifetime, assuming they have been subject to the ideal charging and handling methods.
In practice however, we may expect about 600 - 800 charges/discharges.

A safe method to charge both the NiCads and the NiMHs is by using a constant charge current (CC) at 1/10 of their capacity (0.1C) during 14 hours.
For other charge current values one may use the following formula:
Charge Time (Hours) = 1.4 x Battery Capacity / Charge Current (assuming a constant charge current is used).

However, low cost CC chargers provide no way of detecting when the battery is fully charged.
The user is then expected to estimate the charging time based on the constant charging current value and the battery capacity, according to the formula above.
And providing the NiCads' are discharged to about 1.1V p/cell each time before recharging, this charging method can be used to achieve a reasonably long battery life. Since repeatedly recharging an already fully charged NiCad or one with a large part of its charge remaining will degrade its performance.

Some chargers provide the option to discharge the batteries down to about 1.1V per cell before starting the charging process.
There are also fast battery chargers on the market charging from 1C up to 4C.
But due to the high charging current level, it is required a reliable method of stopping the charge once the battery is fully charged, otherwise overheating and battery damage may occur.

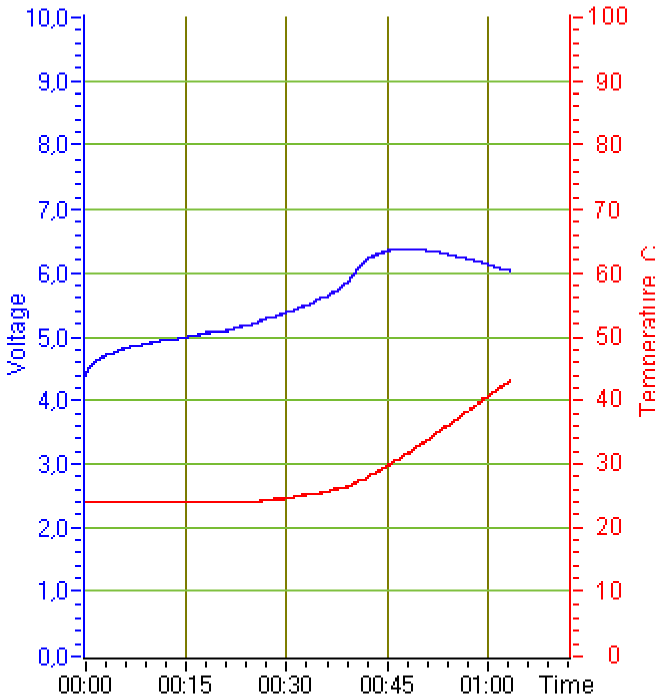
Since the NiMHs' and NiCads' voltage actually starts dropping after they have reached the fully charged state, the fast chargers use the so-called Delta Peak detecting method.
There are "negative delta V (-DV)" and "zero delta V (0D)" detectors.
Also "change of temperature (dT/dt)" detectors are commonly used.
Some manufacturers use negative or zero delta V together with change of temp. detection, in case of one method fails to detect.
Since NiMHs' voltage drop (delta V) after the fully charged state is lower than the NiCads, a more sensitive delta V charger is required for the NiMH batteries.
Some chargers allow the user to set the value of the delta peak detection, which may be between 10 - 20mV per cell for NiCads and 5 - 10mV for NiMHs.
A too low value may cause false peak detection due to electric noise, preventing the batteries from getting fully charged, whereas a too large value may result in overcharge, which reduces the batteries' life.

Some fast chargers offer the possibility to automatically change over to slow charge (trickle-charge, for ex. at 0.05C) when the fully charge status is detected.

The graph on the right shows the voltage and temperature variation of a four cell NiCad during charging at 1C constant charge current.

Notice how the voltage drops after it has reached a top value, whereas the temperature keeps rising.

The battery is considered fully charged when the temp. rises about 10°C above the ambient temp. (24 + 10 = 34°C)

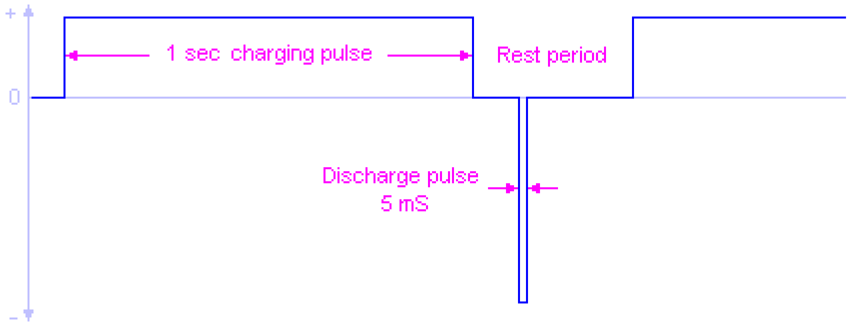


The NiMH batteries tend to dissipate heat during all the charging process, while the NiCads get warm only when they reach the full charge point.
The nominal voltage is 1.2V per cell for both battery types and a charged cell may have about 1.45 - 1.50V.

It's not possible to know exactly the NiCad's or NiMH's cell charge status by only measuring it's terminal voltage, as the cell's charge status is not a linear function of the cell's voltage.
A reliable method to know how much charge is left or whether a cell still has its nominal capacity, is by discharging it with a known constant current and measure the time until the cell voltage reaches about 1.1V.
For example, it should take about two hours to discharge a fully charged 500mAh cell by using a constant discharging current of 250mAh.

Battery researchers have in the recent years come to conclusion that NiCads respond better to a pulsed charging waveform than to a steady DC current.
By applying the charge current in one-second pulses with brief "rest" periods between them, ions are able to diffuse over the plate area and the cells are better able to absorb the charge.

This is particularly true at the higher charge rates used by fast chargers.
These chargers have a microprocessor that samples the "rest" periods between the charging pulses to read the battery terminal voltage.
Another interesting discovery is that the charging process actually improves even further if during the "rest period" between charging pulses, the cells are subject to very brief discharging pulses with an amplitude of about 2.5 times the charging current, but lasting only about 5mS.



It is claimed that these short discharge pulses actually dislodge oxygen bubbles from the plates and help them diffuse during the "rest period". The use of these brief discharge pulses is known as "burp charging".
Tests done by both US military and NASA have shown that NiCads charged by using fast chargers employing the burped pulse system tend to last up to Twice as long as those charged by traditional CC chargers.
Many of the high-end fast pulse chargers for NiCads use a charging method according to those findings.

A battery pack consists of several cells connected in series, which inevitably age at different rates and gradually develop individual different charge status, and since the battery pack as a whole is charged and discharged repeatedly, these differences may become accentuated.
The result is that some weaker cells can eventually be discharged well below 1.0 V and even driven into reverse polarity before the others reach the fully discharged state.
During the recharging process, the weaker cells will be improperly recharged and tend to suffer increased crystal growth, while the others will absorb most of the charge and overheat, which dramatically degrades the whole battery pack performance.
It's therefore advisable checking if the battery cells get different temperatures during the charging process, specially when high charge current rates are used.

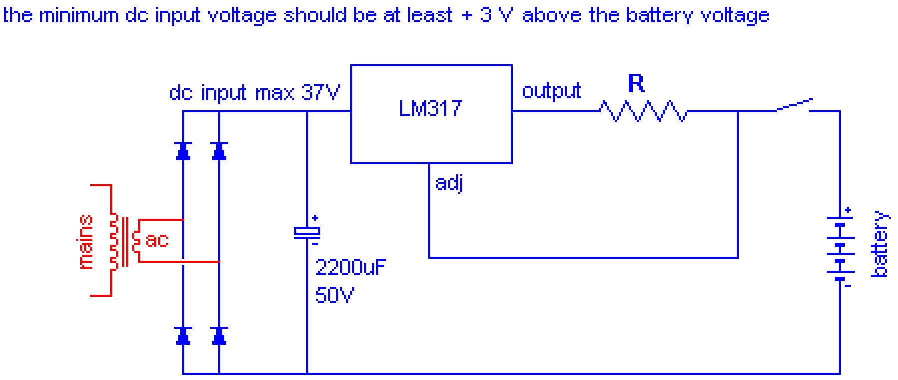
It's claimed that individual cell differences may level out by slow charging the battery pack from time to time at 0.1C during 14h or so.

Some few examples of many battery chargers available on the market:

GWS-MC-2002 Charger
Input Voltage range: 9-15V DC
4-12 cells of 50mAh - 3000mAh
NiCad or NiMH pack can be charged.

TRITON Charger, Discharger
Handles 1-24 NiCd or NiMH cells, 1-4 Li-Ion cells
or 6,12, and 24V Lead Acid batteries.

For those who like to tinker with electronics and can't afford an expensive and sophisticated charger, there's a cheap alternative based on the National Semiconductor® LM317 low cost regulator.
The circuit diagram below shows a constant current charger using the LM317.



The constant current may be set anywhere between 10mA and 1.5A by choosing the appropriate resistor **R**.

R = 1.25 / I

Where R is the resistor value in ohms, 1.25 is a reference drop voltage in Volts and I is the constant current in Amps.

For example, to charge a 500mAH battery at 0.1C, (50mA) the R value will be:
1.25 / 0.05 = 25ohm.
The dissipated power on the resistor R in this example is:
P = V x I = 1.25 x 0.05 = 0.0625W or 62.5mW.

The dissipated power on the LM317 IC is:
(Vin - Vout) x Charging Current.
It's advisable to use a heatsink to prevent the IC from getting too hot.
Notice that the IC's metal package or tab also carries the Vout, so it's necessary to use isolating washers in case you attach the heatsink to a metal case.

NiCads and NiMHs may be on charge during relatively long time without the risk of overcharging damage when using a constant current equal or less than 0.1C. However, it is not advisable to have the batteries continuously on charge longer than 24h, so one may connect the charger to a timer in order to cut the charging after about 14 -18h.

For those who prefer a more sophisticated D.I.Y. NiCad charger based on delta peak method, as well as other interesting circuits, check here or here

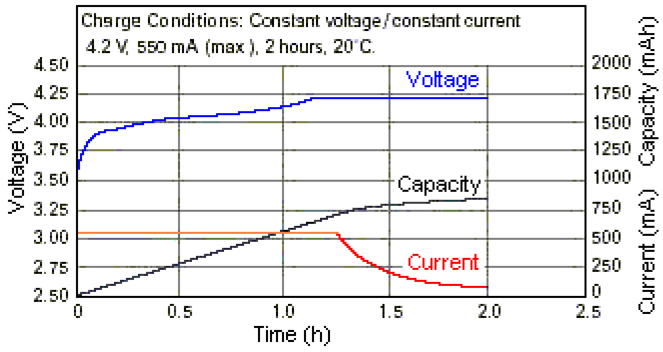
New rechargeable battery types, such as the Li-Ion (liquid electrolyte), the flat Lithium-Polymer (solid polymer electrolyte)
and Lithium-Ion-Polymer (gel electrolyte), are now often used
with slow-flyers, indoors and even with bigger models.
The cell shown on right (Kokam) has 3.7V as nominal voltage,
4.2V max and 3.0V minimum.
Other brands may have different nominal voltages.
For example PowerfLite has 3.6V and Duralite includes a built in charge safety circuitry.
These battery types have much higher energy density than both the NiCads and the NiMHs.

The max charge rate recommended is 1C while the discharge rate should not be higher than 3 - 4C continuous or 5 - 6C during short time.
The self-discharge rate is claimed to be very low, typically 5% per year.
These batteries cannot be charged with the same chargers that are designed for NiCads or NiMH.

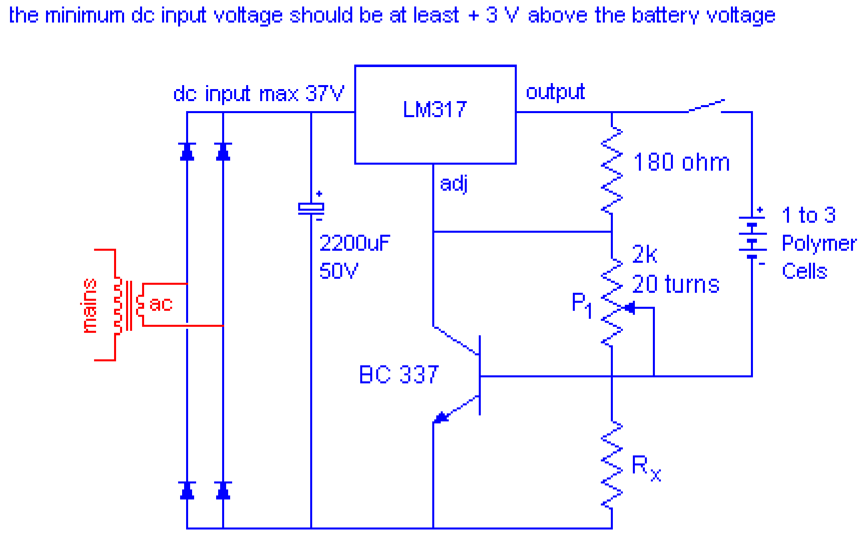
In order to correctly charge the Li-ion/Lithium-polymer batteries, it must be taken into account the number of cells in the actual battery pack, since both the max charging current and voltage have to be set according to the cells' specifications.
Charging these batteries with a wrong charger may cause them to explode.
Also a short circuited pack may easily catch fire.
According to Kokam, the Lithium-polymer batteries should not be discharged below 2.5V per cell, otherwise a rapid deterioration will occur.

The basic charging procedure is by limiting the current (from 0.2 C to max 1C depending on manufacturer) until the battery reaches 4.2 V/cell and keeping this voltage until the charge current has dropped to 10% of the capacity C.
Since the batteries only have 40 to 70% of full capacity when 4.2V/cell is reached, it's necessary to continue charging them until the current drops as described above.
A charge timer should be used to terminate the charge in case the top voltage and/or termination current never reach their values within a certain time, which depends on the initial charging current, (e.g. 2 hours at 1C or 10 hours at 0.2C).
Trickle charging is not good for Lithium batteries, as the chemistry cannot accept an overcharge without causing damage to the cells.

Panasonic's charge curve for their 830mAh cells is shown below:



The circuit diagram below shows a simple Li-ion/Lithium-polymer charger based on National Semiconductor LM317 low cost regulator.



Before connecting the cells to the charger the max charging voltage has to be set by adjusting P1 (2k potentiometer).
The max charging voltage must not exceed 4.2V per cell (Kokam), e.g. 8.4V for two serial connected cells. It is recommended using a digital voltmeter.
The max charging current is set by choosing the value of Rx.
Rx = 0.6 / max charging current

For example, for a max charging current of 600mA, Rx should be 0.6 / 0.6 = 1ohm, while for a max charging current of 1.2A it should be 0.6 / 1.2 = 0.5ohm.
The dissipated power on Rx at a charging current of 1.2A is:
P = V x I = 0.6 x 1.2 = 0.72W

The dissipated power on the LM317 IC is:
(Vin - Vout) x Charging Current.
It's advisable to use a heatsink to prevent the IC from getting too hot.
Notice that the IC's metal package or tab also carries the Vout, so it's necessary to use isolating washers in case you attach the heatsink to a metal case.

The LM317's max output current is 1.5A. For higher charging currents one may use the LM350 rated at 3A or the LM1084 rated at 5A.

Note: if a Li-ion battery gets discharged below 2.9V/cell, it needs to be slow charged at 0.1C until 3.0V/cell is reached before a higher charging current rate may be used.
Also discharging below 2.3V/cell will damage the battery.

According to the manufacturers the Li-ion batteries should be stored charged to about 30 - 50% of capacity at room temperature.
For prolonged storage periods, store discharged (i.e. 2.5 to 3.0V/cell) at -20° to 25° C.

Important!
Make sure to set your charger to the correct voltage according to the number of cells.
Failure to do this may result in battery fire!

Before you charge a new Lithium pack, check the voltage of each cell individually.
This is absolutely critical as an unbalanced pack may explode while charging even if the correct cell count was chosen.
If the voltage difference between cells is greater than 0.1V, charge each cell individually to 4.2V so that they are all equal.
If after discharge, the pack still is unbalanced you have a faulty cell that must be replaced.

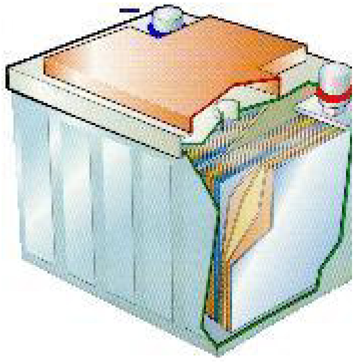
Do not charge at more than 1C.
NEVER charge the batteries unattended.

Caution:
If you crash with Lithium cells there is a risk that they get a latent internal short-circuit.
The cells may still look just fine but, if you crash in any way remove the battery pack carefully from the model and place it on a non-flammable place, as these cells may catch fire later on.
(A box with sand is a cheap fire extinguisher).
Don't use Lithium batteries when flying in areas with large amounts of dry vegetation, as a crash may result in a serious forest fire.

- General Applications Manual for Kokam Lithium Polymer Batteries here
- R/C Applications Manual for Kokam Lithium Polymer Batteries here

A new sort of Lithium (Saphion) cells has now been introduced into the market.
These cells are claimed safe since they don't burst into flames when abused like the traditional Li-Ion-Polymer do.
Their safety aspects result from the incorporation of phosphates as the cathode material, which are stable in overcharge or short circuit conditions and also have the ability to withstand high temperatures without decomposing.
When abuse occurs, phosphates are not prone to thermal runaway and don't burn.

These cells have a nominal voltage of 3.2V, can be discharged down to 2V and charged to 4.2V.
The recommended discharge rate is 5 to 6C continuous for a long life or higher discharge rates for a shorter life.
For further details check out the manufacturer Valence Technology Inc



The lead - acid batteries have much lower energy/weight ratio than all those previously mentioned. Which means that the lead - acid batteries are heavier for the same capacity.

They are not suitable to be used airborne, but since they are rather cheap, they are often used on the flying fields as ground power supply for engine starters and/or to charge the smaller ones.

There are various versions of lead acid batteries:
The Gel-Cell, the Absorbed Glass Mat (AGM) and the Wet Cell.
The Gel-Cell and the AGM batteries cost about twice as much as the Wet Cell. However, they store very well and do not tend to sulfate or degrade as easily as the Wet Cell.
Lead - acid batteries get "sulfated" when the soft lead sulfate normally formed on the positive and negative plates' surfaces re-crystallises into hard lead sulfate when the batteries are left uncharged during long time. This reduces the battery's capacity and ability to be recharged.
Both the Gel-Cell and AGM are the safest lead acid batteries one can use. However, Gel-Cell and some AGM batteries may require a special charging rate.

There are sealed (maintenance free) and serviceable non-sealed Wet Cell batteries. Non-sealed batteries are recommended in hot climates since distilled water can be added through the filler caps when the electrolyte evaporates due to the high environment temperature.

The lead acid batteries have a self -discharge rate of about 1% to 25% a month. They will discharge faster at higher temperature. For example, a battery stored at 35°C (95°F) will self-discharge twice as fast than one stored at 24°C (75°F).

Lead acid batteries left uncharged during long time will become fully discharged and sulfated. The best way to prevent sulfation is by periodically recharging the battery when it drops below 80% of its charge.
It is possible to determine a non-sealed battery's charge status by measuring the concentration of the sulfuric acid of the battery electrolyte ("battery acid") with a hydrometer.

The lead- acid batteries have normally 3 or 6 cells connected in series.
Each cell has a nominal voltage of 2V resulting in a nominal pack voltage of 6V and 12V respectively.
They are usually charged with a constant voltage of 2.4 - 2.5V per cell having the charging current limited to 1/10C. It is not recommended charging these batteries with a charging current exceeding 1/3C.
A lead -acid battery pack is considered fully charged when the charging current falls below 10mA and/or the cell voltage reaches 2.4 - 2.5V.

Should a lead - acid battery be continuously left on charge (when used as power backup); the charging voltage should not exceed 2.25 - 2.30V per cell.
It is also advisable to charge these batteries in a well-ventilated area/room, since

it produces hydrogen-oxygen gases that can be explosive and also the electrolyte contains sulfuric acid that can cause severe burns.
For further details check here.
Lead - acid batteries' life span is about 4 - 6 years depending on the treatment.

Glow Engines

There are two main propulsion systems used by R/C models today:
The internal combustion systems (glow engines) and the electric motors.
Combustion engines' energy source has so far a higher energy/weight ratio than the batteries used to power the electrics.
However, the combustion engines are usually more noisy and more prone to oil spillage than the electric motors.

There are two types of glow engines:
The four-stroke and the two-stroke.

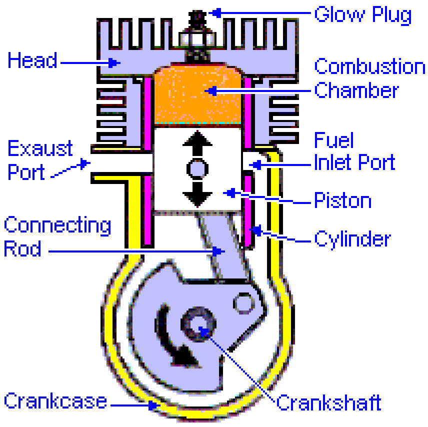
Two-stroke engines are the most used, mainly because they are simple made, light, easy to operate, easy to maintain,
and are usually inexpensive.
Two-stroke engines operate at a high RPM and therefore can be quite noisy without a good silencer.

Nevertheless, the four-stroke engines also enjoy some popularity, mainly because they produce a lower, more scale-like sound and consume less fuel.
They have lower power/weight ratio and
lower RPM, but provide more torque (use larger propellers) than theirs two-stroke counter-parts.

However, since the four-stroke engines require high precision engineering and more parts to manufacture, they are usually more expensive.
They also need more maintenance and adjustment than the two-stroke, yet they are not too difficult to operate and maintain.

A glow engine consists basically of:
- Crankcase: which is the main body of the engine and houses the internal parts.
- Head: mounted on the top of crankcase. It has fins to provide engine cooling.
- Muffler: damps the exhaust noise as it exits the combustion chamber.

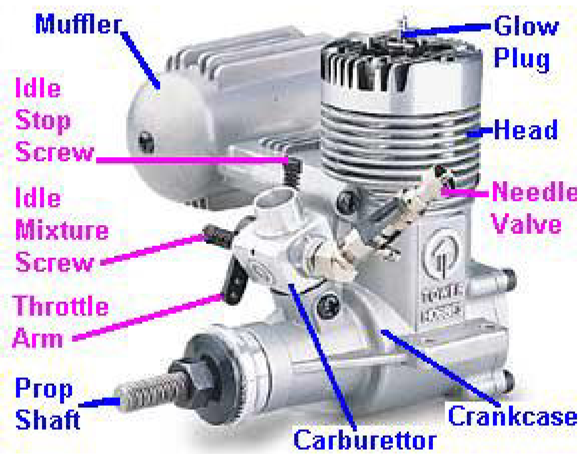
- Carburettor: to control the amount of fuel and air that enters the engine.
- Prop Shaft: is a part of the Crankshaft that protrudes from the crankcase.
- The Crankshaft transforms the movements of the Piston into rotational motion.



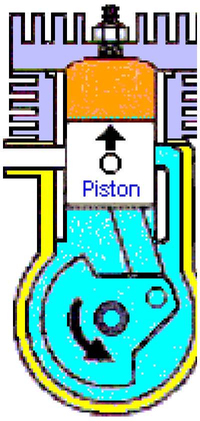
- The Piston has a cylindrical form and operates by an up/down movement (assuming the engine is viewed upright)
inside a sleeve, which is called Cylinder.

The glow motor's Carburettor consists basically of:

- Rotating barrel, which controls the amount of fuel/air mixture going to the combustion chamber.
- Throttle arm connected to the barrel, which enables the engine's speed to be controlled by a servo.
- Idle Stop Screw to adjust how far the throttle barrel closes.
- Idle Mixture Screw to adjust the amount of fuel entering the carburettor while the engine is idling.
- Needle Valve to adjust the amount of fuel entering the carburettor during medium and high-speed operation.



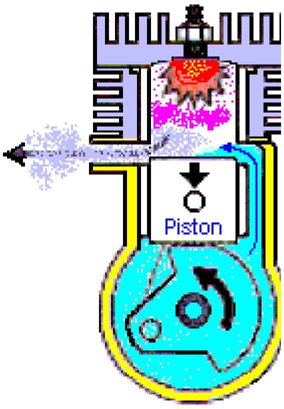
All glow engines require a special fuel, called "glow fuel."
It consists of methanol as base, with some amount of nitromethane to increase the energy and pre-mixed oil into the fuel, which lubricates and protects the engine parts.



Two-stroke engines operate by igniting the fuel in its combustion chamber once every turn of its crankshaft.

The fuel is mixed with air at the carburettor and forced into the cylinder during the down movement of the piston (1st stroke).

While the piston moves up, the mixture is compressed and when the piston reaches the top, the glow plug ignites the compressed gases, forcing the piston down (2nd stroke).



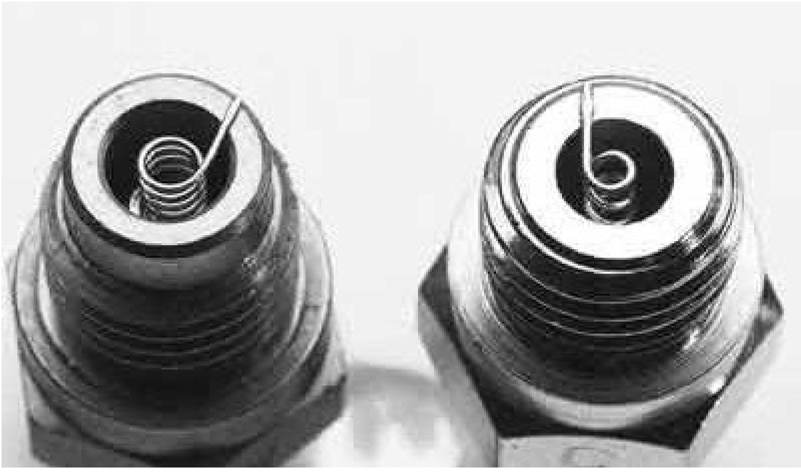
On the way down exhaust gases escape through the exhaust port while the fuel mixture enters the cylinder again.

In a four-stroke engine the fuel/air mixture enters the combustion chamber during the down movement of the piston through a valve operated by the camshaft (1st stroke).
When the piston moves up, the valve closes and the mixture is compressed (2nd stroke).
When the piston reaches the top, the glow plug ignites forcing the piston down (3rd stroke).
On the next up movement of the piston, a second valve opens and allows the exhaust gases to escape (4th stroke).
The piston moves down and the fuel mixture enters the combustion chamber again, repeating the 1st stroke.

The glow engines usually have a simple ignition system based on a glow plug made up of a little coil of platinum wire rather than a spark plug.
A 1.5V battery is used to heat the glow plug only during the starting procedure and is removed when the motor reaches a certain rpm. This is possible because the glow plug keeps glowing by the heat produced during the compression and combustion without needing the battery.
There are two lengths of glow plugs available.
The short ones are normally used on engines smaller than 2.5cc (.15cu in).

Some have a metal bar across the bottom of the plug called for Idle Bar, which prevents raw fuel from dousing the heat from the element during idle.

There are also the so-called "hot" and "cold" glow plugs, which refer to their effective coil operating temperature.
The glow plug's temperature depends on several factors, such as the coil's alloy, thickness and length, the size of the hole in which the coil is located as well as which material the glow plug's body is made of.



Usually smaller engines and those that run on less nitro prefer hotter plugs.
In case of doubt just follow the engine manufacturer's recommendation.

Turbo glow plugs have a chamfered end that matches the threaded hole on the engine's head.
It is claimed to give less compression leakage around the glow plug and less disruption of the combustion chamber.
Also the hole in the cylinder head, which exposes the glow plug to the air/fuel mixture in the cylinder is much smaller, resulting in fewer rough edges that could create unwanted hot spots.
The turbo plug is shown on the left of the picture below.

Glow engines may have plain bushed supported crankshaft or ball bearings.
Ball bearing engines usually have a better performance, run smoother, and last longer but are more expensive than those with bushings.

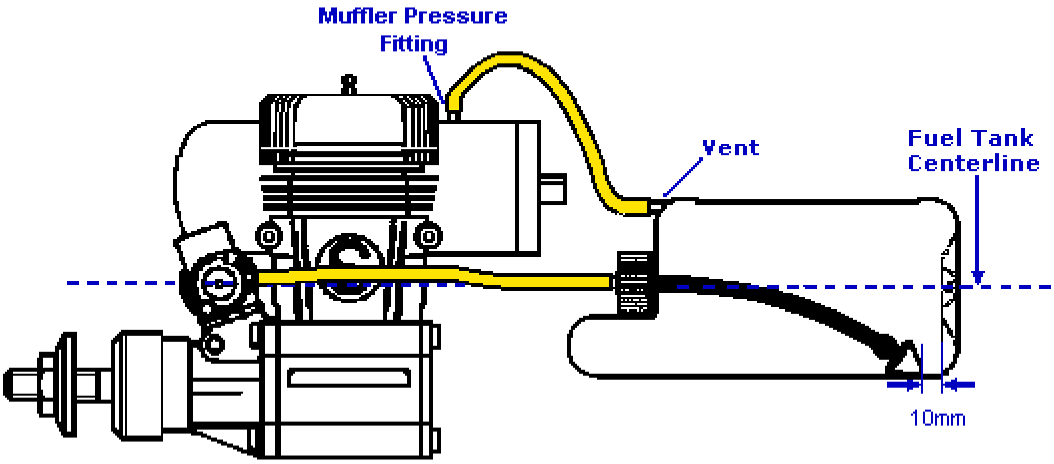
The model engines' piston and cylinders construction are usually based in

two methods: Ringed engines or ABC.
Ringed engines have been the main method of construction until recently.
It consists of an aluminium or iron piston with a ring moving in an iron sleeve.
The ring provides the compression when operating.
Ringed engines are inexpensive to restore its compression after long usage by simply replacing a ring, and are generally slightly cheaper.
They require an extended break-in period where the motor is run very rich to provide lots of lubrication while the ring fits itself to the cylinder. They are also more easily damaged if the engine is run too lean.

A more recent method is the ABC, which stands for Aluminium, Brass, Chrome where an aluminium piston runs in a chrome plated brass sleeve.
The piston and cylinder are matched at the factory to give a perfect fit and good compression.
ABC engines start easily by hand, give more power than the ringed engines, have a good life-span and are less prone to damage with a lean run.

Schnuerle ported engines have several fuel inlet ports on three sides of the cylinder allowing more fuel to flow to the combustion chamber.
This gives somewhat more power than with standard porting, which has only one fuel inlet port on the side of the cylinder opposite the exhaust outlet.
A Schnuerle ported engine is usually slightly more expensive due to higher manufacturing costs involved.

The fuel tank size and location affects the engine operation during the flight.
A typical tank placement is shown on the picture below:



When the engine is in the upright position, the fuel tank's centreline should be at the same level as the needle valve or no lower than 1cm, (3/8in) to insure proper fuel flow.
A too large fuel tank may cause the motor to run "lean" during a steep climb and "rich" during a steep dive.
Normal tank size for engines between 3.5cc (.21) and 6.5cc (.40) is 150 - 250cc.

Ducted Fans

In order to emulate the full-size aircraft jet-power systems, it is often used the so-called Ducted Fan, there a glow-engine drives a fan fitted inside the model.

There are also glow engines specially designed for Ducted Fans, which have a special shaped head, also having the exhaust port facing towards the rear of the model.

These engines are often equipped with a tuned pipe exhaust in order to improve their efficiency at high rpm.

Since a special method to start is often required due to the reduced access to the engine, this arrangement is not recommended for beginners.

For further info and tips on how to extend the life of your engine check here

Extend Engine Life

Helpful tips to keep your powerplant

1

by the staff of Model Airplane News

2

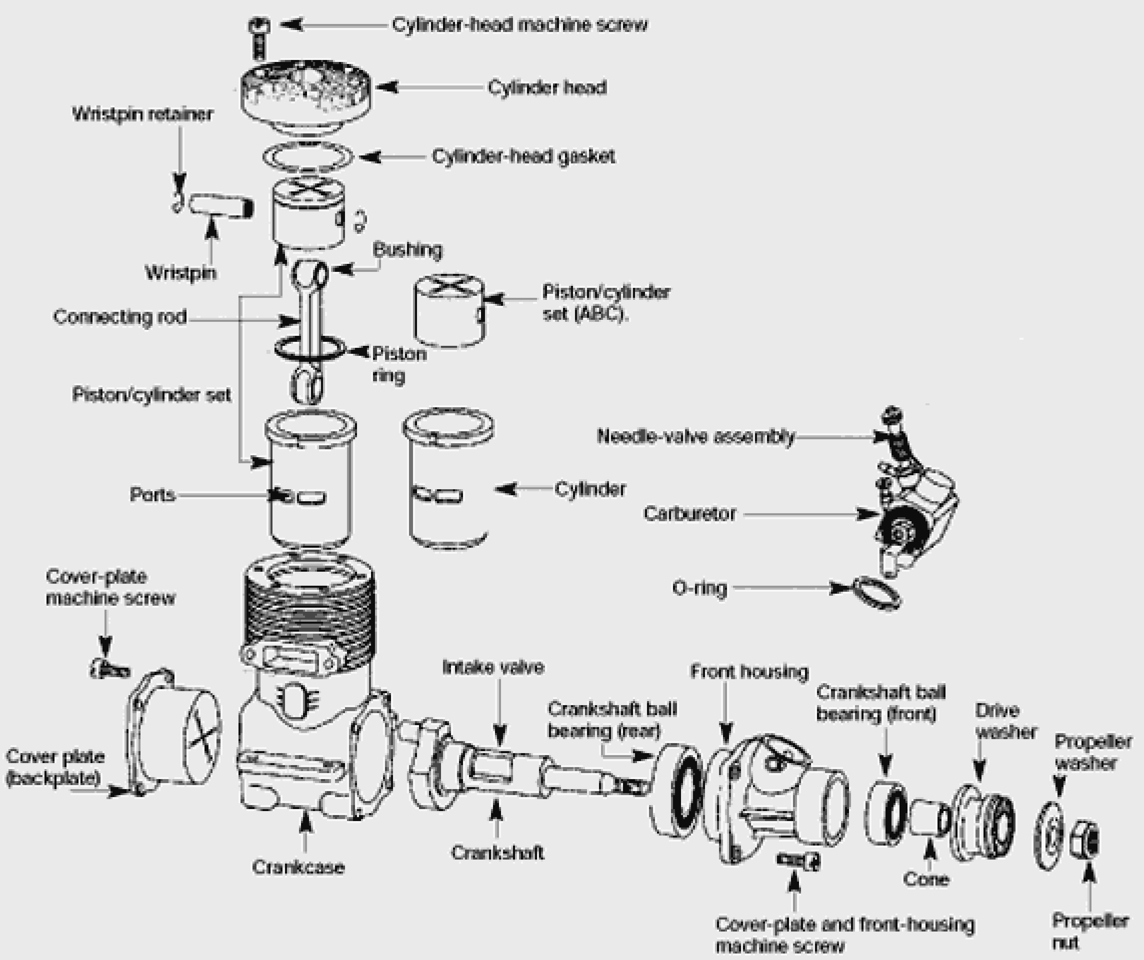
The fun we have flying our glow-powered models is directly proportional to how well our engines run. Proper care of and knowledge about how they run are the keys to engine performance success.

Today’s 2-stroke glow engines are technological marvels; they’re powerful, lightweight, easy to use and, with proper use and care, will last for many years. Next to the radio system, the engine is one of the most expensive investments we make in RC. Over the years, we’ve learned a lot about the care and feeding of engines, and we know there aren’t any secrets to operating a model airplane engine correctly. From adjusting the fuel mixture and choosing the best glow plug to proper maintenance and using common sense to improve reliability, this article is full of helpful hints and information to help you have a happy relationship with your 2-stroke glow engine.

Easy Starting

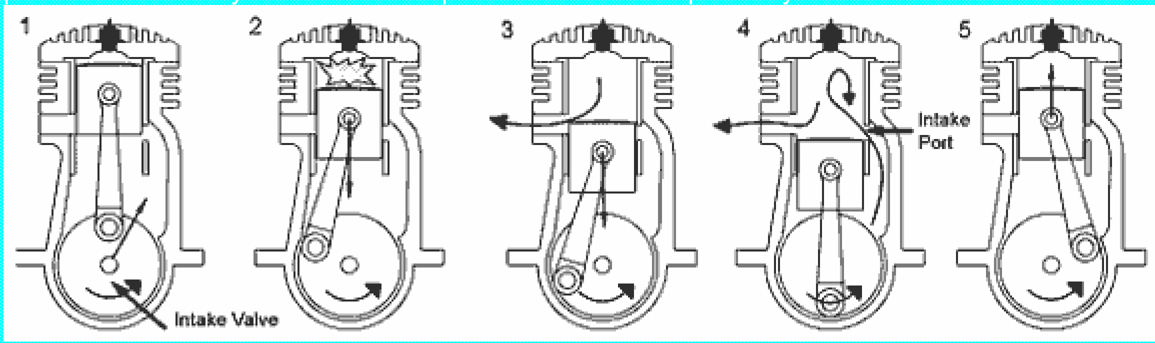
Nothing is more frustrating than owning an engine that’s difficult to start. Our frustration often leads to a flight that ends with a dead-stick landing or a crash. When you start any engine, there are three things to remember. For combustion to occur, your engine needs air, fuel and fire (heat). If your engine won’t start, check the carb to make sure that air and fuel are available, and check your glow plug to ensure that it provides enough heat to ignite the air/fuel mixture. Remove the glow plug and attach the glow driver; its element should glow brightly. If it doesn’t, replace it; if it does, reinstall it. Close the needle valve and then open it three full turns. Place your thumb over the carb, and flip the prop several times until fuel is drawn through the fuel line and into the carb. If you remove any one of these three elements from the equation, your engine will not start.

Exploded view: engine parts description.



TWO-STROKE ENGINE OPERATION

A 2-stroke engine is relatively simple in operation. The crankshaft makes one complete revolution for every power cycle. During the piston's upstroke, the fuel/air mixture above the piston is compressed for combustion. At the same time, a fresh mixture is drawn into the crankcase below the piston. After combustion, the piston is forced downward, and the spent fuel charge is expelled through the exhaust port. At the same time, a fresh fuel/air mixture is drawn through the carb and into the crankcase. The intake valve is sealed, and the mixture is forced through the transfer ports and into the cylinder above the piston to start a new power cycle.



1. As the piston reaches top dead center (TDC), a fresh air/fuel mixture charge is drawn into the crankcase because of the
low pressure created as the piston travels upward.
2. The piston then compresses the mixture in the combustion chamber, and it is heated and ignited by the glow plug; this forces the piston down.
3. As the piston comes down, it opens the exhaust port, and the spent fuel begins to exit the combustion chamber. At the same time, the piston compresses the new fuel/air mixture in the crankcase.
4. At bottom dead center (BDC), the piston opens the bypass port, and the new air/fuel mixture charge flows from the crankcase into the combustion chamber as the last of the spent charge leaves.
5. The piston comes back up and seals the exhaust and bypass ports, and the entire process

Secure fuel lines

Proper fuel-line installation is very important. If your fuel line is too big, it may leak air or even slip off in flight. Fuel lines come in several sizes, so use the size that best fits the carburetor's fuel fittings. Air bubbles in the fuel line may cause the engine to run lean, and if the line slips off, the engine will die. Be sure that there is adequate slack in the line, and secure it to the fuel fitting with a wire clip or a small length of fuel line slipped over the end of the main line.

Make sure the carburetor is securely fastened to the engine. There is an O-ring at its base and if this is damaged, air may leak into the crankcase and cause the engine to run lean.

Tight Seals

If your engine begins to run erratically, and the mixture leans out even after you've adjusted the needle valve, you may have an air leak in the carb. Make sure that the carb is firmly and properly attached to the crankcase. If the intake is sealed with an O-ring, check it for cracks or breaks and make sure that it's seated properly, lies flat and isn't distorted when the carb-attachment screw is tightened. Make sure that all the adjustment screws and the needle-valve assembly are properly sealed and work correctly.

Last, check that the fuel-intake fitting is tightly screwed into place and that it isn't damaged or cracked. The fuel tank and fuel lines must be properly and securely installed. If you have previously nosed the model over or made a hard landing, the fuel pick-up clunk may have shifted forward in the tank; this can pinch off the fuel supply. The clunk and pick-up line should move freely, and you should be able to hear the clunk rattle in the tank.

Fuel Flow

If your engine always runs rich or floods easily, check the position of the fuel tank. The tank should be installed in the fuselage so its centerline is at or slightly below the carburetor's spray bar. Use scraps of foam to position it securely so it can't move around in the tank compartment. If the tank is too high in the fuselage, fuel will tend to be siphoned out and run freely into the carb. Conversely, if the tank is too low or too far away from the carb, the engine may have difficulty drawing fuel into the carb, and it will run lean. To improve fuel draw, attach a line from the pressure fitting on your muffler to the tank's vent line. If you use a third filler line with your tank close it off to allow the muffler pressure to enhance fuel draw.

Left: always make engine adjustments from behind the prop.

Right: fuel lines come in several sizes and materials. It's important to match the line to your engine and fuel. Right: make sure the fuel line fits the fuel fittings tightly. Clamp the line, or slip a short length of tubing over the end of the main line to

Idle reliability

An engine that idles poorly can be frustrating. The last thing you want is for your engine to quit during a landing. Proper fuel mixture, too much fuel line between the tank and the engine and the type of fuel and glow plug you use can all affect an engine's ability to idle reliably. The most common problem is a too-rich mixture. Adjust the high-speed needle for a slightly rich mixture and then adjust the idle. Start the engine and adjust the throttle for an idle of 2,100 to 3,000rpm. After several seconds, advance the throttle to full open. If the engine sputters and spits raw fuel out of the carb, the idle mixture is too rich. Stop the engine, and turn the idle adjustment clockwise (in) about 1/4 turn to lean the mixture. Repeat this procedure until the engine transitions smoothly from low to high speed. If you have an air-bleed carburetor with a small hole at the front of the carb body and an adjustment screw control idle, turn the idle screw in to richen the mixture.

A reliable idle is very important, especially during landings. A carburetor can have either a low-end needle-valve adjustment (left) or an air-bleed hole in the front of the carb housing (right). Adjust the high-end needle valve before you adjust the idle.

A tachometer is a very important accessory to ensure proper engine operation. Use one whenever you adjust the engine's air/fuel mixture to check the change in rpm.

WHY USE A TACHOMETER

A tachometer (tach) is one flightline accessory that I can't do without! I started using one to adjust my engine's needle valve a few years ago, and now I find that using one ensures that my engines run consistently. A tach shows minute changes in engine rpm that you cannot detect by ear. Having the engine set a couple of hundred revs below maximum rpm is ideal. Using a tach to count the prop revs is also much safer than pinching the fuel line to check the mixture setting. Note that the engine should be well broken in; a tight, new engine will rarely hold a good needle-valve setting.

Here are some tips to help you properly adjust your engine.
• Set the high-speed (main) needle valve to the recommended factory setting, and start the engine. The engine should run somewhat rich.
• While using the tach, gradually lean the mixture (turn the needle-valve adjustment screw in, or clockwise) until there is no longer an increase in rpm. Adjust the mixture slowly, and allow the engine speed to stabilize.
• Once you've achieved peak rpm, richen the mixture slightly (again, using the tach) to reduce the rpm by 200 to 300.

Once you've set the high end, check the idle setting. After you have properly adjusted the engine, avoid the temptation to tweak the needle valve whenever you restart your engine. If atmospheric conditions (humidity, air temperature, etc.) change, however, then a click or two of the needle valve may be necessary. Again, use the tach to check rpm while making these adjustments. — *Rick Bell*

Happy glow plugs

The glow plug is a critical part of the engine's overall performance; you can choose from several types, but always refer to your engine's instructions for the recommended plug. Glow plugs come with long and short thread parts, with or without an idle bar and are rated for hot or cold operating temperatures, but they don't last forever. The first sign that a plug is on its way out is a drop in rpm when you remove the glow-plug driver; also, when an engine that normally idles well suddenly doesn't run well at low rpm, you have a problem. If you use a plug that is too hot for your engine, the engine may suffer from detonation and pre-ignition and might overheat and run lean. Using a plug that is too cold will result in lower top-end rpm and poor idling. Small engines (.15 and smaller) should use short-reach plugs; a plug that's too long may hit the top of the piston and damage the engine.


Left: glow plugs come in several sizes and types; here, you see (left to right) a short-reach plug, a standard (or long-reach plug) and a standard plug with an idle bar. Use the type of plug recommended by your engine's manufacturer.

Right: make sure that your glow plug is in good shape before you use it. It should glow brightly when energized by the glow driver.

Staying cool

A cool engine is a happy engine. One of the worst things you can do to an engine is to run it lean. This increases its temperature and can drastically shorten its life. Always use a tachometer to adjust peak rpm and then richen the mixture slightly for a 200 to 300rpm drop from the peak reading. If your engine is inside a cowl (such as in a scale model), make sure you provide adequate ventilation. Ideally, the air-exit area should be at least twice the size of the air-entry area. Don’t block the air outlet with the engine’s muffler, or you’ll greatly increase the engine’s operating temperature.

A GOOD MIX

When you hear someone talking about adjusting an engine, you’ll often hear them refer to “the mixture.” This is the mixture of air and fuel that is combined in the carburetor. Fuel and air enter the venturi, become atomized and enter the engine through the intake port. The atomized mixture then enters the crankcase and is transferred to the combustion chamber through the bypass ports. The needle-valve assembly brings the air and fuel together and controls the ratio between the two. If there is more air in the mixture than the engine needs, the mixture is “lean.” If the mixture has more fuel than is required, it is “rich.”

Of the two, a too-rich mixture is preferred, as little (if any) damage will result from running your engine on the rich side. Running your engine too lean, however, will overheat it and, if you do it

Proper Compression

Compression is important to a glow engine. As well as affecting the density of the fuel mixture, compression is also necessary for the glow plug to fire. If your engine becomes difficult (or impossible) to start, compression may be low. To fix this, check the glow-plug and engine-head bolts to make sure they are tightly fastened. You should also check the backplate attachment bolts. If the cylinder-head bolts are loose, air can leak into the combustion chamber, and this will affect performance. If you have been running your engine too lean, the piston and sleeve fit can be worn out, and this will prevent your having a tight seal. If this is the case, you’ll have to replace the worn components.

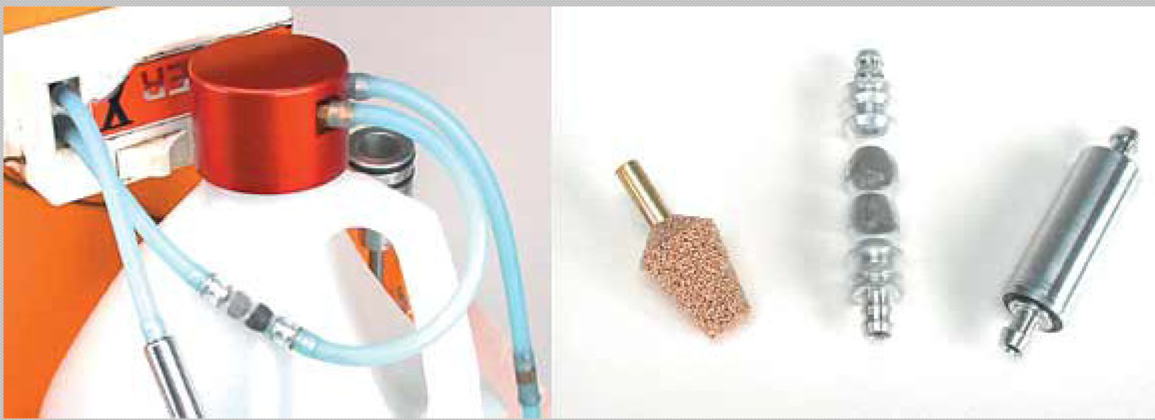
Keep your engine clean

If you fly off grass, there’s always a chance that your airplane will nose over or overshoot the runway on landing. The odds are pretty good that debris will get onto and inside your engine. Always clean your engine after a mishap, and never turn the prop shaft until you’re sure the engine’s inside is clean. If they aren’t removed, dirt and grit can impede engine cooling; even worse, ingested debris can ruin the interior of the engine. Clean the engine by plugging the muffler’s outlet and the carburetor’s venturi with small wads of paper towel. Stand the plane on its nose, and spray a mixture of dishwashing liquid and water onto the engine. Scrub the engine with a toothbrush, and use a toothpick to remove debris from between the cooling fins. Wipe the engine clean and let dry.

FUEL FILTERS

There has always been debate about whether or not to use a fuel filter between the model's tank and the engine's needle valve. For years, I've run my engines without an in-line filter, and I have never had a problem with fuel blockage. This is because I filter the fuel three times before it gets to the tank.

First, I use a sintered-bronze filter as the pick-up clunk in my main fuel jug. It prevents any large particles from leaving the jug.



Filtering your fuel greatly decreases the chances of having contaminants clogging a fuel line or getting into your engine.

After the fuel exits the fuel pump, it passes through a Sullivan Crap Trap, which removes any fine particles the first filter may have missed. The Sullivan filter has a transparent body and a fine mesh screen at both ends; you can see whether there is anything in the fuel.

The last filter I use is a Du-Bro Final Filter. It has two micromesh screens to remove the tiniest particles from the fuel. I use this filter between the fuel-pump line to the model's filler line. The filters are progressively finer, and this keeps out any contaminants that might be in the fuel.
To minimize the chances of your fuel becoming contaminated, change the pick-up lines in your jug twice a year. The nitromethane in the fuel can degrade the lines, and they are inexpensive to replace.

Engine corrosion

Corrosion is the main enemy of our engines. It forms on the bearings and other ferrous components. The alcohol contained in glow fuel is hygroscopic (it attracts moisture). To prevent corrosion, at the end of the flying day, always run your engine until it is dry of fuel and use after-run oil. When you've finished flying for the day, empty the fuel tank, start the engine and let it run until it quits. This will ensure that there isn't any fuel residue left in the engine. Squirt after-run oil into the carburetor and the glow-plug opening, and turn the prop manually several times to fully coat the inside of the engine with the protective oil. Before storing an engine for an extended period, remove it from your model, oil it well, wrap it in a cloth and place it in a sealable plastic bag for safekeeping.

SYMPTOM	CAUSE	CURE
Engine doesn't start	Low voltage on glow-driver	Replace/recharge battery
	Bad glow plug	Replace glow plug
	Insufficient fuel prime	Repeat priming procedure

	Flooded owing to excessive	Remove plug, and rotate prop to clear
	Pressure lines and fuel	Remove fuel lines and reinstall them
	Needle valve not set	Set adjustment needles to factory
Engine starts and then		
	Idle set too low	Reset idle for higher rpm
	Low-speed needle is set	Lean out low-speed mixture
	Low-speed needle is set	Richen low-speed mixture
	Glow plug is loose	Tighten glow plug
	Glow plug is bad	Replace glow plug
	Mixture is too rich	Lean out main needle valve 1⁄42 turn
Engine bogs when full		
	Low-speed needle is set	Lean out low-speed mixture
	Low-speed needle is set	Richen low-speed mixture
	Glow plug is too cold	Install hotter glow plug
	Mixture is too rich	Lean out main needle valve
	Mixture is too lean	Richen main needle valve
Engine idles erratically	Air leak (hole) in pressure	Replace lines
	Low-speed needle set too	Richen low-speed mixture
	Bad glow plug	Replace glow plug
Engine doesn't reach full		
	Mixture is too rich	Lean out main needle valve
	Mixture is too lean	Richen main needle valve

How much fun we have when we fly our models is directly proportional to how well our engines behave. Taking proper care of them is the best way to keep them happy. It's time well spent and an investment that keeps paying us back.

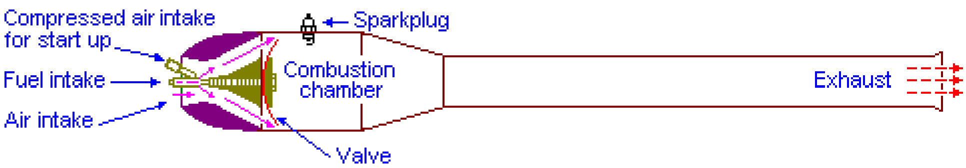
Pulsejet Engines

Aircraft model builders have always strived to emulate the full-sized aircraft, as well as their propulsion systems.
The word "pulse" engine may be tracked back to around 1880 - 1890 and it is claimed that a Frenchman has build a pulsejet engine in the beginning of 1900 however, it's unknown whether he was successful.

The Germans used this type of engine
during the W.W.II to power the well-
known
V-1 flying bomb.
This power concept was eventually
proven
to be relatively inefficient, terribly noisy
and
also having a very short lifetime.

The valves on the V-1 engine lasted no longer than 30 minutes continuous use. The pulsejet was therefore abandoned as a full-size aircraft propulsion system. Nevertheless, it has been used on model aircraft by some enthusiasts until now.

A model pulsjet engine is basically made of a tube consisting of a head with a venturi shaped air-intake, a diffuser, a combustion chamber, reed valve plates, a spark plug and an exhaust.



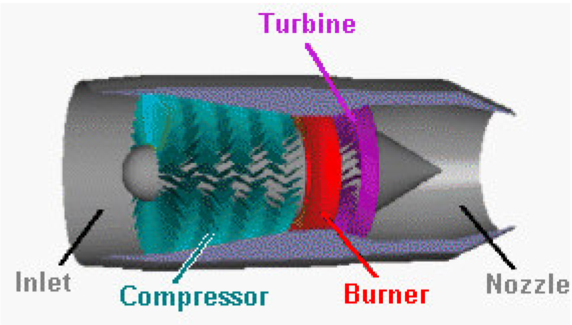
In order to start the engine, a compressed air from an external pump or air bottle is fed to the angled pipe located near the diffuser while a pulsed high voltage supply is applied to the sparkplug.
The air/fuel mixture is pushed through the valve into the combustion chamber and ignited, which causes a noisy explosion that closes the valve plates while the expanding gasses escape trough the exhaust.
This produces a low pressure inside the combustion chamber that opens the valves and new air/fuel mixture enters the chamber again, which is ignited by the residual heat and gasses from the previous explosion.
The high temperature developed keeps the motor running without the spark plug and the compressed air, which are only needed at the start moment.
Some types have no sparkplug attached. The initial ignition is then obtained by introducing external sparking wires through the exhaust.
The pipe has an acoustic resonant frequency depending on its length, which must be close to the valves' working frequency in order to get a reliable operation.

The extreme heat developed means that this
engine needs a lot of air cooling and cannot stand static running on a test-bench for longer
period than about 10 seconds.
It must also be mounted outside the model to
prevent burning damage to the structure.

Due to the extreme noise and the high temperature involved, this engine is absolutely not recommended for beginners and should not be used near residential areas.

Gas Turbines

Another well-known propulsion system is the gas turbine or jet engine.
There are several types of gas turbine engines, but the simplest ones are the so-called turbojets.



These engines are shaped like a
cylinder containing several parts inside, which rotates on a central
shaft.
An auxiliary electric motor is needed to start the turbine engines.

The outside air enters the engine through the inlet into the compressor, which consists of one set of fixed blades (stator) and another of rotating blades (rotor).
The air is then compressed at the compressor section and enters thereafter the burner where the fuel/air mixture is ignited.
This creates a hot gas passing through the turbine and out the nozzle, which is shaped to accelerate the hot exhaust.
The turbine uses the energy from the hot exhaust to rotate and since the turbine is linked to the compressor by the central shaft, it will also keep the compressor rotating, thus no longer needing the electric motor.

Normally the model aircraft turbines
use propane/butane gas along with
a glow plug to start the ignition and
rise the burner's temperature above
100°C before liquid fuel is injected
through small holes into the burner.
Once the combustion gets started,
the glow plug is no longer needed.

The combustion process may be controlled or stopped by regulating the amount of the fuel available, the amount of oxygen available or the source of heat.

Unlike the conventional combustion/piston engines, the jet engines don't have a natural limitation of the rpm.
This means that the rpm will keep rising as more fuel is fed to the engine until the materials no longer withstand the high temperature and/or the high rpm and will breakdown.
Therefore, an Electronic Control Unit (**ECU**) is required to limit the max fuel flow.
The max value is set by using an external device called Ground Support Unit (**GSU**).

Since model aircraft powered by gas turbines flies very fast, with speeds up to 500Km/h (312mph), these type of engines are definitely not recommended for the beginners.
Besides, operating gas turbines also involves some risks.
So, it's highly recommended to read the BMFA operational guide before using these engines.

Electric Motors

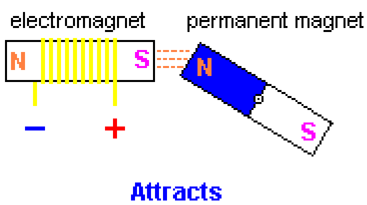
Electric powered model aircraft has gained popularity, mainly because the electric motors are more quiet, clean and often easier to start and operate than the combustion motors.

They need batteries to operate and
despite some developments in this
area; the batteries still are
somewhat
heavier as energy source
compared
with the gas fuel.

Thus, the electric flier has to strive
to
build the model as light as possible
in order to obtain a reasonable
wing
loading and/or a reasonable flight
time.

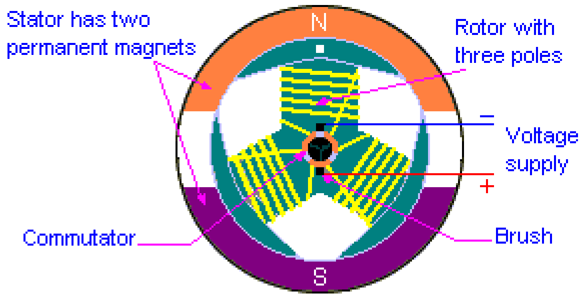
The electric motor's operation is based on the electromagnetic principle.
When electric current flows through a coil it creates a magnetic field with a
strength proportional to the current's value, the number of windings of the coil
and is inversely proportional to the coil's length.
The strength of the magnetic field will further increase by introducing a so-called
ferromagnetic material inside the coil.

An electromagnetic device only gets magnetic when electric current is applied,
whereas a permanent magnet doesn't need electric power to be magnetic.



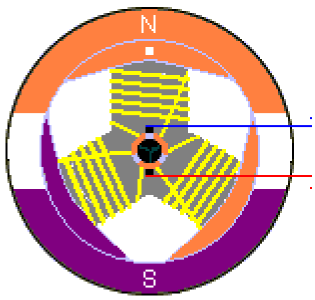
Both electromagnets and permanent
magnets
have the so-called poles at either end.
One is called N (north) and the other S
(south).
When two magnets get close together the
N
and the S poles attract, whereas the same
poles (N N or S S) will repel each other.
The electric motor functions according to
the
same principle.

There are two main different motor types used in model aircraft:
The **brushed** and the **brushless**.



A brushed motor consists mainly of
a cylindrical metal case containing
a stator and a rotor.
The rotor is part of the motor shaft,
which rotates inside the stator.
The rotor has several coils (poles)
that may either have an iron core or
are coreless.
The stator consists usually of two
permanent magnets mounted close
to the metal case.

The rotor coils receive electric current via a so-called
commutator, which is connected to a DC voltage
through two brushes (hence the name).
The commutator changes the voltage polarity to the
coils at a certain instant once every turn of the motor
shaft, thereby keeping the motor running.
The motor shaft is supported by two bearings, which
may be of plastic, porous brass bushes or ball
bearings (more expensive).



The coreless motor has the rotor coils not wrapped around an iron core but just fastened into shape with glue, which makes the rotor much lighter and faster to accelerate and thus suitable for servos.
Since the coreless don't have iron core they have much less iron losses, which make them more efficient than cored motors.
However, the coreless motors will not stand continuous high r.p.m. and/or loads without falling apart.
That's why they are generally rather small, with low speed and low power.
As flight power motors the corless are only used with small indoor planes.

A DC motor converts the electric current into torque and the voltage into rotations per minute (**rpm**).
The power consumption of a DC motor is equal to its terminal voltage times the current.
However, every motor has losses, which means that the motor consumes more

power than it delivers at its shaft.

The motor's efficiency (η) is the ratio of the output to the input power:

η = **P**out/**P**in

Every motor type has an ideal voltage, current and rpm at which the motor's max efficiency is obtained.
These values are often shown in the manufacturer's data sheets.
Brushed motors efficiency is normally between 30 and 80% depending on the type and price.

Most motors supplied in kits for beginners have the stator made of low cost ferrite magnetic material. They are called ferrite or "can" motors.

"Can" motors are rather inefficient and cannot be opened and serviced like other higher quality motors. However they are cheap and most kits will fly just fine with these motors, so it's ok to use a "can" motor for your first plane.

"Rare hearth" motors such as Cobalt and Neodymium are considered to be far superior to ferrite motors, but they are also much more expensive.

Unlike ferrite magnets, the "rare earth" magnets withstand high temperatures without losing their magnetic properties.

Electric motors have several designations such as 280, 300, 400, 480 and 600, which refer to the case length and also give an idea of their power and weight. For example a 480 motor has about 48mm case length, is heavier and is able to deliver more power than a 280 motor.

Generally a 280 motor is suitable to power models up to 400gr and a 480 motor may be suitable to models up to 800gr, while a 600 motor may power models up to 1200gr, assuming direct drive (without gearbox reduction).

As a rule of thumb the input power for a sports plane should be about 110 W/kg (50 W/lb) in order to get good sport flying characteristics.
Gliders and parkflyers may use less power, 65 W/kg (30 W/lb), while pylon racers and aerobatics may need much more power, e.g. > 200 W/kg (90 W/lb).
This assuming that the motor used has about 75% efficiency.

However, the power to weight ratio recommended above is by itself not enough to determine the plane's performance in flight, as other factors have to be taken into account, such as the pitch speed of the propeller, which refers to propeller's rpm times the pitch. Note that the static rpm is lower than when the model is flying.
The minimum pitch speed recommended is 2 to 3 times the plane's stall speed.
The stall speed of an aircraft (both model and full-scale) is approximately equal to four times the square root of the wing loading.
To calculate the aircraft's approximate stall speed click here
To calculate the aircraft's approximate level flight speed click here

Another factor is the Static Thrust, which refers to how much the aircraft is pulled or pushed forward by the power system when the aircraft is stationary.
The Static Thrust should be at least about 1/3 of the aircraft's weight.
However, in order to be able to hover with 3-D models, their Static Thrust should be equal or greater than their weights.
To estimate the prop's approximate Static Thrust click here
Note that the Static Thrust alone is not enough to predict how the aircraft will fly, as other factors like the prop pitch speed should also be considered.

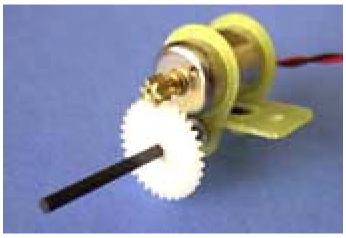
Measuring and comparing the propellers' Static Thrust may be misleading, as the blades of a given prop may stall, resulting in a low static thrust on the test bench, while it may give excellent performance in flight and even outperform others that have a better Static Thrust.

Output Power = thrust × forward speed

So, with a given power, the more thrust you have, the less top speed you get.
In other words, assuming the same rpm:
Larger diameter & less pitch = more thrust, less top speed (like low gear on a car).
Smaller diameter & more pitch = less thrust, more speed (like high gear on a car).

The prop diameter-to-pitch ratio for sport models should be between 2:1 and 1:1
In case the pitch is too high, the prop becomes inefficient at low forward speed and high rpm, as when during the take-off and/or climbing.
At the other end of the scale, a propeller designed for greatest efficiency at take-off and climbing will accelerate the model very quickly from standstill but will lose efficiency rapidly as the forward speed increases.
To estimate the results of a given Motor & Prop combination click here

Gearboxes are often used to reduce the motor's rpm at the propeller shaft, increasing their torque and allowing the use of larger propellers. Since the propeller blades also are more efficient at moderate rpm, this combination is often worth-while despite the increased weight.



Indoors and slow flier models have often a gearbox which allows the use of relatively smaller and lighter motors improving the slow flight performance and prolonging the flight time.
The drawback is that the top speed is reduced.

High-speed models such as those powered by Electric Ducted Fans, (EDF) require motors that have their max efficiency at high rpm (typ. above 22.000 rpm).

The flight time of an electric powered model depends on some variables like: Aircraft's flight characteristics (based on wing loading and lift), the combination motor/propeller, the motor's efficiency (**P**out/**P**in) and last but not the least, the batteries energy/weight ratio.

Flight time in minutes = (battery capacity / average current drawn) x 60.

Electric flight models may be built small and lightweight enough to fly inside a sports hall.
They are the so-called Indoor Models, having approx. 75cm wingspan (30") with a weight less than 200gr (7oz) and flying no faster than 8-16Km/h (5-10mph).

The so-called Park Fliers are somewhat faster. They are often made of foam material and may fly at speeds anywhere from 25Km/h up to about 40Km/h (16 to 25mph). They are rather sensitive to strong winds, so it's recommended to fly them during calm weather. For further pictures and info about Indoors/Park Fliers check: [Aeronutz]

A-10 thunderbolt Twin Electric Ducted Fan, Wingspan: 969mm (38"), Weight: 400g (14oz), Wingloading: 29g/dm2, Batt: 8.4V 500mAh

Piper Cub Wingspan: 1160mm (45.6"), Weight: 550g (19.3oz) Wingloading: 20g/dm2, 3 ch, Motor size: 400

Of course, it's also quite possible to build much bigger electric powered aircraft models.

To see some beautiful examples just check [here] and/or [here.]

As the motor rpm increases it requires the rotor coils to be energised sooner so that they get the full magnetic field strength in time to react with the stator's magnetic field.
Also when the load increases, the magnetic field in the rotor coils increases, which interacts with the stator's magnetic field, producing a rotated resultant magnetic field.
Some motors allow the brushes' angle to be changed by the same amount as the field rotation, thereby increasing the motor's efficiency under a given load. That's called for motor "timing".

An electric motor may be timed under load by slowly changing the brush holder's angle while measuring the current.
The ideal brush angle is when the motor draws less current.
There is no fixed ideal timing angle, since the best timing angle changes as the motor load and speed changes.
If the motor has been timed at clockwise rotation it has to be re-timed in case the rotation needs to be reversed.
The motor's direction of rotation may be reversed by inverting the voltage polarity

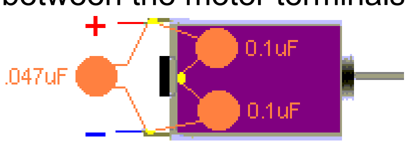
at the supply terminals.
A timed motor gets higher idle current (with no load).

Brushed motors need some maintenance, since both the brushes and the comm. will wear after a while due to the friction.
Most quality motors allow brush replacement.
The commutator itself also needs cleaning as it gathers deposits of carbon and gunk due to the graphite powder from the brushes.
It may be cleaned by a very light polishing action with scotchbrite or with a so-called commutator stick.
The gunk can also be cleaned off while the motor is running manually, using a few drops of alcohol.
If commutator is pitted or shows brush skipping and chattering means that it has been overheated and got deformed (out of round). It needs to be repaired, as polishing will not cure the deformation.

Brushes are usually made of three different compounds:
Graphite, Copper and Silver.
Brushes made of silver are normally used in competitive racing as they have low resistance, but they produce the highest commutator wear and also have medium brush wear and lubrication. Silver brushes produce sludge that only can be removed by lathing the commutator.
Copper brushes don't produce sludge and work best at high rpm. These brushes produce medium commutator wear and have high brush wear and low lubrication.
Graphite brushes produce low commutator wear, have low brush wear and high lubrication but have high resistance, which means that they are not suitable for racing.

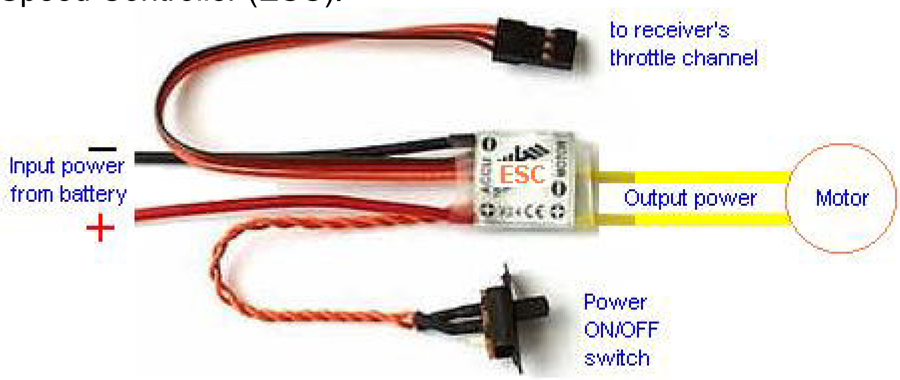
Usually it's necessary to "break-in" a new brushed motor so that the flat brushes get a curved surface and thus increasing the contact area with the commutator.
Running a motor with new flat brushes at full load will cause a lot of arcing, which pits the contact surfaces and degrades performance.
The "break-in" may be done by running the motor without load (without prop), at about 1/2 its rated voltage for about a hour or two. The brushes should get a curved surface without sparks/arcing.
Some high-quality motors do not need to be "broken-in". This will be mentioned in the respective motor's manual. In case of doubt, just break it in.

Sparks that occur between the brushes and the commutator can cause radio interference.
In order to prevent radio interference it is recommended the use of ceramic capacitors soldered between each motor terminal and the motor case.
For extra security against interference, a third capacitor should also be fitted between the motor terminals.



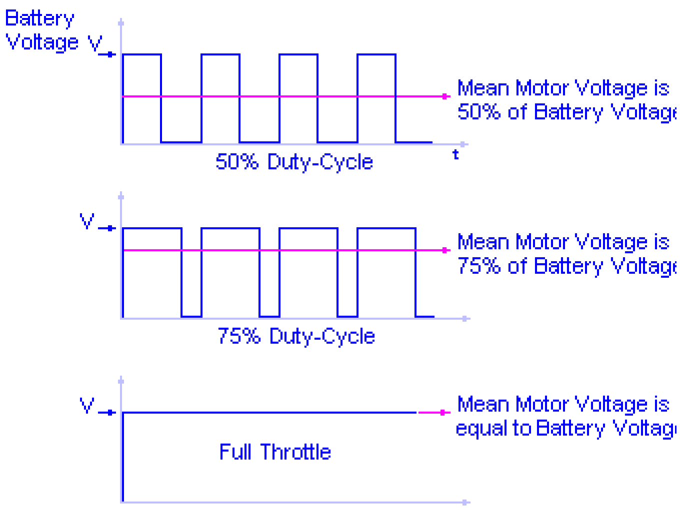
Note: many Graupner Speed xxx motors have the first 2 of these capacitors already fitted internally.

A common way to control the electric motor's speed is by using an Electronic Speed Controller (ESC).



The Electronic Speed Controller is based on Pulse Width Modulation (PWM), which means that the motor's rpm is regulated by varying the pulses' duty-cycle according to the transmitter's throttle position.

For example, with the throttle at the minimum position, there will be no pulses, while moving the throttle to the middle will produce 50% duty-cycle. With the throttle at the max position the motor will get a continuous DC voltage.



Most ESCs have a facility known as Battery Eliminator Circuit (BEC).
These controllers include a 5V regulator to supply the receiver and servos from the same battery that is used to power the motor, thereby eliminating the weight of a second battery only to power the radio and servos.
The motor power is cut-off when the battery voltage falls, for example below 5V. This prevents the battery from getting totally flat allowing the pilot to control the model when the motor stops.
Some controllers also include a brake function that prevents the propeller from keeping spinning when the motor power is cut-off.
Electronic Speed Controllers are available in different sizes and weights, which depends on their max output current capabilities.
Another important characteristic of an ESC is the on-resistance of the output power switching transistor(s).
The on-resistance should be as low as possible, since its value is proportional to the power loss dissipated by the output transistor(s): $P = R \times I^2$

The on-resistance is normally between approx. 0.012 and 0.0010ohm. The value depends on how many output parallel-connected transistors the actual ESC has. The higher the current capability the lower the on-resistance should be.
These figures are normally shown on the ESC data sheet along with the BEC voltage cut-off value and the max. output current to the receiver and servos.

As a safety measure many ESCs have a function that won't allow the motor to start running unless the throttle is initially set in the minimum position.
Another safety device is the so-called arming switch connected between the motor and the controller.
The arming switch should be off until the plane is ready to taxi out on the runway or be hand-launched.
After the flight, the arming switch should be turned off as soon as possible.
This will prevent the motor from start running in case the throttle stick is moved forward unintentionally.

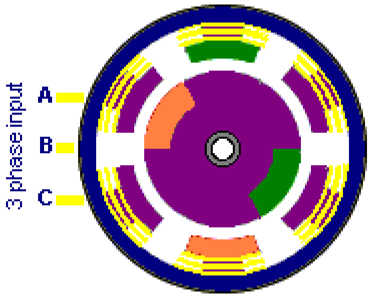
In order to keep the arming switch contacts in good shape (lowest resistance) it's advisable to never switch it on/off under power. This means that the arming switch should be only turned on/off when the throttle is in the minimum position.

The more powerful the motor, the more need for the safety of an arming switch.
A reasonable approach is using an arming switch on flight models larger than speed 400 size (approximately 100 watts and above).

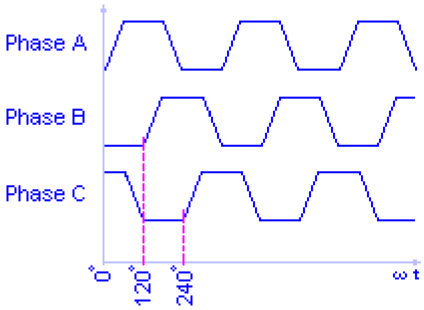
Large batteries are capable of delivering very high currents when shorted or when the propeller gets blocked.
Such high currents are enough to overheat and melt components/wiring, which may lead to a fire.
Some organisations that provide insurance for modellers require a fuse in electrically powered models.
To choose the correct rating for the fuse just put the largest and highest-pitch prop that you expect to fly with. Measure the current draw of your power system on the bench and multiply the value by about 1.25.
This 25% margin should prevent nuisance blows. Find the fuse with a rating at or just above this current level.

Another type of electric motors for model aircraft are the so-called **brushless**.

These motors are rather expensive,
but they have higher efficiency.
Typically between 80 to 90%.
Since they have no brushes, there
is less friction and virtually no
parts to wear, apart from the bearings.

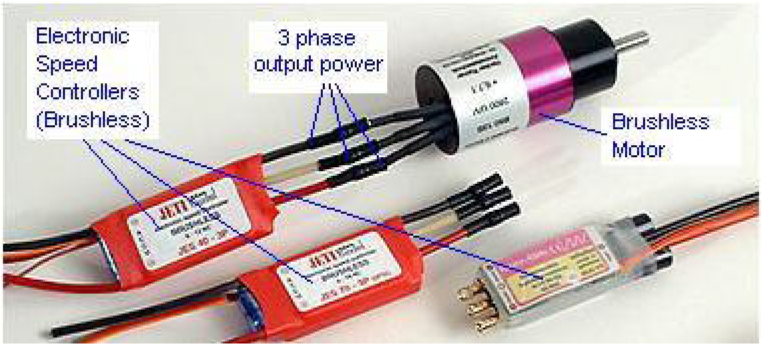


Unlike the DC brushed motor, the stator of the AC
brushless motor has coils and the rotor consists
normally of permanent magnets.
The stator of a conventional brushless motor is part
of its outer case, while the rotor rotates inside it.
The metal case acts as a heat-sink, radiating the
heat generated by the stator coils, thereby keeping
the permanent magnets at lower temperature.



They are 3-phase AC synchronous motors.
Three alternated voltages are applied to the
stator's coils sequentially (by phase shift)
creating a rotating magnetic field which is
followed by the rotor.

It's required an electronic speed controller specially designed for the brushless motors, which converts the battery's DC voltage into three pulsed voltage lines that are 120° out of phase.
The brushless motor's max rpm is dependent on the 3-phase's frequency and on the number of poles: rpm = 2 x frequency x 60/number of poles.
Increasing the number of poles will decrease the max rpm but increase the torque.



A brushless motor's direction of rotation can be reversed by just swapping two of the three phases.

Earlier speed controllers needed an additional set of smaller wires connected to the motors' internal sensors in order to determine the rotor position to generate the right phase sequence.

New controllers read the so-called "back EMF" from each phase, which allows the motor to be controlled without the need of the extra wires and sensors. These new controllers are called "sensorless" and can be used to control motors with or without internal sensors.

At less than full throttle the 3-phase pulses are chopped at a fixed frequency with a duty-cycle depending on the throttle position. At full throttle the phase pulses are no longer chopped giving the max rpm and torque.
The ESC's 3-phase actual output frequency and thus the motor's rpm depend on motor's Kv (rpm / volt), the actual load and the voltage applied, as the ESC needs the EMF positioning pulses back from the motor before it sends the output pulses.

A recent type of brushless motor is the so-called "outrunner".
These motors have the rotor "outside" as part of a rotating outer case and the stator is located inside the rotor.
This arrangement generates much higher torque than the conventional brushless motors, which means that the "outrunners" are able to drive larger and more efficient propellers without the need of gearboxes.