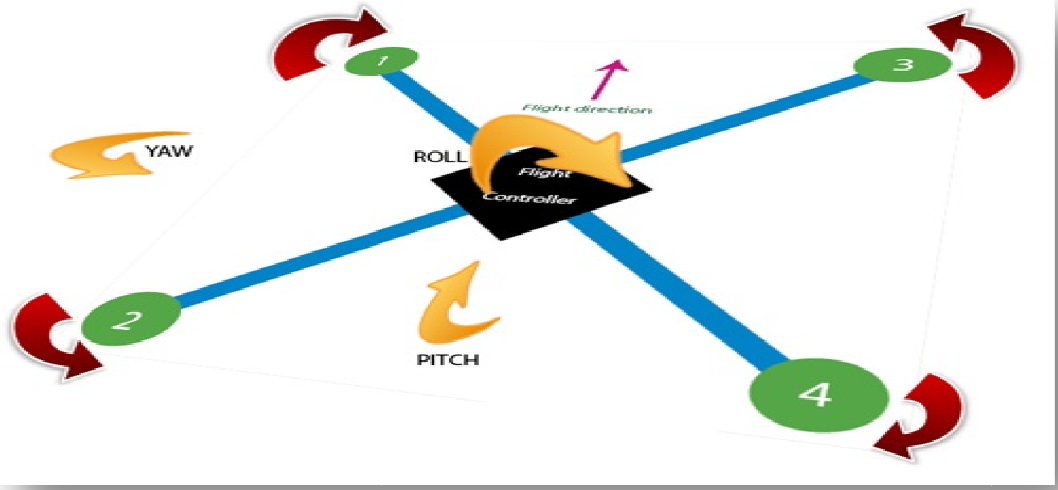
QUADCOPTER

Basically a Quad copter is a quad rotor helicopter that is lifted and propelled by four rotors. Unlike helicopters they use symmetrically pitched blades. Control of vehicle motion is achieved by altering the pitch and/or rotation rate of one or more rotor discs, thereby changing its torque load and thrust/lift characteristics. Check the image below for the principle behind the quad's motion.



As you can see, the motors 1 and 4 rotate in CW direction while 3 and 2 rotate CCW thus creating a downward thrust which lifts the quad. By varying the speed of the 4 rotors various movements are possible. There are three important terms mentioned above namely the YAW, ROLL and PITCH which we must have a clear concept of before understanding the quad's movement will be discussed later.

Working Principle

Before going in technical field let's see what principle is behind quad copter flying

Concept of flying:- Principle behind the Quad copter flying is same as flying principle of Aero plane and Helicopter i.e. Bernoulli's Principle.

In 1738, Daniel Bernoulli's has given the Bernoulli Principle, which draws a relation between Velocity(V) and Pressure(P).It is usually based on conservation of energy.

Bernoulli's Principle:-it state that "the total energy in steadily flowing fluid system is a constant along the flow path or within a flow of constant energy ,when a fluid flows through a region of lower pressure it speeds up and vice versa"

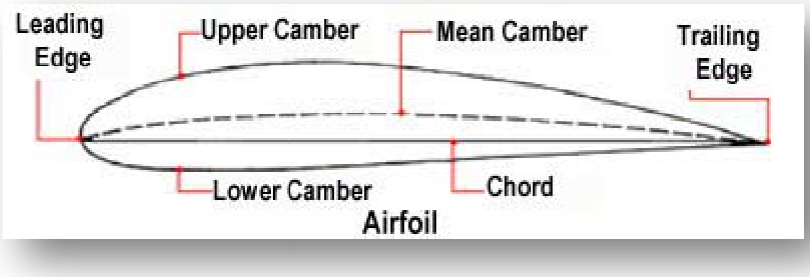
Bernoulli's Principle concerns itself with changes in speed and change in pressure within a flow field. It state that

Velocity is inversely proportional to Pressure.

$$V = \frac{1}{P}$$

Application:-

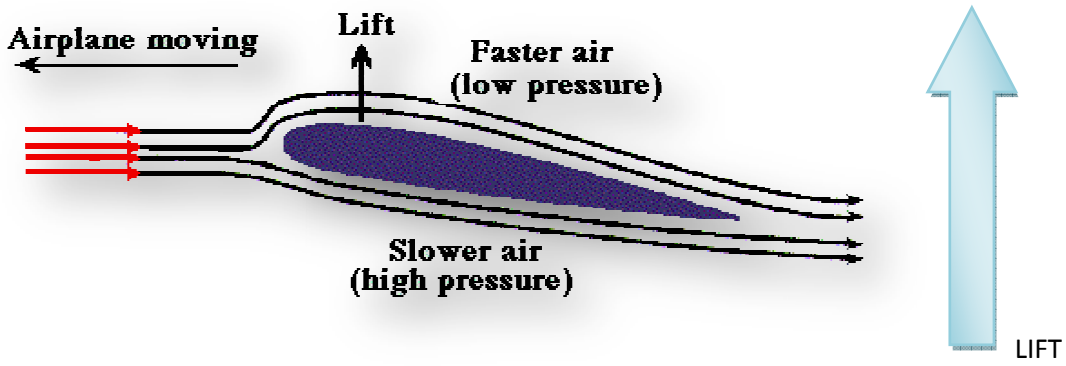
1- In Aeroplane:- The wing of Aeroplane follows this principle , the shape of wing are like mostly as a single water drop also known as Airfoil.



Airfoil(wing) are so designed that the Upper camber should be large then Lower camber .When the Aeroplane

runs (before fly) on runway its wing get strongly stirke to air, which spilt it into two parts , a upper part air and lower part air. As Aeroplane speed up, due to large area of Upper portion , the upper part air striking it get along with the velocity(speed) of Aeroplane and due to this air's velocity in upper portion is fast than lower portion air.

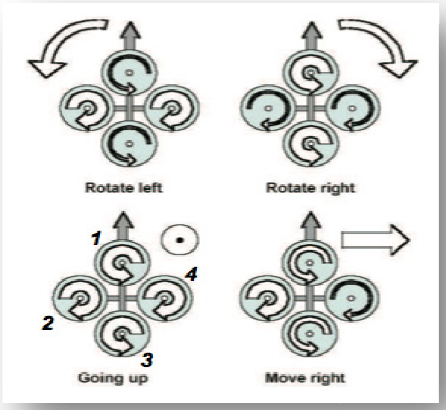
Here V⇧ and P⇩

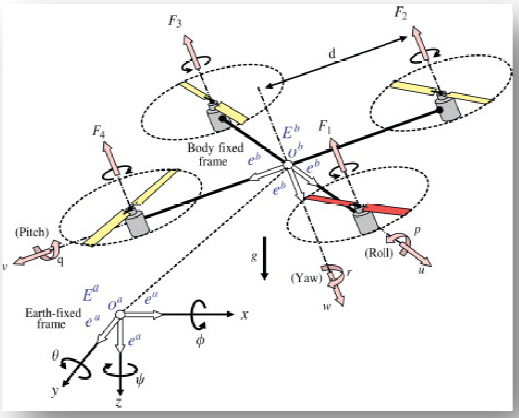


UPWARD

Here V ⇩ and P ⇧

As we see that pressure at lower chamber side is higher than upper chamber and as nature of pressure to moves form high to low, the lower chamber pressure will a exerted a force in form of LIFT towards upper side and thus the aeroplane suck up in the sky.
Same principle is also follows by Helicopter, in which action is play by BLADES of helicopter.
On same principle Quadcopter also work instead of a big blades as in Helicopter it has 4 small propellers. The total
Weight of Quadcopter is eqully divide among all blades.





In Quadcopter type plane they follows one more principle known as Newton 3rd law which state that *"Every action has equal And opposite reaction".* This reaction force is called as torque reaction. So each blades of Quadcopter produces both a thrust and equal & opposite a torque reaction.
Due to movement of 2 blades in Clockwise and 2 in Counter Clockwise the torque reaction get cancel by each other and only thrust remain which make it to fly.

** If all blades rotate in one direction then torque reaction play a role ,which make whole body to rotate in blades rotating direction.

V

Technical Details

In the construction of Quad copter we usually required:-

- Brushless Motors
- Propellers
- ESC-Electronic Speed Controller
- Battery
- The frame

We will now goes in details:-

Brushless motors:-

As I said Quad Copters do have 4 motors with a propeller each. Most of the times the so called Brushless Motors are used to drive the propellers.

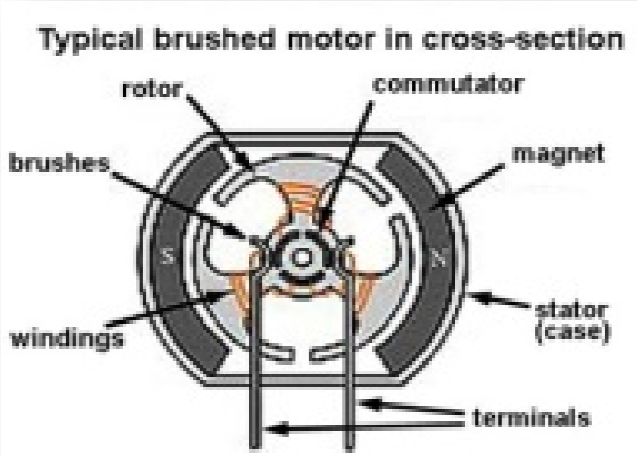
BLDC motors have many advantages overbrushed DC motors and induction motors. A few ofthese are:

• Better speed versus torque characteristics
• High dynamic response
• High efficiency
• Long operating life
• Noiseless operation
• Higher speed ranges
In addition, the ratio of torque delivered to the size of the motor is higher, making it useful in applications where space and weight are critical factors.

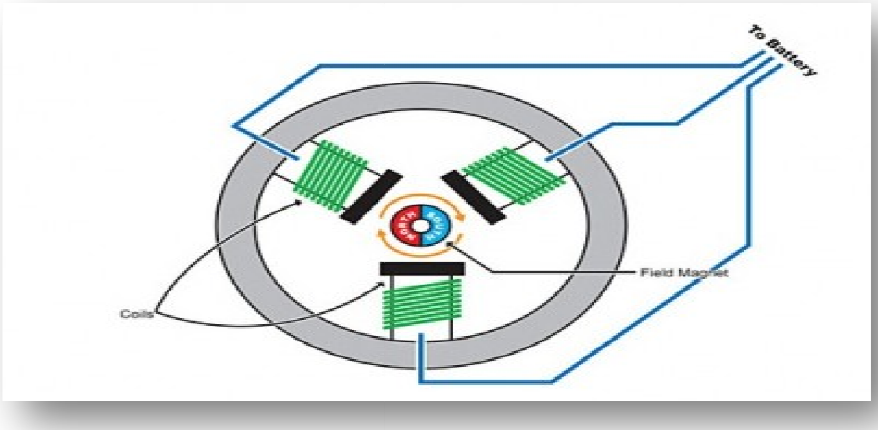
Brushless motors are a bit similar to normal DC motors in the way that coils and magnets are used to drive the shaft.

In brushed DC motor magnets are mounted on the stator and coils are wounded on rotor pole. As to energize the coil we use a contacts b/w source & coil known as brushes. To make motor run fully we use commutator, working as rectifier. Due to impurely connection b/w brushes and

commutator, brushes produced spark which meant to power loss and reduces the speed. So it has limited speed, but to make fly we want large speed which can achieve by using brushless motor



Firstly we see that how brushless motor can be made:-
To produce high speed in a motor we have to reduce the power loss, which is due to presence of brushes so we have to arrange like that brushes need goes end.
If we mount coil on stator and permanent magnet on rotor shaft . Now we can make a directly and purely contact b/w source and coils and necessity of brushes goes end . Though the brushless motors do not have a brush on the shaft which takes care of switching the power direction in the coils, and this is why they are called brushless.
The brushless motors have three coils on the stator of the motor, which is fixed to the mounting. On the outer side of rotor it contains a number of magnets mounted to a cylinder that is attached to the rotating shaft. So the coils are fixed which means wires can go directly to them and therefore there is no need for a brush.



Brushless motor internal

The reason why QuadCopters use brushless motors instead of normal DC motors is the much higher speeds and less power usage for the same speed. The brushless motors are more efficient as there is no power lost as there is in the brush-transition on the DC motors.

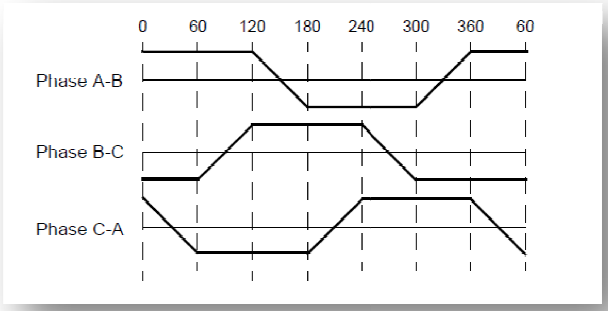
PRINCIPLE CONSTRUCTION AND OPERATING:-

As usual BLDC Motors also have two main parts that are

Stator - The stator of a BLDC motor consists of stacked steel laminations with windings placed in the slots that are
axially cut along the inner periphery **.** Most BLDC motors have three stator windings connected in star fashion. Each of these windings are constructed with numerous coils interconnected to form a winding. One or more coils are
placed in the slots and they are interconnected to make a winding. Each of these windings are distributed over
the stator periphery to form an even numbers of poles.

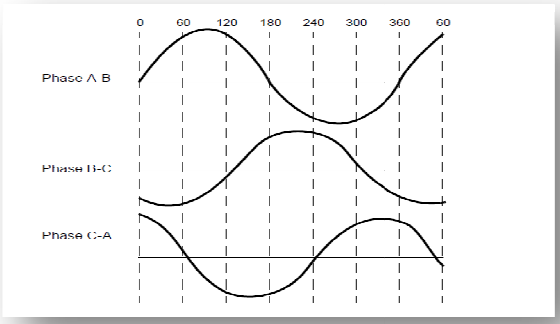
There are two types of stator windings variants trapezoidal and sinusoidal motors. This differentiation
is made on the basis of the interconnection of coils in the stator windings to give the different types of back
Electromotive Force (EMF).

As their names indicate, the trapezoidal motor gives a back EMF in trapezoidal fashion and the sinusoidal
motor's back EMF is sinusoidal, as shown in Figure 1 and Figure 2. In addition to the back EMF, the phase
current also has trapezoidal and sinusoidal variations in the respective types of motor. This makes the torque
output by a sinusoidal motor smoother than that of a trapezoidal motor. However, this comes with an extra
cost, as the sinusoidal motors take extra winding interconnections because of the coils distribution on
the stator periphery, thereby increasing the copper intake by the stator windings.



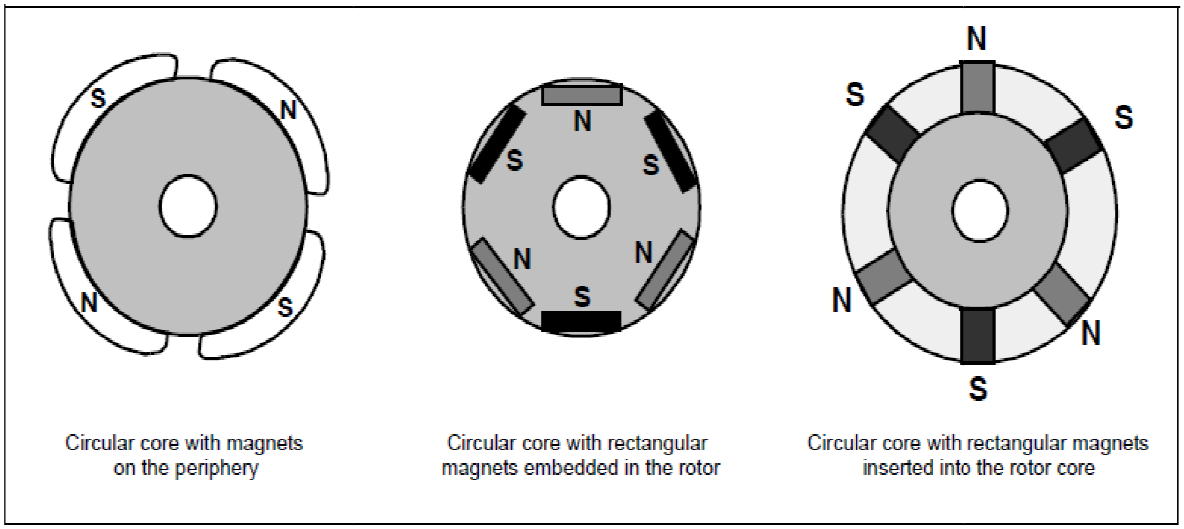
1

2



Rotor-The rotor is made of permanent magnet and can vary from two to eight pole pairs with alternate North (N) and South (S) poles.
Based on the required magnetic field density in the rotor, the proper magnetic material is chosen to make
the rotor. Ferrite magnets are traditionally used to make permanent magnets. As the technology advances, rare earth alloy magnets are gaining popularity. The ferrite magnets are less expensive but they have the disadvantage of low flux density for a given volume. In contrast, the alloy material has high magnetic density per volume and enables the rotor to compress further for the same torque. Also, these alloy magnets improve the size-to-weight ratio and give higher torque for the same size motor using ferrite magnets.
Neodymium (Nd), Samarium Cobalt (SmCo) and the alloy of Neodymium, Ferrite and Boron (NdFeB) are
some examples of rare earth alloy magnets. Continuous research is going on to improve the flux density to
compress the rotor further.
Figure 4 shows cross sections of different arrangements of magnets in a rotor.

FIGURE 4: ROTOR MAGNET CROSS SECTIONS



Circular core with magnets on the periphery

Circular core with rectangular magnets embedded in the rotor

Circular core with rectangular magnets inserted into the rotor core

To sense the rotor position , HALL sensor

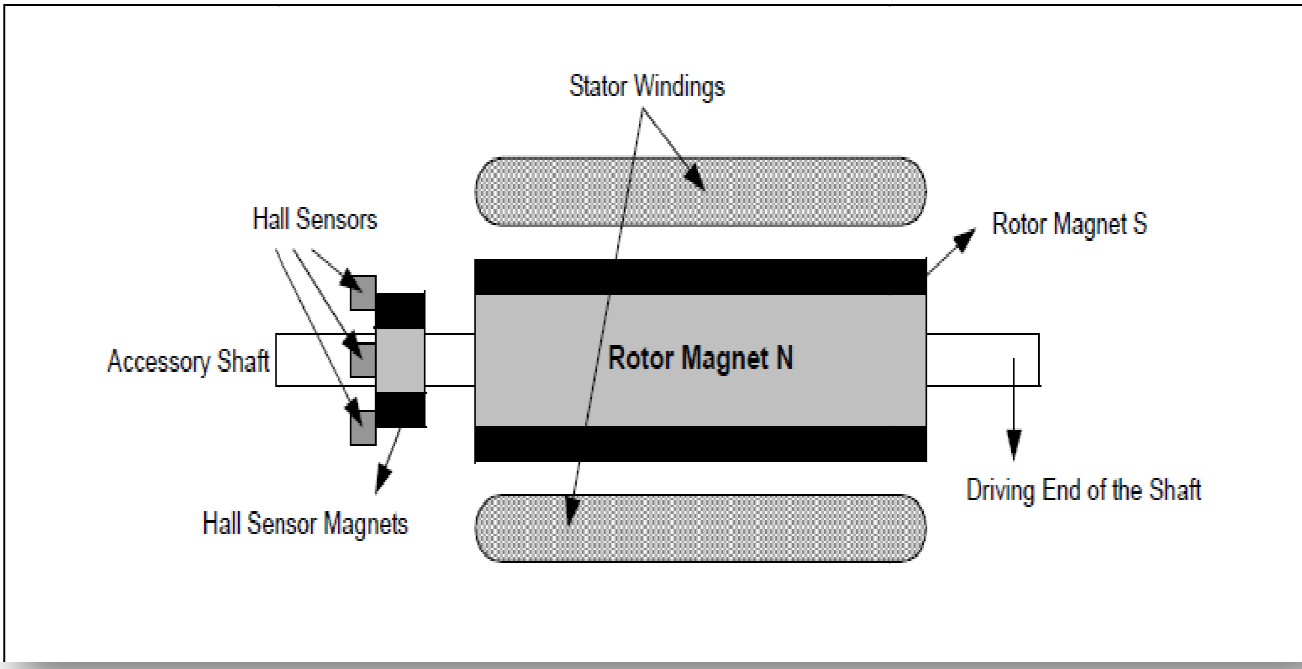
HALL SENSORS- HALL sensors used the principal of HALL EFFECT THEORY which state that " *If an electric current carrying conductor is kept in a magnetic field, the magnetic field exerts a transverse force on the moving charge carriers which tends to push them to one side of the conductor. This is most evident in a thin flat conductor. A buildup of charge at the sides of the conductors will balance this magnetic influence, producing a measurable voltage between the two sides of the conductor. The presence of this measurable transverse voltage is called the Hall effect after E. H. Hall who discovered it in 1879.*

Rotor position is sensed using Hall effect sensors embedded into the stator. Most BLDC motors have three Hall sensors embedded into the stator on the non-driving end of the motor.

Whenever the rotor magnetic poles pass near the Hall sensors, they give a high or low signal, indicating the N or S pole is passing near the sensors. Based on the combination of these three Hall sensor signals, the exact sequence of commutation can be determined. Embedding the Hall sensors into the stator
is a complex process because any misalignment in these Hall sensors, with respect to the rotor magnets,will generate an error in determination of the rotor position.

To simplify the process of mounting the Hall sensors onto the stator, some motors may have the Hall sensor magnets on the rotor, in addition to the main rotor magnets Therefore, whenever the rotor rotates, the Hall sensor magnets give the same effect as the main magnets..

FIGURE 5: BLDC MOTOR TRANSVERSE SECTION



WHAT IS BACK EMF?

When a BLDC motor rotates, each winding generates a voltage known as back Electromotive Force or back EMF, which opposes the main voltage supplied to the windings according to Lenz's Law. The polarity of this back EMF is in opposite direction of the energized voltage.

Back EMF depends mainly on three factors:

- Angular velocity of the rotor
- Magnetic field generated by rotor magnets• The number of turns in the stator windings

Once the motor is designed, the rotor magnetic field

$$\textbf{Back EMF} = (E) \quad NlrB\omega$$

where:

N is the number of winding turns per phase,

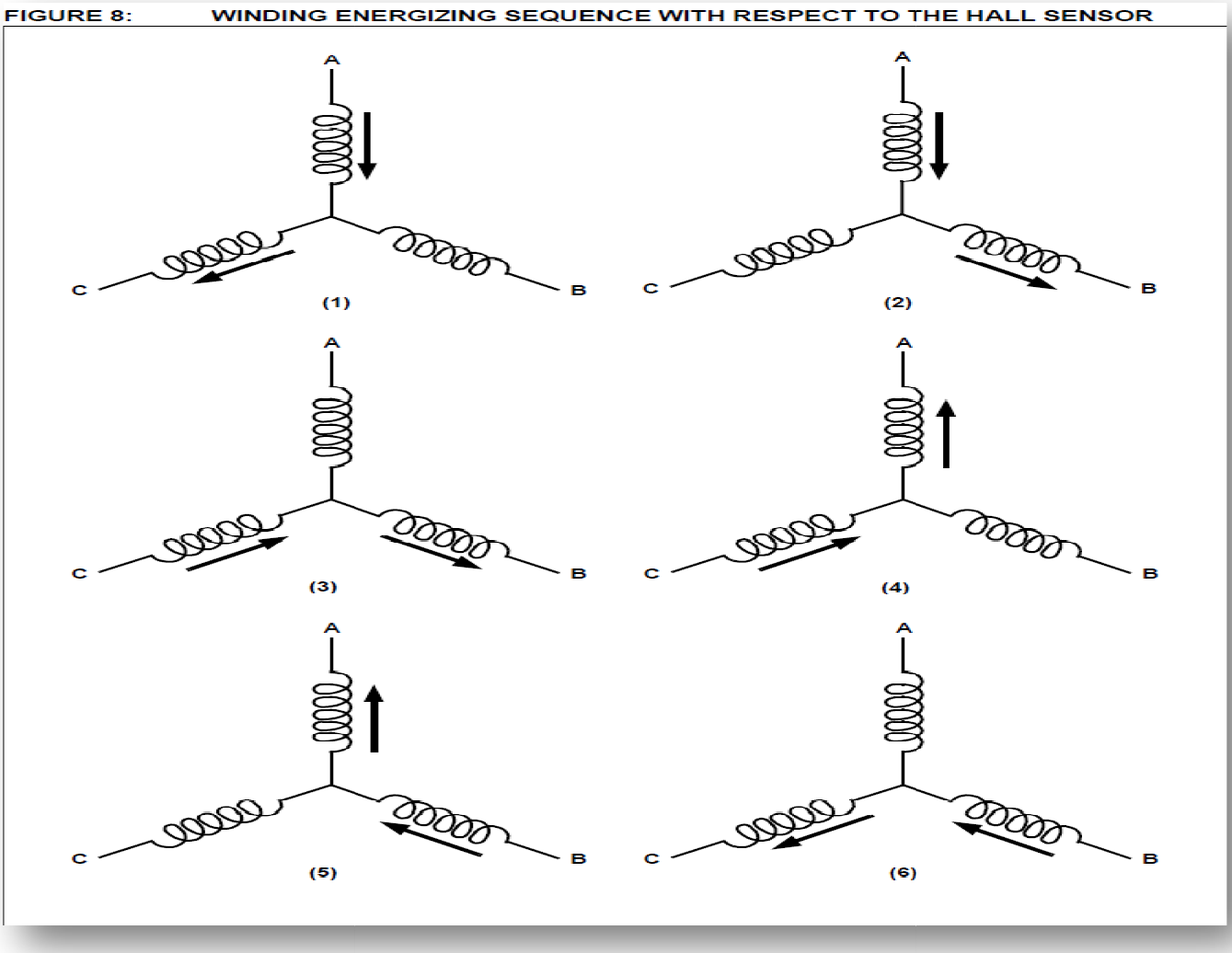
l is the length of the rotor,

r is the internal radius of the rotor,

B is the rotor magnetic field density and

ω is the motor's angular velocity

Once the motor is designed, the rotor magnetic field and the number of turns in the stator windings remain constant. The only factor that governs back EMF is the angular velocity or speed of the rotor and as the speed increases, back EMF also increases. The motor technical specification gives a parameter called, back
EMF constantThe potential difference across a winding can be calculated by subtracting the back EMF value from the supply voltage. The motors are designed with a back EMF constant in such a way that when the motor is
Running at the rated speed, the potential difference between the back EMF and the supply voltage will be sufficient for the motor to draw the rated current and
deliver the rated torque. If the motor is driven beyond the rated speed, back EMF may increase substantially,thus decreasing the potential difference across the
winding, reducing the current drawn which results in a drooping torque curve.



There are two types of Brushless RC Motors that are used in RC, Inrunner and Outrunner.

The only real difference in how they are constructed is where each of those magnets are located.

Inrunner Type- Inrunner Brushless RC motors have their permanent magnets mounted directly to the armature (motor shaft) which is

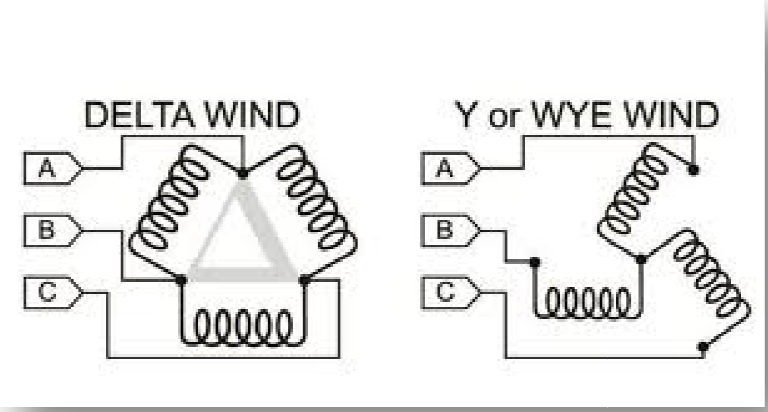
located “*inside of the windings*” . The electromagnet or “windings” of Inrunner Brushless RC Motors are located on the inner wall of the motor can.
The armature/shaft is the only part that rotates while the rest of the motor is stationary. Inrunner Brushless RC Motors are used in applications that require higher RPMs such as RC Cars/Trucks or lightweight RC Planes.

Hacker A20-20L EVO Brushless RC Motor – inrunner

Out runner Type- Out runner Brushless RC Motors have multiple permanent magnets mounted on the inside wall of the motor stator can which is “*outside of the windings*”.
The electromagnets or “windings” of the Out runner type brushless motor are located on the armature or shaft.
The shaft is fixed to the motor can and the can and shaft both rotate while the back of the motor is still. Out-runner Brushless RC Motors are used in applications that require an extreme amount of torque such as larger RC Planes.

Inside of a Hacker Brushless Outrunner Motor

Below is an illustration of the two types of wind connections; the only real difference between them is that like sized Brushless RC Motors with the Delta wind will have a much higher KV rating than those with a "Y" wind.

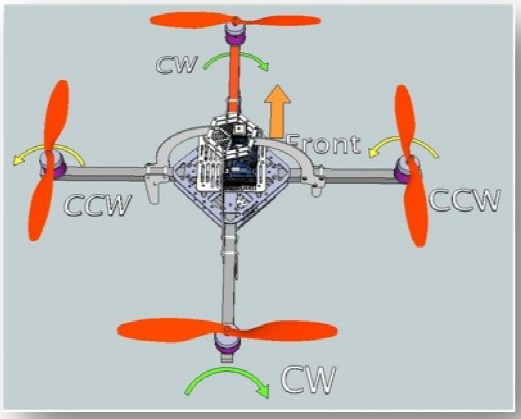


Delta and "Y" Wye Wind- Wire Coil Schematic

KV rating of Motors- **KV AS WE USE IT REFERS TO THE RPM CONSTANT OF A MOTOR - IT IS THE NUMBER OF REVOLUTIONS PER MINUTE THAT THE MOTOR WILL TURN WHEN 1V (ONE VOLT) IS APPLIED WITH NO LOAD ATTACHED TO THE MOTOR. IN SUMMARY, WE CALL IT REVS PER VOLT**

PROPELLERS:-

On each of the brushless motors there are mounted a propeller. You might not have noticed this on the pictures, but the 4 propellers are actually not identical. If you have a look at the CrazyFlie picture above you will notice that the front and the back propellers are tilted to the right, while the left and right propellers are tilted to the left.



This reason for this is that the motor torque of and the law of physics will make the QuadCopter spin around itself if all the propellers were rotating the same way, without any chance of stabilizing it {explain in principle above}. By making the propeller pairs spin in each direction, but also having opposite tilting, all of them will provide lifting thrust without spinning in the same direction. This makes it possible for the QuadCopter to stabilize the yaw rotation, which is the rotation around itself.
The propellers come in different diameters and pitches (tilting). You would have to decide which one to use according to your frame size, and when that decision is made you should chose your motors according to that.
Some of the standard propeller sizes used for QuadCopters are:

EPP1045 10 diameter and 4.5 pitch this is the most popular one, good for mid-sized

quadsAPC 1047 10 diameter and 4.7 pitch much similar to the one above

EPP0845 8 diameter and 4.5 pitch regularly used in smaller quads

EPP1245 12 diameter and 4.5 pitch used for larger quads which requires lot of thrust

EPP0938 9 diameter and 3.8 pitch used in smaller quads

In general you should select your propeller according to the following four tips:

The diameter of the propeller indicates how much air the propeller will be able to move while the pitch indicates how much air the propeller moves all the time not said that you can use this in any way to calculate the air moved.

The larger diameter and pitch the more thru the propeller can provide. But be-aware that a large pitch makes it much harder for the motor to drive it, it requires much more power, but in the end it will be able to lift more weight.

When using high RPM motors you should go for the smaller or mid-sized propellers

When using low RPM motors you should go for the larger propellers as you can run into troubles with the small ones not being able to lift the quad at low speed (RPM)

A faster rotating propeller (small diameter and small pitch) is used when you have a motor that runs at a high RPM (Kv > 1000) and can provide a decent amount of torque.

A slower rotating propeller (longer or larger pitch) is used when you have a motor that manages fewer revolutions but can provide more torque.

ELECTRONIC SPEED CONTROL:-

As the brushless motors are multi-phased, normally 3 phases, you can,t just apply power to it to make it spin. The motors requires some special phase-control electronics that is capable of generating three high frequency signals with different but controllable phases, but the electronics should also be able to source a lot of current as the motors can be very power-hungry.

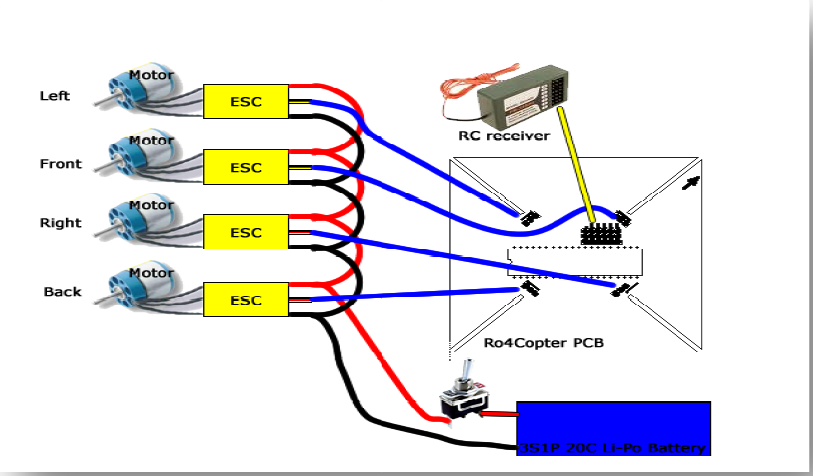
In this case we got the Electronic Speed Controllers, known as ESCs. An electronic speed control or ESC is an electronic circuit with the purpose to vary an electric motor's speed, its direction and possibly also to act as a dynamic brake. ESCs are often used on electrically powered radio controlled models, with the variety most often used for brushless motors essentially providing an electronically-generated three phase electric power low voltage source of energy for the motor.An ESC can be a stand-alone unit which plugs into the receiver's throttle control channel or incorporated into the receiver itself, as is the case in most toy-grade R/C vehicles.

The ESCs is simply a brushless motor controller board with battery input and a three phase output for the motors. For the control it is usually just a simple PPM signal (similar to PWM) that ranges from 1ms (min speed=turn off) to 2ms (max speed) in pulse width. The frequency of the signals does also vary a lot from controller to controller, but for a QuadCopter it is recommended to get a controller that supports at least 200Hz or even better 300Hz PPM signal, as it should be possible to change the motor speeds very quickly to adjust the QuadCopter to the stable position. It is also possible to get ESCs that is controlled thru OneWire of I2C. These tends to be much more expensive though, but sometimes it is also possible to mod other ESCs to add the I2C feature.

Brushless ESC systems basically drive tri-phase Brushless motors by sending sequence of signals for rotation. Brushless motorsotherwise called outrunners or inrunners have become very popular with radio controlled airplane hobbyists because of their efficiency, power, longevity and light weight in comparison to traditional brushed motors. However, brushless DC motor controllers are much more complicated than brushed motor controllers.

The correct phase varies with the motor rotation, which is to be taken into account by the ESC: Usually, back EMF from the motor is used to detect this rotation, but variations exist that use magnetic (Hall Effect) or optical detectors. Computer-programmable speed controls generally have user-specified options which allows setting low voltage cut-off limits, timing, acceleration, braking and direction of rotation. Reversing the motor's direction may also be accomplished by switching any two of the three leads from the ESC to the motor

ESCs can be found in many different variants, where the source current is the most important factor. You should always chose an ESC with about 10A or more in sourcing current as what your motor will require.



BATTERY:-

All this leads to the battery, the power source for the whole device. For the battery two types can be used, whereof one of them is highly recommended. The NiMH and the LiPo. I wont say much about the NiMH as most communities tells us to stay away from these for driving QuadCopters as they first and foremost are not able to provide enough current and secondly they weight a lot more than LiPo batteries when they have the necessary current ratings. Instead we should talk about LiPo batteries, but in this world there are also a lot of different variants of these too. LiPo batteries can be found in packs of everything from a single cell (3.7V) to over 10 cells (37V). The cells are usually connected in series, making the voltage higher but giving the same amount of amp-hours.
For a QuadCopter you should go after the 3SP1 batteries which means 3 cells connected in series as 1 parallel (just forget the parallel, as it has no sense because we just use 3 cells in

series). This should give us 11.1V but at fully charged it actually gives us around 12V instead. For a brushless motor with a Kv-rating of 1000, this gives us a maximum of 12000 rounds per minute. This number is totally fictive as the battery voltage will drop immediately to around 11.1V (at fully charged state) when current is being drained. Anyways, this gives us a good idea about how fast the propellers will be spinning!

ZIPPY Flightmax Battery, 4000mAh 25C

As for the battery capacity regards you should make some calculations on how much power your motors will draw and then decide how long flight time you want and how much influence the battery weight should have on the total weight. A good rule of thumb is that you with four EPP1045 propellers and four Kv=1000 rated motor will get the number of minutes of full throttle flight time as the same number of amp-hours in your battery capacity. This means that if you have a 4000mAh battery, you will get around 4 minutes of full throttle flight time though with a 1KG total weight you will get around 16 minutes of hover.
Another thing to be-aware of when selecting the right battery is the discharge rate, formerly known as the C-value. The C-value together with the battery capacity indicates how much current you are able to source from the battery. The calculations follow this simple rule:
MaxSource = DischargeRate x Capacity

THE FRAME:-

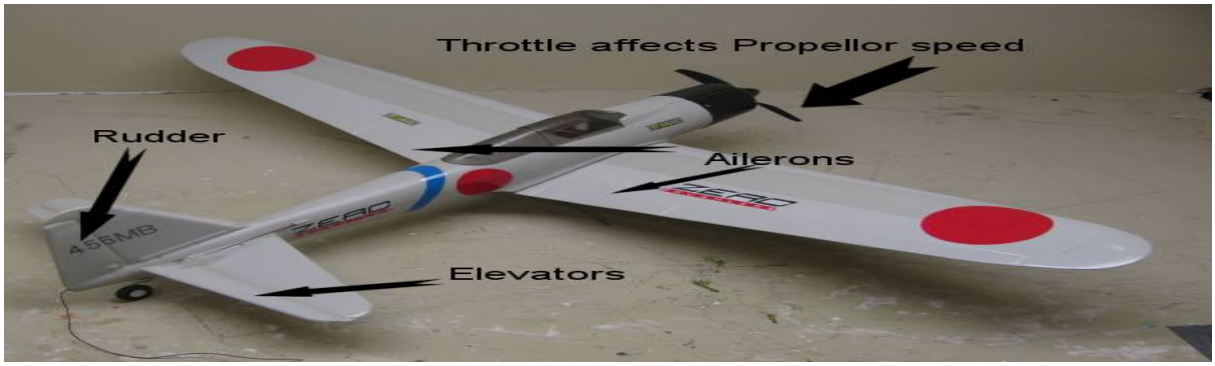
Every part in a QuadCopter design works together and the frame is the one joining all of them. The frame can be designed in many ways with many different kinds of materials. The important things are to make it rigid and to minimize the vibrations coming from the motors
.
A QuadCopter frame consists of two to three parts which dont necessarily have to be of the same material: The center part where the electronics and sensors are mounted
Four arms mounted to the center part
Four motor brackets connecting the motors to the arms
There are three kinds of materials that I recommend using for a QuadCopter frame:
Carbon Fiber
Aluminium
Plywood or MDF
Carbon fiber is the most rigid and vibration absorbant of the three materials but is also by far the most expensive.

Most of the times the arms used in QuadCopters are made of hollow aluminium square rails which makes the QuadCopter relatively light weight but still makes it rigid. The problem with these hollow aluminium rails are the vibrations, as they arent damped and will therefor vibrate to the center part and maybe mess up the sensor readings.
Instead solid MDF plates could be cut out for the arms as they will absorb the vibrations much better than the aluminium. Unfortunately we have another problem then, as the MDF plates are not very rigid and will break if the QuadCopter falls to the ground.
As for the center part everything from carbon fiber, aluminium or plywood can be used. Plywood is commonly seen as the center part because it is light weight, easy to work with and is reliable and rigid so it can hold the four arms together as required.
The arm length varies a lot from QuadCopter to QuadCopter as it is up to the individual to decide how big he would like his quad to be. In the QuadCopter terminology we use the abbreviation motor-to-motor distance to explain the distance for the center of one motor to the center of another motor of the same arm (or in the same direction).
The motor to motor distance decision goes hand in hand with the propeller diameter decision, as you should definitely make enough space between the propellers. Usual QuadCopters with EPP1045 propellers, which means a propeller diameter of 10, has a motor to motor distance of around 60 cm ~ 24, though it will be possible to make it less. Others with smaller propellers, fx with a diameter of 8 or less, will be able to have a motor to motor distance of around 12.

Contol System

This is a short tutorial with pictures that shows you the basics of how a Remote Control airplane works. I go over the theory of how the whole set up operates including a look at the actual mechanics of the airplane and the use of the hand-held controller. There are lots of different controls and controllers and they will vary but in this tutorial I take a look at a pretty standard set up and it will give you a good understanding of how RC airplanes work.

The controls on an RC airplane are pretty much the same as on a real airplane. This makes sense because you have the same thing (An airplane), it is just the size that is changed. There are four major controls in an RC airplane:



An explanation of the Controls

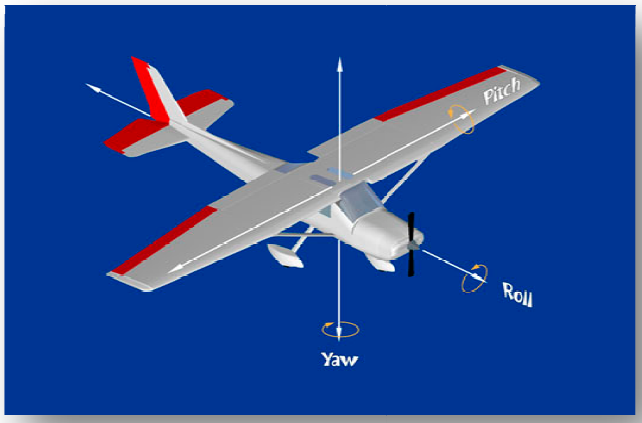
1. The Throttle: This affects the speed of the airplane. The more throttle you apply the faster the airplane will go. This also affects the climbing and descening speed. Applying more or less throttle will cause the airplane to descend or climb faster. This is important to know because it means that the other controls are not the only thing that affect take off and landing.

The three next parts: Elevators, Ailerons and Rudder control three movements of the airplane called "Pitch, Roll, and Yaw". I explain these parts and these three movements are

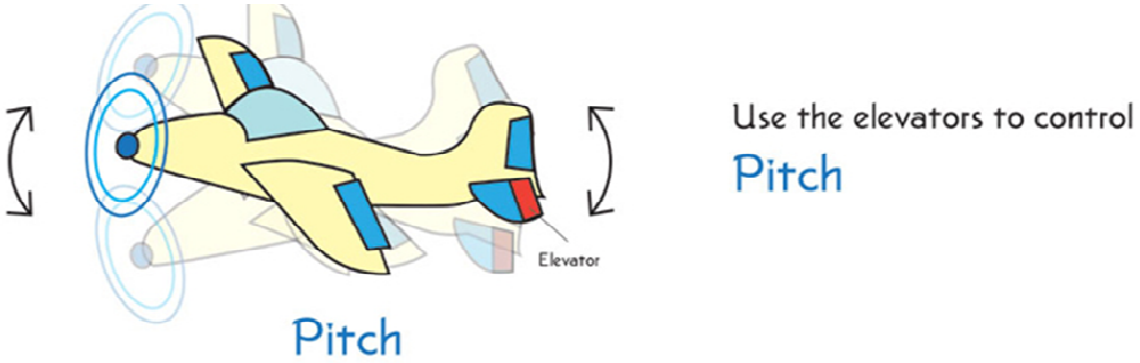
What are Roll, Pitch, and Yaw?

Imagine three lines running through an airplane and intersecting at right angles at the airplane's center of gravity.

- Rotation around the front-to-back axis is called **roll**.
- Rotation around the side-to-side axis is called **pitch**.
- Rotation around the vertical axis is called **yaw**.



PITCH{ELEVATORS}

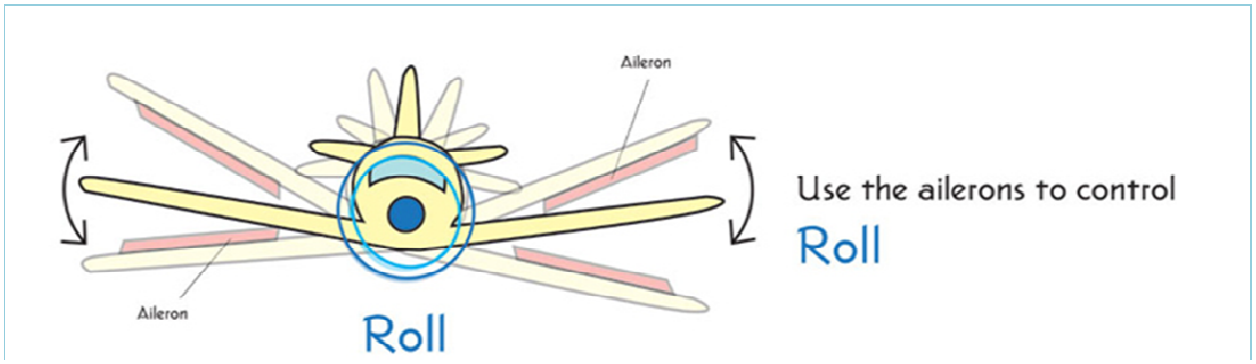


1. Elevators: These control something called "The Pitch" of the airplane. Changing the angle of these elevators will control whether the airplane goes up or down. Now, its important to realize that if the elevators go down the airplane will go down and if the elevators go up the airplane will go up. This is because the elevators control whether the nose of the airplane goes up or down. The picture below explains this concept.In this picture the elevator is down. This will

force the nose of the airplane down and the airplane will descend. Conversely, if the elevator is up the plane will ascend.

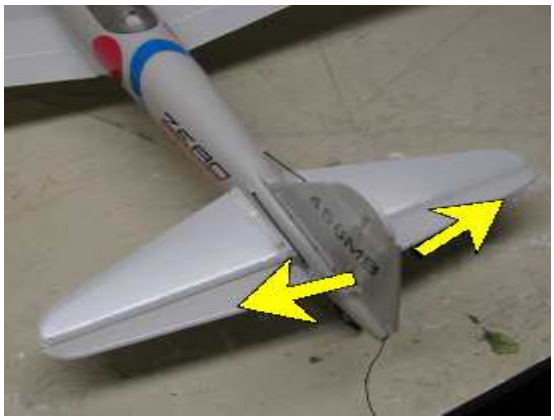
On the horizontal tail surface, the elevator tilts up or down, decreasing or increasing lift on the tail. This tilts the nose of the airplane up and down.

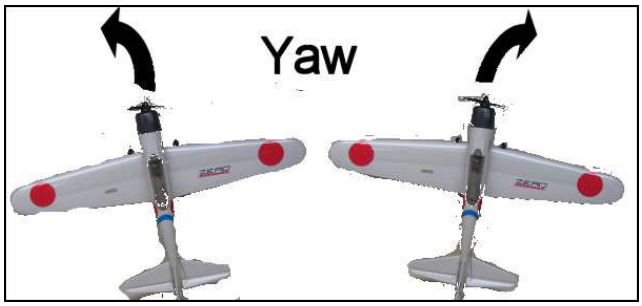
ROLL{AILERONS}

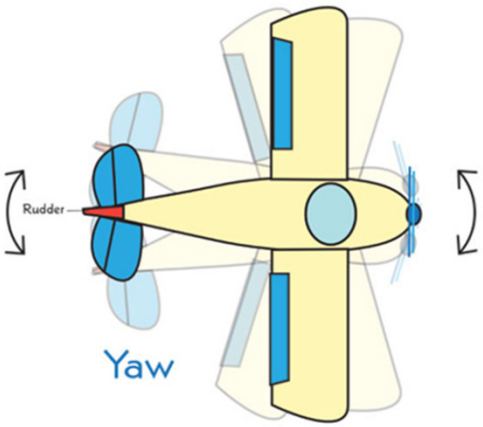


2. Ailerons: These are not on all RC airplanes. And they are not needed, many RC airplanes work just fine without them. And, if you are a beginner you don't need them. They can just make it a little bit more of a challenge to operate. The Ailerons control the roll of an airplane. On the outer rear edge of each wing, the two ailerons move in opposite directions, up and down, decreasing lift on one wing while increasing it on the other. This causes the airplane to roll to the left or right. To turn the airplane, the pilot uses the ailerons to tilt the wings in the desired direction

YAW{RUDDERS}

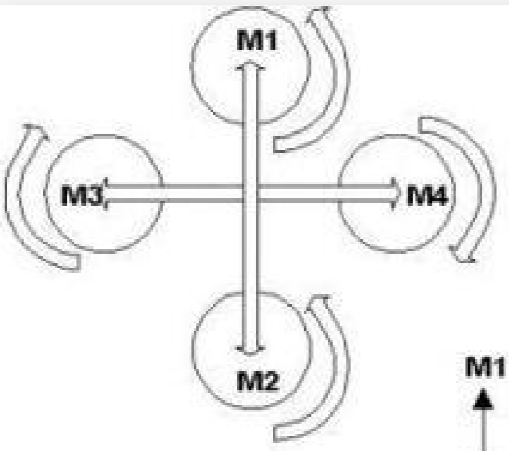


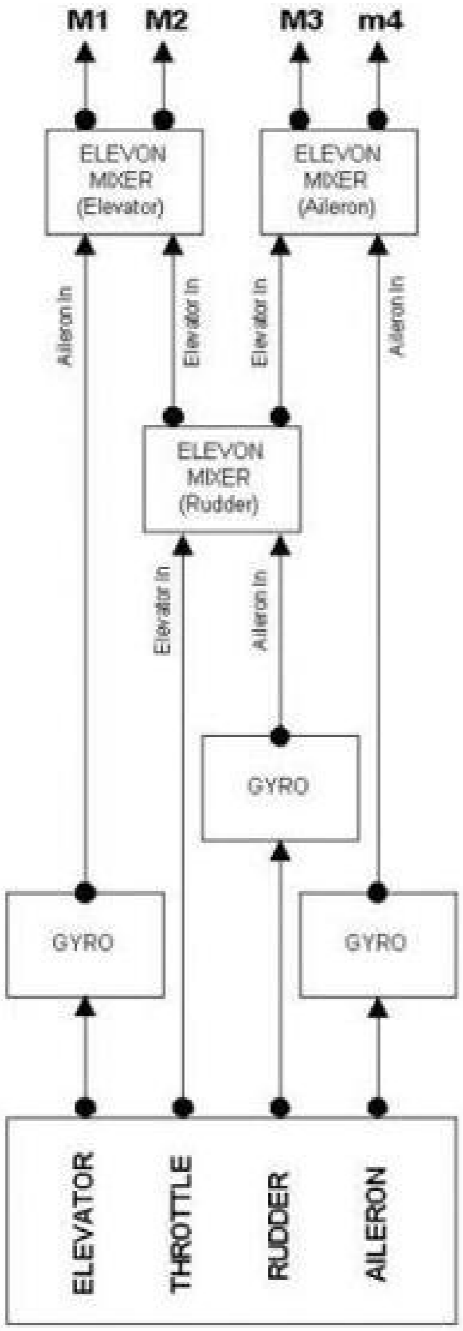




Use the rudder to control
Yaw

Rudder: The rudder controls the Yaw of the airplane. This is what turns it to the left or right. This picture shows how the rudder moves. The motions of the rudder will control the Yaw of the airplane ;On the vertical tail fin, the rudder swivels from side to side, pushing the tail in a left or right direction. A pilot usually uses the rudder along with the ailerons to turn the airplane.





Notes:

- m1,m2,m3,m4 connect to speed controls and then to the motors
- Gyros are heading hold
- Mixers are Elevon Mixing with user programable end points

ELEVATOR FUNCTION:
Up Elevator: M1 rotor is increasedl M2 rotor is decreased

Down Elevator : M1 rotor is decreased,M2 rotor is increased

AILERON FUNCTION:
Left Aileron Function: M3 rotor is decreased; M4 rotor is increased

Right Aileron: M3 rotor is increased; M4 rotor is decreased

RUDDER FUNCTION:
Left Rudder: M1 and M2 rotors are increased; M3 and M4 rotors are decreased

Right Rudder: M1 and M2 rotors are decreased; M3 and M4 rotors are increased

THROTTLE FUNTION:
Throttle Up: M1, M2, M3 and M4 rotors are increased

Throttle Down: M1, M2, M3 and M4 rotors are decreased