



**DRONE  
BUILDING  
— AND —  
REPAIRING**

**DRONEYBEE**

# Contents

- Introduction ..... 3
- HOW DO MULTICOPTERS WORK? : The basics..... 5
  - The flight ..... 6
- The motor direction ..... 10
  - Why motors and propellers are placed this way? ..... 12
  - Gaining and losing altitude ..... 13
  - Pitch ..... 14
  - Roll ..... 16
  - Yaw ..... 18
- The basic physics of how multirotors work (optional chapter) ..... 19
  - Physics of the hover ..... 20
  - Acceleration and deceleration..... 25
  - PD (Proportional and Derivative) and PID control ..... 26
  - PID Control..... 28
- Building and choosing parts..... 29
  - Picking the drone body/frame ..... 29
  - Picking the motors and propellers ..... 33
  - Picking ESCs ..... 41
  - Picking flight controller ..... 43

Picking Transmitters and Receivers .....	48
Picking batteries .....	54
Picking a drone kit .....	57
Putting it all together (Building a simple multicopter).....	59
ACCESSORIES.....	69
Drone cases .....	69
Sunshade.....	71
Lens improvement: lens protection, ND filters and hood .....	73
Propeller guards .....	75
Propeller balancer.....	77
Lights.....	79
Gimbal guards .....	80
Range extensions.....	82
Framework for fixing and repairing your multicopter .....	85
Tools and skills you'll need .....	85
Diagnosis and parts replacement.....	86
Fixing motors and ESCs.....	90
Fixing unbalanced propellers.....	91
Fixing the flight controller and PID tuning made easy .....	105
Testing the PID .....	107
Things to keep in mind.....	108
In closing.....	109

# Introduction

Welcome to the drone building and repairing manual! Here, we'll cover everything you need to know about multirotors as a drone pilot. You will also learn how to build and repair your multirotors should the necessity arise.

While programming a microcontroller and turning it into a flight controller is out of scope of this manual, we are confident that after reading this manual, you will have enough knowledge to build your own custom multirotor from scratch and program and tune pre-existing flight controllers. We recommend you assemble a multirotor from scratch to know how they work first-hand.

Consider that you have the option to hire two drivers. Both of them are great drivers, but one of them has the skill to work under the hood and fix things if something goes wrong with your car. Who would you hire? I'd personally pick the one with the extra skill!

Drones are much like vehicles in this regard. At the professional level, any number of things can go wrong to impede your project including broken or unbalanced props, broken motors, gimbal obstructions, body imbalances and many other malfunctions. While you do not need to have the technical know-how on how to

engineer a drone or program a flight controller, you'll be at a significant advantage if you know how to assemble a drone kit into a fully functional drone.

In this manual, we'll first touch on the basics of how multirotor works (including some basic physics), how to build one from scratch and how to diagnose and repair in case something goes wrong.

# HOW DO MULTICOPTERS WORK? : The basics

A multicopter “drone” is essentially a helicopter which has motors that are equally spaced, arranged on the corners of a square (X) body. Unlike helicopters, multirotors are inherently very unstable without electronic assistance because it is extremely herculean to control multiple rotors manually. The decreases in cost of modern microprocessors lead to these machines getting popular in the recent years. In this article, we will cover how multicopters work. The concepts discussed here apply to almost any kind of multirotor but to keep things simple, we’ll stick to using quadcopters to demonstrate the concepts.

## The flight

First we will address why we need propellers at all and how it generates lift. To those of you who are unfamiliar with Bernoulli's principle, definition states - **“for an inviscid flow of a non-conducting fluid, an increase in the speed of the fluid occurs simultaneously with a decrease in pressure or a decrease in the fluid's potential energy”**.

In simple terms, a fast moving fluid has lower pressure than a stationary fluid. What does this mean for aircrafts? Well, don't mistake 'fluid' for liquid. Air is gas and essentially a fluid.

A popular misconception is that due to the curvature of the wing at the top, the air at the top of the wing has to “catch up” with the air at the bottom. So, the speed of the air increases at the top in relation to the bottom. This causes a difference in pressure, and this difference in pressure through Bernoulli's principle, is what creates the lift. However, this has been debunked .

A wing is constructed in such a way that the air at the bottom is slowed down and deflected down the wing, making it higher pressure than the atmospheric pressure ( $P_d > P_a$ , where  $P_d$  is the pressure at the bottom of the wing and  $P_a$  is the atmospheric pressure) (see figure below).



By the Coanda Effect, the air above the wing is guided along the curved surface of the wing. Remember that this is only possible if the atmospheric pressure is greater than the pressure at the surface of the wing, making it 'stick' along the surface. Meaning, the pressure at the wing is lower than the atmospheric pressure at the top ( $P_u < P_a$ , where  $P_u$  is the pressure right at the top of the wing).

Combining both, we get ( $P_u < P_d$ ). This means that the pressure at the top of the wing is less than the pressure at the bottom of the wing.

Since the air sticks to the surface at the top, the air is deflected down when it reaches the back of the wing. This deflection downward also causes the air at the bottom to deflect downward. This turning of the angle of the wind flow downward causes the "push" or "lift" upwards.

The wind can be turned in two main ways: Increase the speed of the wind around the wing, by speeding up the plane or increase the angle of attack by tilting the plane upwards, which turns the wind down at a sharper angle. Flaps can also be used but that is a topic for another day!

Hence, the following are responsible for the lift in a wing:

- Newton's third law (every action has an equal and opposite reaction) - generates a lift in a wing at the bottom, since the mass of air is pushed down and back (lift and drag).
- Bernoulli's explanation is incomplete, but it is right that the pressure difference between the air at the top and at the bottom due to the Coanda Effect generates a lift towards the lower pressure (top).

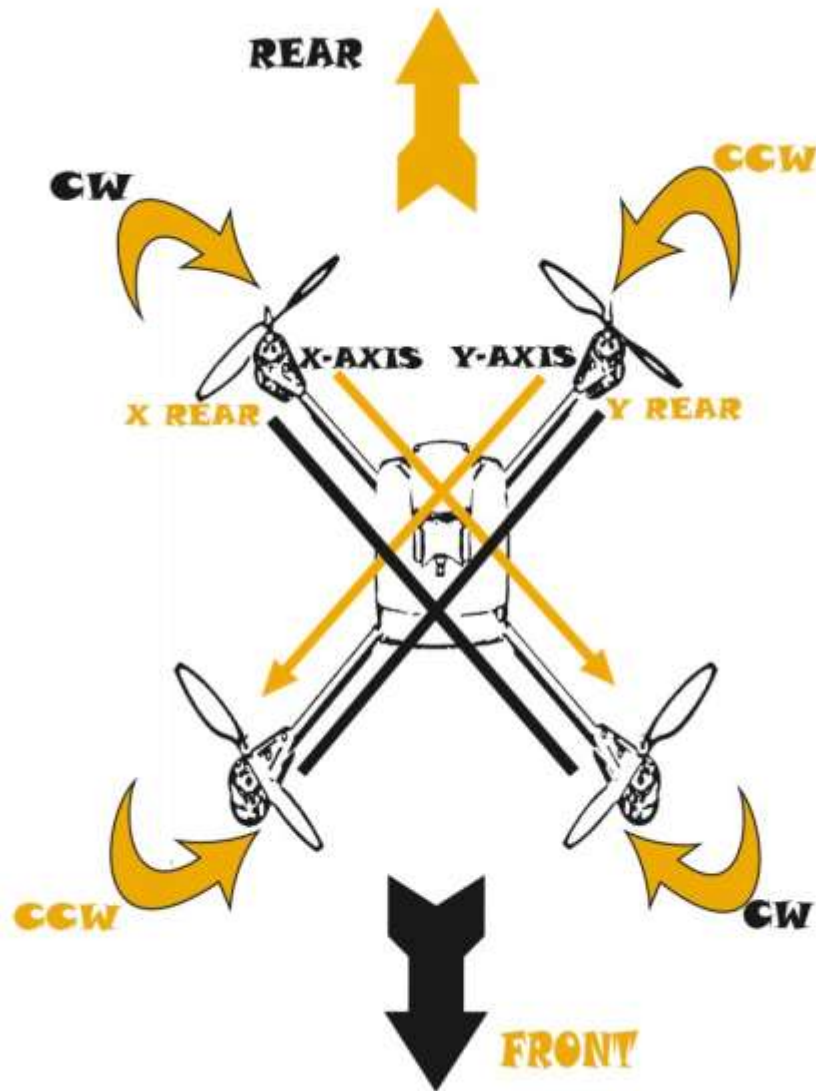
A propeller uses the same principles to keep these forces in action.

However, it keeps spinning to produce a push backward in order to move forward (Newton's third law in action). In a helicopters and multirotors, this also means a push downwards to move upwards due to its placement. Essentially there are two explanations:

- Mass of air is pushed downwards to generate lift.
- Difference in air pressure at the top and bottom of the props generates lift. This is why ducting a propeller can improve efficiency by limiting "air leak" due to centrifugal force that is lost as vortices. In simple terms, it stops the higher pressure air

at the bottom of the propeller from freely moving to the top and uses this energy instead, to contribute to lift.

# The motor direction



To have a balanced quadcopter, the propeller rotation has to be toward the quadcopter's main body at all times. To achieve this, a CCW motor has to be placed at the front right, a CW motor at

the front left, a CW motor at the back left and a CCW motor at the back right (as shown in the figure above).

This means that motors that rotate in the same direction will be placed at the opposite ends of the quadcopter.

Make sure that the placement of propellers on the motors is proper. You want to place a CCW propeller on a CCW motors.

If your propeller doesn't come with directions, it is easy to figure out what direction your propeller is supposed to be spinning by finding out which side the leading edge of the propeller is. This is easy - the leading edge is the 'sharp' or 'protruding' edge of the propeller.

## Why motors and propellers are placed this way?

When propellers rotate, applying the rotational analog of Newton's third law of motion (Every action has an equal and opposite reaction), it generates a torque effect on the quadcopter's body in the opposite direction.

Hence, if all motors rotate in the same direction, then the quadcopter will keep rotating (or yaw) in that direction. The cause and effect is an important function to understand here.

In order to counteract this torque effect, we need an equal amount of motors that spin in the opposite direction.

Helicopters work in a similar way. There is a main propeller at the top that generates the lift and another one at the tail end that acts as a counter-acting agent to the torque effect the main lifts propeller generates. You must have seen a helicopter's tail end getting gunned in action movies (or even real life, if your life is adventurous!), causing the helicopter to spin out of control before it crashes down eventually.

Hence with this setup in place, to yaw (or rotate) in a certain direction, the blade rotation must work in a way that the speed of two opposite motors that rotate in the same direction of the intended yaw is increased relative to the other two motors. For example, increasing the speed of two counter-clockwise motors will yaw the quadcopter to the counter-clockwise direction and vice versa.

## Gaining and losing altitude



So how do quadcopters fly high? In order for the quadcopter to gain altitude, all four of the motors must increase the speed of rotation **simultaneously**. Conversely, to descend down, all four of the motors must decrease speed of its rotation **simultaneously**.

This is what happens when you increase or decrease the elevator control on your transmitter - the speed of the motors change simultaneously.

# Pitch



The 'pitch' control tells the quadcopter whether to fly forward or backward. In order to pitch backward for example, the speed of the motors at the front of the quadcopter must increase, relative to the speed of the motors on the rear. This 'pitches' the tail (back) of the quadcopter down, resulting in the backward movement.

This is achieved by either increasing the speed of the rear motors or decreasing the speed of the front motors.

Conversely, in order to 'pitch' forward, the speed of the motors at the back of the quadcopter must increase relative to the speed of the motors at the front.

# Roll



The 'roll' control tells the quadcopter to move side to side. In order to 'roll' to the right for example, the speed of the motor at the left of the quadcopters must increase, relative to the speed of the motors on the right. This 'rolls down' the right side of the quadcopter, resulting in a side-ways swaying movement.

Like pitch, this is achieved by either increasing the speed of the left motors or decreasing the speed of the right motors. Conversely, in order to 'roll' left, the speed of the motors of the right of the

quadcopter should increase relative to the speed of the motors at the left.

# Yaw



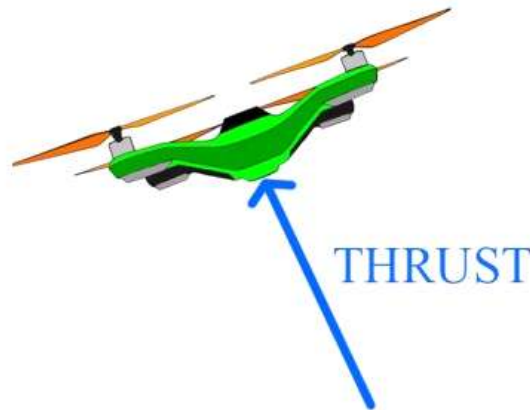
The 'yaw' or 'rudder' is a rotation movement of the quadcopter. In this case, the rotation speed of diametrically opposing pairs of motors are increased or decreased, varying the torque in the direction of rotation of that pair (remember that diametrically opposing motors in a quadcopter rotate in the same direction), causing the quadcopter to rotate in the direction of the increased torque.

# The basic physics of how multirotors work (optional chapter)

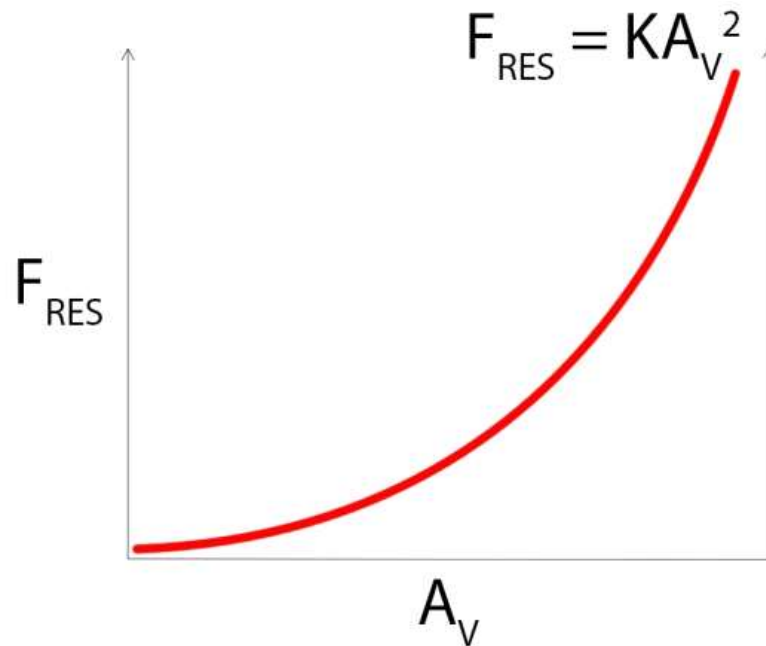
So far, we have covered the very basics of how quadcopters work. Here we will dive into some of the physics behind it. The quadcopter working principle and physics we are going to cover is by no means going to be exhaustive, but we'll discuss some basic mechanics underlying the quadcopter. In order to truly understand how quadcopters work, it is essential to delve deep into the mathematics.

## Physics of the hover

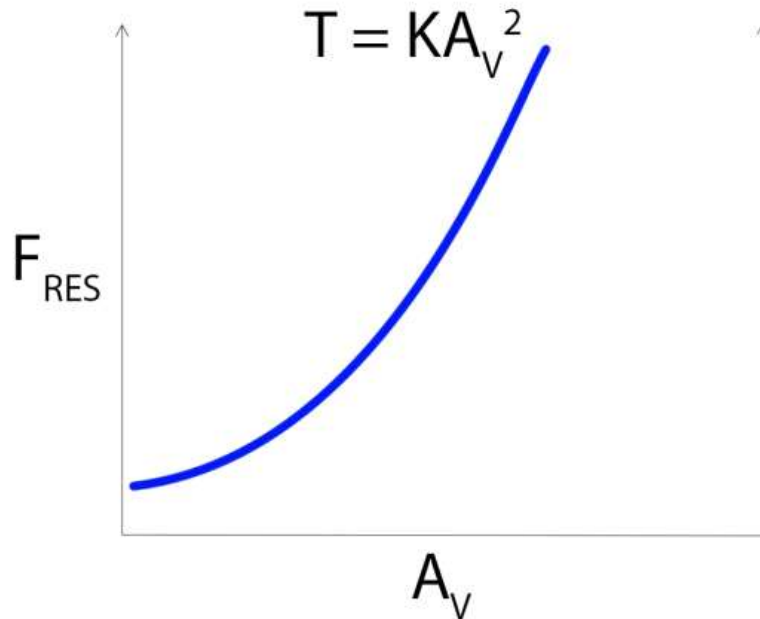
As we have already covered, the quadcopter has four rotors that act to support the craft's weight. This is how quadcopters fly each rotor in the quadcopter spins to generate thrust force (which we will denote here as  $F$ ).



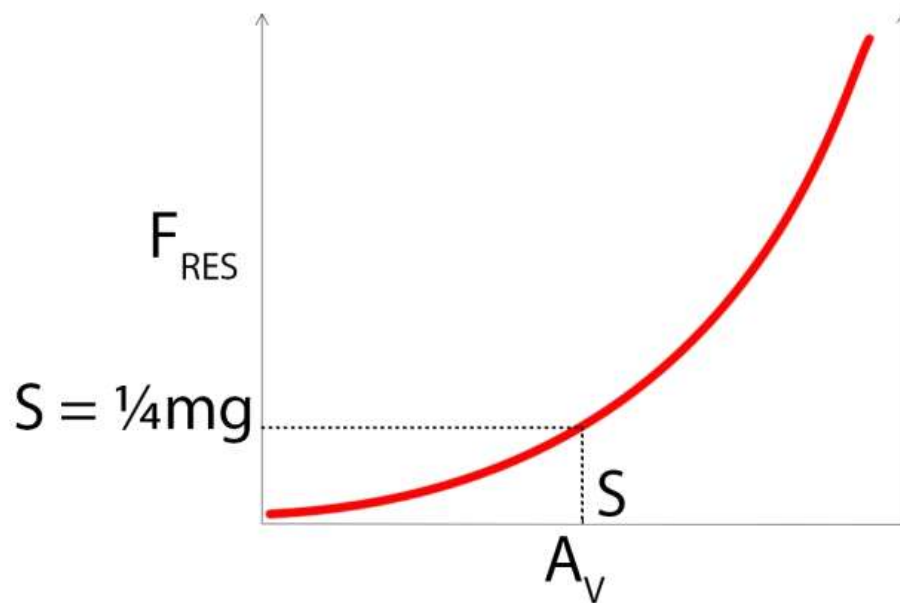
The relationship between this thrust and the RPM of the motors or the angular velocity ( $\omega$ ) is approximately quadratic. That is,  $F_{res} = K * \omega^2$  (where  $K$  is some constant).



We have also established what a drag is. Each rotor in a quadcopter has to overcome drag every time it spins. And as you may already know, a **moment** is the ability to make an object rotate (torque). The relationship between the RPM and the **drag moment (T)** is also quadratic. That is,  $T = K * A_V^2$

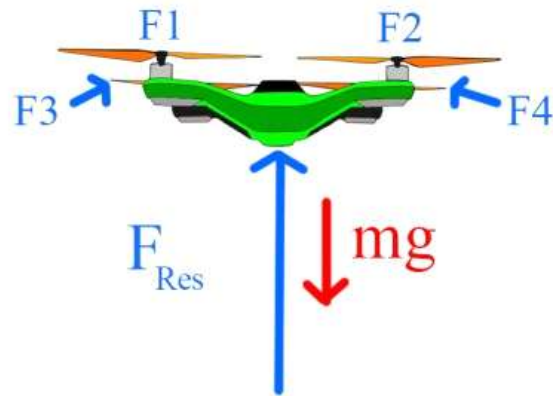


Since the quadcopter has four rotors, every rotor has to account for 1/4<sup>th</sup> of the total weight of the quadcopter, in order to hover. Hence, if you go back to the curve from the first graph (thrust vs RPM), you can elicit the speed that each rotor needs to spin in ( $S = 1/4$  Mass of the quadcopter \* acceleration by gravity).



That speed of rotation however, has to overcome the drag moment. This is where the problem of picking the appropriate size of the motor comes in. The size of the motor is chosen in a way that it can produce enough torque to counter this drag moment.

When the quadcopter is in a state of hover, the speed of each of the rotors compensate for the weight. After you have determined the speed ( $S$ ) of each rotor, from this, you can determine the torque each of the rotor.



The resultant force of the spinning of the rotors on the quadcopter is the sum of all the thrust forces by the four rotors, minus the force of the gravity ( $F_g = mg$ ), where  $m$  = mass of the quadcopter and  $g$  = acceleration by gravity ( $9.8 \text{ m/sec}^2$ ).

$$F_{\text{Res}} = F_1 + F_2 + F_3 + F_4 - mg$$

In case of the hover, this resultant force is zero ( $F_{\text{res}} = 0$ )

If we have determined the center of mass of the quadcopter, you can also calculate the total moment (torque) around that center resulting from the thrust forces.

$$M = r_1 * F_1 + r_2 * F_2 + r_3 * F_3 + r_4 * F_4 + M_1 + M_2 + M_3 + M_4$$

(where  $M_1 \dots M_4$  are moments around the rotors themselves and  $r_1 * F_1 \dots r_4 * F_4$  being the moments that are the reactions from the rotation of the rotors in clock wise and anti-clockwise direction.)

## Acceleration and deceleration

In order for the quadcopter to accelerate or decelerate, the resultant force and moment has to be non-zero. For example, for the quadcopter to vertically ascend, the resultant force has to be non-zero, increase the motor speed while keeping the thrust of the motors equal.

$$\text{Mass} * \text{acceleration (ma)} = F_{\text{Res}}$$

Similarly, if you reduce the motor speeds, the quadcopter will descend.

Hence, a combination of the motor thrusts and the weight of the quadcopter will determine the direction of the acceleration.

## PD (Proportional and Derivative) and PID control

Understanding this is very important to truly understand how quadcopters work. Since we need a  $F_{res} = ma$  to ascend or descend the quadrotor to a desired height  $x$ , we can write  $a$  (acceleration) as  $a = d^2x/dt^2$  (second order derivative) =  $x''$ .

Also, let us introduce  $u = 1/m * F_{Res}$ .

Therefore, we now have a second order derivative equation with the input as 'u' and the variable  $x$ , such that  $u = x''$  (since  $1/m * F_{Res} = a = x''$ ). That is, **second order dynamic system,  $u = x''$** .

The goal here now is to determine the input 'u' such that the quadcopter goes to the desired position  $x$ . That is to find a control input  $u(t)$  so that  $x(t)$  follows the desired trajectory  $x_{des}(t)$ .

The difference between the desired trajectory of the quadcopter and the actual trajectory is the error of the trajectory.

That is,  $e(t) = x_{des}(t) - x(t)$ .

Our goal is to minimize the error, making it converge exponentially to zero.

Hence, to do this, we find  $u(t)$  such that,

$$e'' + K_v * e' + K_p * e = 0 \text{ where } K_v, K_p > 0$$

By finding values of  $K$  that are  $> 0$ , we can guarantee that the error will go exponentially to  $0$ .

The equation for the control input is given by  $\mathbf{u}(\mathbf{t}) = \mathbf{x}''_{\text{des}}(\mathbf{t}) + \mathbf{K}_v^* \mathbf{e}'(\mathbf{t}) + \mathbf{K}_p^* \mathbf{e}$ . With this, the error will converge exponentially to  $0$  and ensure that our desired trajectory is achieved. Here,  $\mathbf{K}_p^* \mathbf{e}$  is the proportional gain while the  $\mathbf{K}_v^* \mathbf{e}'(\mathbf{t})$  is the derivative gain (since  $\mathbf{e}'$  is the derivative of the error,  $\mathbf{e}$  here). The  $\mathbf{x}''_{\text{des}}(\mathbf{t})$  is the feed forward term, which is the second derivative of the  $x_{\text{des}}(\mathbf{t})$ .

This is the control law, PD control law that is used to drive the motors of the quadcopter. With this in application in the code, the quadcopter trajectory may first start off with a slight error, but will eventually converge to  $0$  error, even if the error offshoots to the negative direction.

The proportional control acts like a spring. The higher the proportional term in the control law equation, the springier the quadcopter gets. Higher the proportional gain, the more likely the quadcopter is to offshoot its trajectory to negative error.

The derivative control acts like a dampening agent. High derivative gain will make the quadcopter converge its error to zero very slowly but is less likely to offshoot its trajectory to negative error.

## PID Control

In cases where there are external disturbances like wind or presence of unknown errors such as the mass of the quadrotor being unknown, PID control is used, which is a more complex version of the PD control. This is how quadcopters work better today.

The equation for this is  $\mathbf{u}(t) = \mathbf{x}''_{des}(t) + \mathbf{K}_v * \mathbf{e}'(t) + \mathbf{K}_p * \mathbf{e} + \mathbf{K}_i$

Where  $\mathbf{K}_i$  is the extra term. Note that this equation goes into the third order derivative.

For the PD system, when  $\mathbf{K}_p$  and  $\mathbf{K}_v > 0$ , the quadcopter becomes stable.

When  $\mathbf{K}_p > 0$  and  $\mathbf{K}_v = 0$ , the quadcopter becomes marginally stable.

When both the values  $< 0$ , the quadcopter becomes unstable.

# Building and choosing parts

## Picking the drone body/frame



The frame or body is what holds everything together. They are generally designed to be strong and lightweight and consist of a center plate where the main flight controller chip and sensors are mounted and arms where the motors are mounted. It is most often

made of carbon fiber, titanium, fiberglass, aluminum, balsa wood or steel. Some cheaper, smaller models also use plastic.

Carbon fiber is the most ideal material for a quadcopter frame. They're very strong, stiff, durable and light. If you are building your own frame however, know that carbon fiber is toxic to breathe!

The second most commonly used material is the fiberglass. They are however, softer and less durable than carbon fiber. They are also relatively heavier. However, they're pretty cheap!

If you are looking to build your own frame, we suggest you use balsa wood or plastic to begin with. Though they are not the most ideal in terms of sturdiness or weight, they are easier to acquire and build on.

With some creative thinking, you can even build frames out of PVC or duct tapes!

As of pre-made frames, they come in varieties for different multicopter types: Tricopter, quadcopter, hexacopter, octocopter. It also varies on different builds, especially if you are building a quadcopter. The X-frame is the most popular and is used on most quadcopters, the I-frame (mainly used on racing drones) and the V-tail frame.

You should also consider the size of frame. Different sized frames will be capable of swinging different sized props. And as we'll see

in the next section, larger multirotors are usually used to fly high altitudes and in rougher wind conditions while smaller multirotors are more capable of agility.

In conclusion, consider the following before picking a frame for your multirotor:

- Do you want to build one on your own or buy a pre-existing one? If you want to build one, consider using materials such as plastic, balsa wood, PVC or even duct tape! If you want to buy a pre-existing frame, we recommend you start with either fiberglass or carbon fiber.
- Consider the size of the multirotor you want to build and choose the frame size accordingly. Larger multirotors are ideal for flying high altitudes and in tough weather and for carrying payloads for photography, videography and thermal imaging while smaller ones are agile, maneuverable flyers (think indoor flying and drone racing).
- This is related to the above point, but consider the size of the propeller you want the drone to rotate. You do not want your frame to be so small that the propeller would clip into the frame while swinging. At the same time, you want your frame to be small and light enough for your chosen propeller size to generate enough thrust to generate lift. We'll see this in the next section.
- Choose if you want to build a tricopter, quadcopter, hexacopter or octocopter.

- Pick the type of frame: X-frame and I-frame are the most common types of frames if you are building a quadcopter. X is the most stable with perfect centre of gravity while I frame is suitable if you need room to add stuff ON the quadcopter, for example, FPV equipment for drone racing.

## Picking the motors and propellers



The motivation behind using motors is to turn the propellers, which is responsible for providing thrust for countering gravity and drag. Every rotor ought to be controlled separately by a speed controller. Motors are the primary force behind how quadcopters fly.

They are somewhat like typical DC motors in the sense that coils and magnets are utilized to drive the shaft. The brushless motors do not have a brush on the shaft that deals with iterating the power in the coils, hence, the 'brushless' reference.

The brushless motors have 3 coils on the inside center of the motor, which is settled to the mounting. On the external side, it contains

multiple magnets mounted to the cylindrical structure that is appended to the turning shaft.

Hence, the coils are fixed and there is no need for brushless. Brushless motors turn a lot quicker and utilize less power at the same speed relative to DC motors. Unlike DC motors, they don't lose power in the brush-transition, so it is a lot more vitality productive.

The Kv (kilovolts) - rating in a motor demonstrates how various RPMs (Revolutions each moment) the motor will do per volt. The higher the kV rating is, quicker the motor rotates at a steady voltage.

Having a basic idea about brushless motors and the ability to understand different configurations and specifications will go a long way if you want to tweak and build your multicopters.

Though the specifics behind the inner workings of these motors are beyond the scope of this post, we will cover enough for you to be choosing motors and propellers that are right for your craft.

## **KV rating**

The first thing you need to understand is the KV rating. Here, it stands for the number of rotations the motor makes per minute for every volt applied to it. Higher the KV, the faster it rotates per volt.

Most motors come with the KV rating printed on it. If you are unsure, you can use a tachometer to get a rough idea of the RPM (Divide the RPM on the tachometer with the number of volts the battery you connect to has)

Generally speaking, high KV ratings are found on smaller motors and these are used to drive smaller propellers. These motors tend to be thinner. Larger motors with lower KV drive larger props. These motors tend to be wide and short.

The choice should be on whether you want speed and acrobatics or the ability to carry heavy loads and fly high (typically for aerial photography). For speed, you typically want a high KV - small prop setup. For carrying heavier loads, you want larger propellers and motors capable of such propellers.

## Voltage, Power (Watts) and Thrust

The voltage specification on your motor determines how much voltage can be applied to it. This generally comes as a function of propeller size. As the amount of voltage applied on the motor increases, it is recommended that the prop size be reduced. Most manufacturers will have a recommended propeller size.

Power (Watts) is Voltage x Current. Generally, higher the Watt rating of the motor, the higher will be the power of the motor itself.

This is maximum potential horsepower your motor can produce, without being damaged.

Thrust is roughly the measure of how much the motor is capable of producing a propulsive force. Most manufacturers will print the thrust rating of motors on the motor itself. If you are unsure, you can use an [online calculator](#). It is still recommended to contact your manufacturer to make sure.

So that's it for motors. Hopefully by now you have an idea about the KV, voltage and thrust ratings of motors and what it means. We will be using this information very soon.

## Propellers

Understanding propellers and knowing how to choose the right ones is important as it typically goes hand in hand with the choice you make with the motors. While you can use this information to decide what propeller to choose, never go overboard and always stay within the prop size ranges recommended for the motor.

### Propeller diameter and pitch

When you go to purchase propellers, the specifications on it are defined in terms of diameter and pitch (D x P). For example, a 9 x 4 propeller has a diameter of 9 and a pitch of 4.

The **diameter** is the end to end length (in inches) of the propeller. It determines how much surface area of the prop is in contact with air around it at all times. Note that slight variations in propeller sizes can drastically change the responsiveness and efficiency of your craft.

Larger props swinging at lower RPMs are paired with lower KV rated motors and are more efficient relative to smaller props paired with higher KV rated motors.

Larger props are used in scenarios where there are heavy loads (like a camera) attached to the craft and are ideal for aerial photography and videography. Smaller props are ideal for speedy crafts ready to take on acrobatic maneuverers.

The '**pitch**' of a propeller can be defined as the distance (in inches) travelled per revolution. Higher the pitch of a prop, the speedier your craft gets. This comes with a price - higher pitched props produce turbulence and are not as energy efficient.

Lower pitched propellers, like the longer ones are ideal for flight efficiency, hence used for aerial photography and videography while higher pitched propellers are picked for speed and acrobatics.

When picking the right propeller, it is important to consider both the diameter and pitch. Finding the balance between both is one of the key factors to building an amazing craft.

## Material used

Propellers are built with different materials including plastic, carbon fiber and wood. The material that the prop is built with can make a difference in flight times and efficiency. Generally, carbon fiber props tend to be lighter and can add to flight times.

As a general rule of thumb, quality matters more than the specific material used and can make a world of difference in your flying experience including reduced vibrations and increased responsiveness and stability.

## Rotation

It is very important to purchase both clockwise and counter clockwise propellers while building or tweaking your craft. Both should be purchased in the same amount. It would be simply impossible for your quadcopter to hover and fly around if all of the props rotate in the same direction.

## Putting it together

Now that we have shed some light into the basics of motors and propellers, it is time to put that knowledge to use to build or tweak our craft.

First, we need to consider the weight our craft. While measuring the weight, it is important to consider everything including any cameras or loads that maybe attached to it. Next, we have to take into consideration the **thrust to weight ratio** of the multirotor. This is the most important element.

We want our craft to be able to hover at about half (50%) throttle. This is to ensure that we have ample headroom for speeding and gaining altitude when necessary. To get this, it is generally recommended to **aim for a thrust to weight ratio of 2:1**.

However, we should aim for a little bit more than that to account for any inefficiency with the motors and/or propellers. Hence, a **2.5:1** thrust to weight ratio would be ideal. For example, if our craft weighs 500 grams, we should then aim for a total thrust of 1250 grams.

Note that when we measure the thrust, it is the **total** thrust. Hence, while picking motors, we divide the total thrust by the amount of motors. Hence, for quadcopters, we divide the thrust by 4. In our previous example, thrust per motor would be  $1250/4$  or about 312 grams. For tricopters, we divide total thrust required by 3 and so on.

After you have picked your motor, it now boils down to picking the right propeller to go along with it. As mentioned before, stick to using propellers near what is recommended for the motor for any particular cell count.

We have already covered the basic things that you need to know about propellers. Remember that larger propellers with lower pitch ratings are more efficient than smaller propellers with higher pitch ratings. Higher KV ratings on the motor aren't everything for every scenario. Remember - balance is key and you may need to play around a little bit before you find the perfect combination for your specific purposes.

Other important things to consider -

- **Make sure your motors can handle the voltages of the battery.**
- **Make sure the propellers come within recommended range.**

## Picking ESCs



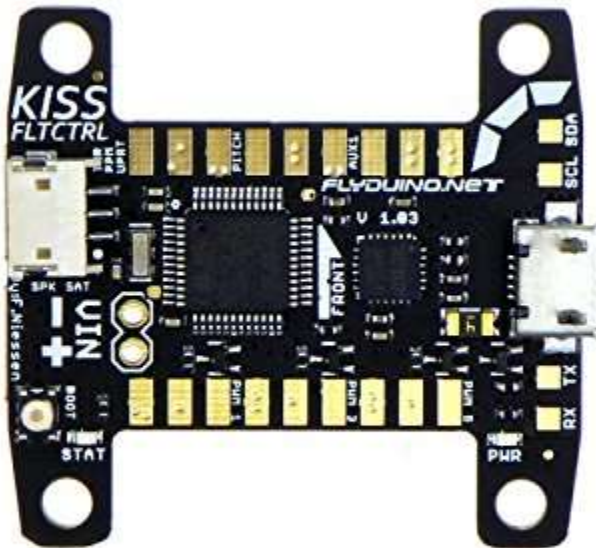
Motors spin, but in order to fully understand how quadcopters work, we need to understand how the motor is controlled. The electronic speed controller or (ESC) is what tells the motor how to spin. It is responsible for controlling the rate at which the motor it is connected to, spins. Since the multirotor motors are supposed to spin at variable speeds, depending on control inputs, ESCs are crucial. In a multirotor, each motor will have an associated ESC connected to it.

The ESCs are connected to the batteries via the power distribution board within the multicopter's frame. Most ESCs come with a battery eliminator circuit (BEC) which acts as a voltage regulator, allowing other electronic components like the flight controller and receiver to power up without connecting them directly to a battery. If your ESCs do not come with an in built BEC, make sure to get a compatible BEC!

It is important to measure the current draw of the motors to make sure that the ESCs can support it. Never load the ESCs with motors that draw more than the current rating of the ESC.

Suppose our motors have a current draw rate of 10 Amps, it is important to make sure that the ESCs have a current rating of at least + 30% to allow for some headroom in case of unforeseen circumstances. In this example, we will be picking at least 13A ESCs.

## Picking flight controller



The flight controller is the mind or 'brain' of the multirotor. This board is what sits at the center, controlling the firmware within the ESCs, consequently controlling the spin rate of the motors. This is how a quadcopter flies.

Essentially, it takes the inputs from the receiver (Throttle, Elevator, Rudder and Aileron) and adjusts the motor RPM accordingly, via ESC.

Flight control systems house additional sensors to enhance control and stability of the craft. The controller usually contains gyroscope, accelerometer and barometer. GPS can also be added onto the flight controller to feed coordinate information and altitude information of the multicopter.

The following is the sequence of how quadcopters work: Flight controller -> ESCs -> Motors.

To figure out what is the best flight controller for your craft, you must first figure out **WHAT EXACTLY** you are trying to accomplish. Are you a beginner trying to build that first quadcopter/multicopter? Do you want to A 5C charge rate on a 1000 mAh battery would allow you to charge it completely in 60 minutes/ $5 = 12$  minutes.

build a fast, racing style multicopter? Or are you a tech savvy cinematographer looking to build a multicopter to add to your photography and videography repertoire?

Of course, depending on what you want to accomplish, the price will vary. A flight controller like the KK2.X for a beginner or a Naze32 (which is typically popular on racing quads), would be way cheaper than a flight controller capable of autonomous flight and videography. Racing quads are often equipped with flight controllers that are on the cheaper end of the scale (mainly because they are prone to crashing).

## Ease of setup and firmware

I don't know about you, but to us, a flight controller that is a pain to setup is less valuable than one that is easy to get going with. Some boards are compatible with configurator software packages such as CleanFlight and OpenPilot, which are very easy to setup. CC3D and Naze 32 are examples.

Other boards like the KK 2.X models, come with an on-board UI that makes tuning (PID, for instance) very easy, without having to go back to your PC all the time. Many boards come with their own configurator package and firmware.

## Fly-ability

Not all flight controllers fly the same. Some flight controllers are better than others at handling and balancing. The KK 2.X model's handling capabilities for example, is far inferior to the Eagle tree vector.

**Quick note:** Please make sure to update your flight controller firmware before even setting it up and taking it out for flying. Many boards have reported to have significantly improved their fly-ability from their initial firmware release (including the KK 2.Xs).

## Supported sensors and capabilities

Last but not in any way the least, you must consider the capabilities that the said flight controller supports. The following is a list of sensors and features that you must check whether or not the flight controller supports, depending on your needs:

- Microcontroller bit size (8bit vs 32 bit): 32 bit flight controllers are far superior to 8 bit ones in terms of handling the craft
- Gyroscope and accelerometers : All flight controllers have these
- Barometer : Holding altitudes (A requirement for most cinematography based multicopters)
- Magnetometer : Useful for detecting direction (head holding)
- GPS : Useful for autonomous flights
- Whether or not the flight controller supports the kind of craft you want to build: (quadcopter, hexacopter, tricopter, octocopter and so on and so forth)

In Summary, consider the following before making a purchase:

- What do you want to build with the flight controller? A 250 style quad? An autonomous flying machine? A cinematography capable drone?
- Supported sensors and other capabilities
- Open source vs. closed source?

- Is the said flight controller new or is it tested thoroughly and battle hardened over the years?

## Picking Transmitters and Receivers



The radio transmitter and receiver is used to control the quadcopter. In order for a quadcopter to work, four channels (throttle, elevator, aileron rudder) are required. Getting a transmitter with 6 or 8 channels is recommended for additional functionalities.

Quadcopters can be programmed and controlled in totally different ways. However the most common ones are in either rate

(acrobatic) or stable mode. In rate mode, only the gyroscope is used to control the quadcopter balanced, it does not self-level.

If switched to stable mode, the accelerometer gets activated, helping to stabilize the quadcopter. The speed of the 4 motors can be adjusted automatically and perpetually to keep the quadcopter balanced.

A transmitter may also have an FPV screen on which a camera mounted on the multirotor beams video in real time. This gives the pilot a unique experience of flying by seeing what the multirotor sees.

## Budget

Before you go about looking for the best RC transmitter for your RC quad, heli or plane, you should first set a budget. RC transmitters can range from \$50 to all the way up to \$1000! Now of course, this will depend on how committed to flying you are. If you are a beginner, it is recommended that you get a cheap (but good quality) transmitter.

However, if you plan on flying for years to come, we recommend you invest in a higher end, higher quality transmitter that you can use for multiple, different crafts that you would purchase or build on your own.

## Number of channels

This is more or less tied to the budget. Typically, the higher the number of channels the transmitter supports, the higher the price. RC transmitters for quadcopters, planes and helicopters range from 4 channel to all the way up to 10 channels and beyond.

- The basic 4 channel transmitter offers the following functionalities on its 4 different channels -
  - Throttle
  - Yaw
  - Pitch
  - Roll

The additional channels on the transmitters are typically used for changing flight modes or changing control to a camera gimbal by 'switching'. For example, on a quadcopter, you could use the additional channel switches to change from 'Acro' mode to self-level mode.

For a beginner, a 6 channel transmitter like the **Spectrum DX-6i** would be a great long term investment. A transmitter like this would allow you to have all the basic functionalities plus the ability to change flight modes.

If you are more advanced, an 8 channel transmitter like the **Futaba T8J** or a 9 channel model like the **Hi-Tec Aurora 9** is a great buy. Another GREAT transmitter you should check out is the

**FrSky Taranis X9D**. It is reasonably priced and supports over 14 channels!

## Memory

Model memory is another consideration that must be taken into account, especially if you plan on flying multiple different crafts including different quadcopters, helicopters or planes. Needless to say, the ability to store settings for your different crafts should not be underestimated.

The basic models like the **Spektrum DX-6i** has a model memory of 10, which should be more than enough for a beginner. On the other hand, some models like the **Spektrum DX9**, can store up to 250 models!

## Features and build quality

The amount of features your transmitter has is yet another consideration. Having a backlight in the display screen can seem trivial but can make a big difference in your usability experience. Other things to consider are:

- Build quality and how the gimbals and the sticks feel

- Buddy training support
- Programmable firmware

## Bind and fly models

This is something that cannot be stressed enough. If you plan on purchasing a transmitter for a bind and fly quadcopter, plane or helicopter, make sure that it is going to be compatible with the model or you'll be wasting your money.

## Modes

Note that there are 4 different modes transmitters come in. The most common mode that you would see is mode 2. Make sure to check that your transmitter supports the correct mode you are used to flying in.

## The ability to use with a simulator

We recommend that you do not overlook this. Especially if you are a beginner, you might want to train plenty on a flight simulator. The OrangeRX T-SIX for example, is a cheap, 6 channel transmitter for beginners and it works well with flight simulators, so we consider it as a great buy.

Flight simulators are a great way to train if you are a beginner. They are also an excellent tool to maintain your skills during harsh winter conditions since you probably wouldn't be able to head out much!

## Picking batteries



Lithium Polymer (LiPo) batteries are the most famous power source for controlling multirotors (or 'drones') today. Without going a lot into detail, the principle explanation behind this is on the grounds that they are rechargeable and ordinarily have expansive limits.

LiPo batteries can have discharge rates sufficiently expansive to control even probably the most taxing multirotors. This settles on them the favoured decision over different choices, for example, the

Nickel Cadmium (NiCd) battery. This is likewise the essential reason they can be a genuine fuel source for multirotors.

## Capacity

Higher the capacity for your battery, the longer flight times you can expect. There is an important caveat here however - batteries tend to get really large and heavy at larger capacities and so you cannot simply scale this indefinitely.

Weight is an important factor to consider when selecting your LiPo batteries. Even if you get a battery with the largest capacity on the planet, it may not give you the flight times you'd expect.

Remember that the heavier the craft gets, the harder it is on your motors and propellers. This means more power drawn and that defeats the purpose of going for a larger battery in the first place! And if you go too heavy, your craft may not fly at all. Remember the thrust to weight ratio!

## Go for the highest C (discharge) rating possible

If budget permits, go for the highest C rating possible on any given capacity. If you get too frugal here, you could damage your motors and ESCs! Not to mention you would be completely limited in your ability to do all the cool moves with your RC craft!

When you are out LiPo shopping in your local hobby store, it is better to pick one solid, highly dischargeable battery than 2 or 3 batteries with low C rating.

## Voltage

When you pick your LiPo, make sure it meets the voltage requirements of your motors! For example, if your motors require 10 volts, make sure your batteries have a reading of at least 10 volts!

This means that the amount of required cells in your battery (The 'S' rating) would vary from motor to motor!

Like discharge rate, if you go too low, it will damage your motors!

# Picking a drone kit



Kits are the easiest way for a beginner to learn how to assemble a multirotor drone. It comes with all the basic parts you'll need and every part is designed to work with one another.

The other advantage of a quadcopter kit is that it is cheaper. A similarly powerful RTF quad would be much more expensive.

You could of course buy all the parts needed separately and build a custom quad instead of getting a quadcopter kit, but we discourage you from doing that if you are new to this. Quadcopter

kits come with all the necessary parts in configurations that **work well with each other**. You don't have to calculate and experiment.

## Quadcopter size

Before you go about choosing the best quadcopter kit, you should decide the size of the quadcopter you want to build. The 450 quad is fit to carry heavier batteries and other payload. They are also faster and stable, especially in windy conditions. That being said, the 250 style quad is more maneuverable.

## Glass fiber vs. Carbon fiber for the body

Most kits come with a body that has a glass fiber body while others have a carbon fiber body. What you need to know is that carbon fiber is lighter and more rigid but glass fiber is much more "flexible", making it less prone to breaking. Cost wise, glass fiber is much cheaper.

[Here is a list of quadcopter kits](#) that we usually recommend to beginners. We try to keep the article updated as much as possible!

# Putting it all together (Building a simple multirotor)

Mount the power distribution board onto center of the frame



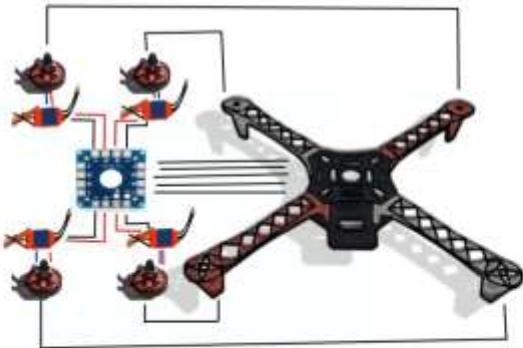
Connect the ESCs onto the power distribution board, zip tie them onto the frame under each arm.



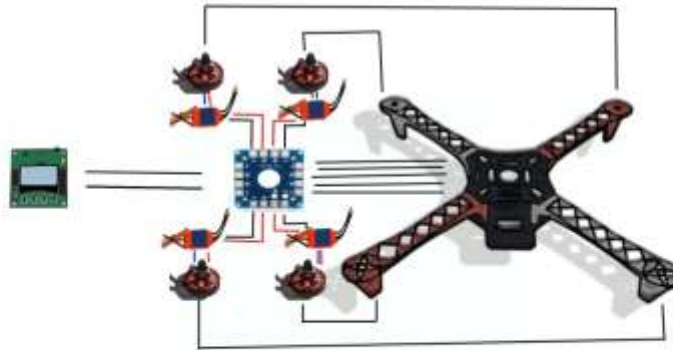
Connect the motors to the ESCs (use bullet connectors)



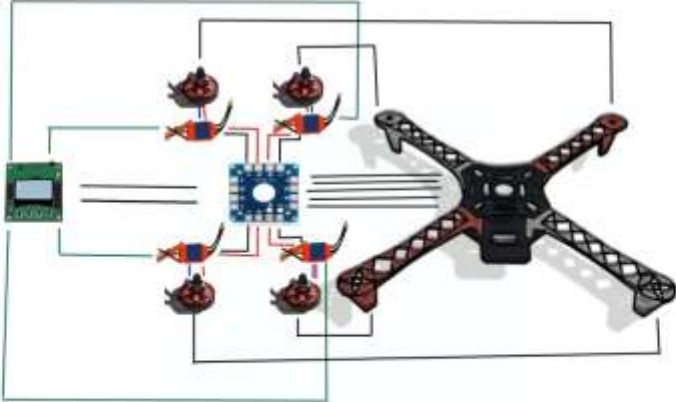
Screw the motors onto the frame.



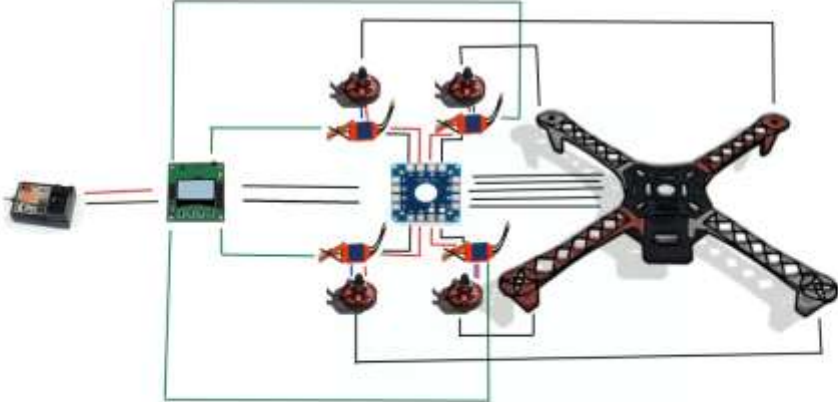
Mount the flight controller onto the center of the frame, above the power distribution board. Note that the flight controller will not be directly connected to a power source. The power will be delivered via the ESCs



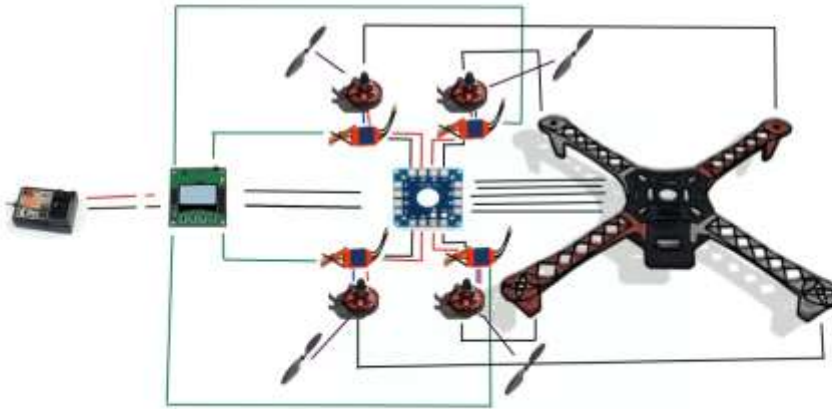
Connect the ESCs to the flight controller



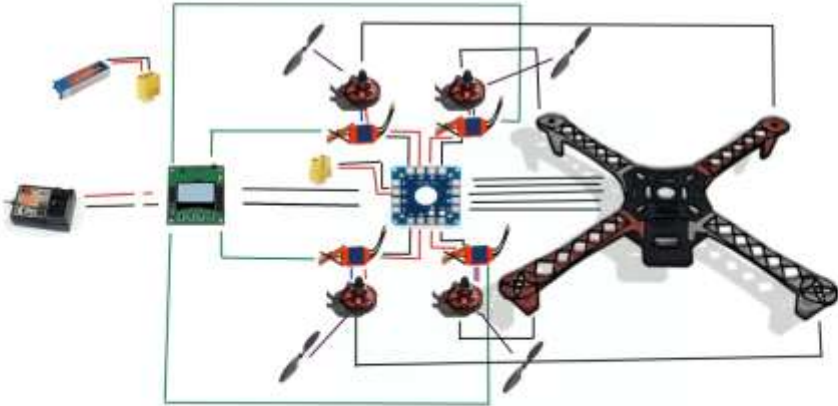
Connect the flight controller to the receiver



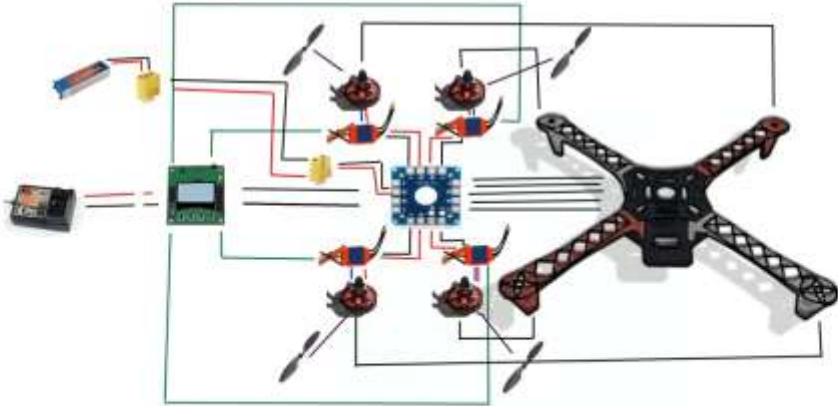
Mount the propellers onto the motors. Note: You may want to skip this step and leave it till the end if you want to test the motor orientation. If the rotation of any motor is not correct, simply switch the ESC -> motor wires for that particular motor.



Connect the battery and solder wires onto the power distribution board onto complimentary connectors so they can be connected.



Connect the battery. Your multirotor should now power up. Time to test it out!



# ACCESSORIES

## Drone cases



The very first accessory we recommend as one of the best drone accessories is a solid case to put your drone in. Drones generally

have delicate parts and joints that can easily be damaged if you are not careful. This holds true not only when you are carrying it when you are headed out, but also when you store it somewhere around your household.

There are two different kinds of drone cases out there. The first type is one that is custom made for your particular drone model and has a placeholder that is shaped according to the drone model. The second type is multi-purpose in which you can put any type of craft in.

If you have to pick one, we recommend going for the custom made case. However, if there are no cases available for your particular drone model, go for the multi-purpose one. In either case, getting a drone case (no pun intended) should be one of the top priorities especially if you are planning on traveling with a drone.

Although you have a variety of different options, hard case, custom made ones are usually the most expensive. If you have a semi-professional grade and above class drone, we recommend you not try and save money here. It is usually not a good idea to try to protect a \$1000 drone with a cheap quality drone case.

# Sunshade



A sunshade is a must have for heading out on a sunny summer day. Even if you are not flying FPV, you do want to see what is happening on the FPV screen attached to your controller, right? It is important to know where your camera is pointing at!

They are generally made of cardboard or plastic, attached to the controller over the phone grip or the screen. They may look a bit cheesy but they also make your life much easier! Definitely one of the best drone accessories you can invest in.

You do not even have to purchase one. It's pretty easy to make one. You could cut up a cardboard box or gable box, measure your screen and controller size and build your own sunshade around it!

## Lens improvement: lens protection, ND filters and hood



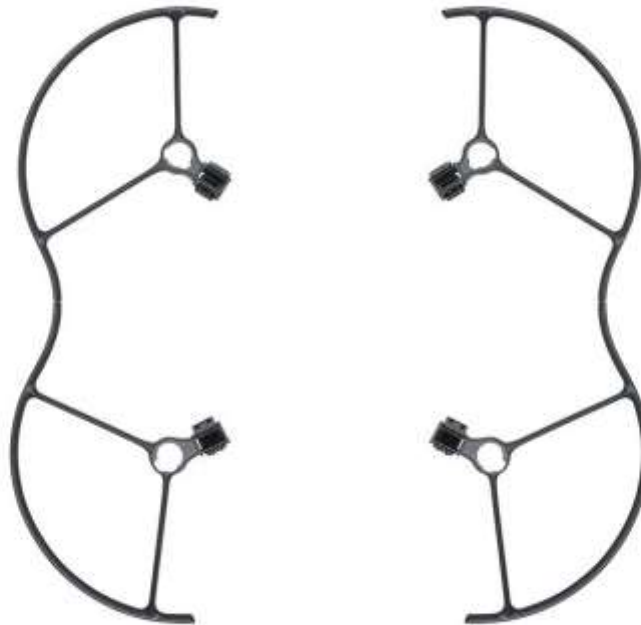
An important accessory you might want to consider is lens protection. Though it might not protect your camera lens from cracking or serious damage if you crash, they will do a pretty good job of making it scratch resilient.

Another accessory to improve your lens is a lens hood. This is one of the best drone accessories, despite being simple and a must have especially because it is a cheap solution for lens flares and propeller shadows.

Yet another accessory that will come in handy during a sunny summer day is an ND filter. If the amount of light in the environment is too much, the camera will have to increase its shutter speed, causing a “jerky” effect. An ND filter is a workaround for this problem.

Simply put, it will allow your camera to shoot at a slower shutter speed even during bright sun light making it one of the best drone accessories you can get if you are into drone photography. We’ve tested the ND filters by Newer in the picture and it worked great!

## Propeller guards



We recommend getting a propeller guard for your drone no matter what your skill level is. It will definitely improve the resilience of your drone by making it less prone to damage from collision.

However, the main reason we recommend installing a prop guard on your drone is because it provides an additional layer of protection **AGAINST** the drone crashing onto a person. No matter how skilled you are, it is not a 100% certain that accidents will not happen. A sudden, strong gust of wind is all it would take to blow a drone off its course unexpectedly.

Do note that if you install a propeller guard and it is rather heavy, you can lose a lot of flight time and speed. Remember that the heavier the drone gets, the shorter the flight time becomes!

## Propeller balancer



A prop balancer is an accessory you will most likely want to add to your repertoire today if you are regular flyer. Propellers get worn out and hence unbalanced with use. Moreover, some manufacturers ship poor, unbalanced propellers in the box right from the start. One side of a propeller for example, can be heavier than the other and so on.

An unbalanced prop is the number one reason for drone's "wobble" or "jello". If you notice this phenomenon, it is time to

balance your propellers. A must have drone accessory and one of the best drone accessory for any serious drone flyer.

Unbalanced propellers on your quadcopters are not only a mere annoyance, but can also damage your internal electronics and engine bearings over time. An unbalanced propeller also turns relatively lower RPM. So why let this problem linger? If you want suggestions, then the DuBro Truspin propeller balancer is a great product. You can get this off Amazon.

## Lights

Some of nature's most beautiful moments are during dawn and dusk. Arguably, these are the times you want to head out for the best possible shots. However, unless you have eagle eye+x-ray vision, your line of sight range is going to be much lower when it is nearing dark/after dark.

Getting an LED light and installing it on your craft solves this problem. Hence, they are one of the best drone accessories you should look forward to installing on your drone.

The best way to install LED lights onto your multicopter is to get a receiver controlled switch as an intermediate. This receiver controlled switch will then be connected to the receiver. This way, you can turn your LED lights on and off with your controller (based on the channel on the receiver you connected it to).

## Gimbal guards



Gimbal guards are attached to the bottom of your drone and will help keep objects such as grass, stones and sticks away from the gimbal motors, giving it an additional layer of protection. It is also great if you are a beginner and haven't mastered proper, smooth landing yet.

The best gimbal guards are usually made from carbon fiber and have cut-outs that make it lighter, without reducing the integrity and sturdiness of the guard. With proper installation, the camera view won't be obstructed even if it faces directly downwards.

What's more - No more error message that says "Gimbals motors are overloaded!". Any additional layer of protection is always good for a drone that you paid a fortune for!

## Range extensions



A range extender may not be a **MUST HAVE** for most situations. After all, you can only legally fly up to 400 feet and within line of sight (In the US at least). Moreover, flying long distances will

ultimately be limited by the amount of charge your battery can hold.

A range extender, most commonly a power booster is however a great add-on to your drone. Such power boosters can boost the output of your transmitter to 2W! With appropriate setup, ranges as far as 30 miles are not unheard of. Do take into account the potential noise output, from using such high power setup.

Another way is by replacing stock antennas with high gain antennas that run with more power.

So if your stock antenna has is a 2 dB, you might want to upgrade to a 4 or 5 dB antenna. This will increase your power draw to about double. Say it was 60mW, with this setup, you could be hitting 200mW! This can increase your range anywhere from 30 - 50%.

Yet another way is by using an UHF system like DragonLink. This gives you the flexibility to pick lower frequency radio within the UHF range. (Well below the standard 2.4 GHz to about 400 MHz).

As you may or may not know already, lower frequency radio waves travel longer distances before getting attenuated than their higher frequency counterparts. Lower frequency radio waves also tend to travel through objects better.

Not only this, you get to lower the frequency for your video transmitters and receivers as well without having it interfere with the transmitter radio. This means, longer range for your video signals as well. Be wary though, lower frequency waves like the 400 MHz are littered with interference! You might have to get your hands on a spectrum analyzer to see how much noise output a particular spectrum has.

What's cooler than having a craft which essentially becomes an extension of yourself with FPV and capable of flying long distances? That's right. Nothing!

# Framework for fixing and repairing your multicopter

## Tools and skills you'll need

To fix a drone, you will usually need soldering equipment, screw drivers and tape. Soldering skill is an **absolute must** not just for repairing but for building a multicopter from necessary components. Why delegate mastering it?

Also, remember that you will be starting small. If you repair and disassembling skills are not sharp, do not try it on an expensive camera drone. Learn to disassemble and repair smaller quadcopter and gradually work your way up to the more expensive ones.

Understanding how a multicopter drone is structured is extremely important too. This is why we recommend learning how to assemble a cheap quadcopter from a kit at a bare minimum to achieve an almost intuitive understanding, so you will be able to diagnose and fix the problem immediately.

## Diagnosis and parts replacement

It's not time to throw away your drone if you crash it and it happens to not function from then on. It is important to know how to methodologically understand and isolate what the problem is and fix it. Not having a framework to fix your drone may make your flying endeavors very expensive in the long run.

If you have crashed and damaged your drone a small replacement will get you back to flying in most cases. If you think replacement is too much, we've even listed how to fix some of the common problems with damage and imbalances to different parts of a multicopter.

First, here is a diagnosis test to check what is causing the problem and where the damage or imbalance has occurred. 99% of the time, if you isolate and fix that problem, you've fixed your drone's flying issue.

## Damaged propellers

The most common damage is done to the props. Check if it is broken. If it is, replace them.

## Worn and unbalanced propellers

This is harder to detect but if you fly regularly, then your propellers are going to get unbalanced and worn out at some time. Observe carefully and see if any or all of your props are worn out.

## Wrong propellers

Make sure the right propellers are installed on the right places! Do not for example; install a CCW prop on a motor that is supposed to spin clockwise. We have already covered how to identify propeller orientation.

## Damaged motors or ESCs

If you props are okay and it is simply the case that your motors simply won't turn, then either the motor or the ESC is damaged. Before you decide which one, disconnect the suspected motor from the suspected ESC and test it with another motor that works. If it works, you know that it is the motor. If not, you know that the ESC has probably fried.

## Damaged or worn out frame

An unbalanced or broken frame can easily make your multicopter unflyable. Check for worn out or unbalanced parts of your frame. Do not take it for granted that it is safe to fly a drone with a broken frame!

## Damaged or worn out batteries

Battery care is extremely important. If you suspect your batteries are out of whack. Replace them immediately. DO NOT be lazy on this one or it can be hazardous!

You can tell if a LiPo battery is bad and needs to be disposed by the following:

- If the battery cells discharges too unequally every time, time to throw it away. For example, after flights session on a fully charged 3S battery, if the battery cells read something like 3.3, 3.3 and 3.5, your battery is bad.
- A sure way to tell if your LiPo battery has to be disposed is if your LiPo battery gets puffed. Never keep using a puffed battery even if it works. It is a risky endeavor and you risk fire/explosion.

## Malfunctioning transmitters and receivers

Switch the transmitter/receiver onto another multirotor to check if they are functioning. Don't blame the poor drone if it is not its fault!

## Connection breaks

Disassemble the drone and check for connection breaks and wire damages. If you find any, replace them and solder fresh ones.

## Flight controller tuning

If you are sure none of the above is a problem, the flight controller of the multirotor is either completely dead or it is out of tune or out of position.

If it is dead, you need a replacement. If it is out of position and tune, you need to re-position it onto the center of your multirotor and re-calibrate and tune it. We'll see how, in one of the next sections.

# Fixing motors and ESCs

## Fixing stiff motors

The easiest way to fix a stiff motor is to disassemble the motor from the drone, hold a screw driver perpendicular to it and tap and drive the screw driver onto the motor.

## Fixing ESCs

ESCs are usually best replaced. Even, if you own a relatively expensive drone, the replacement ESCs can cost some money but in relative terms, getting a replacement ESC should still be cheap.

Sometimes your ESCs can stop functioning if the voltage regulator or BEC gets fried. In such cases, you can replace the voltage regulator. But first, you need to check what voltage regulator is being used on the ESC in the first place and then replace it with a similar one.

# Fixing unbalanced propellers

## Tools you'll need

- An unbalanced propeller
- Tape
- Cyanoacrylate (super glue)
- Prop Balancer. The Du-Bro Tru-Spin is an excellent choice. It is also the most widely endorsed prop balancer out there and it works great even on bigger propellers. You can get this off Amazon.

## Step 1: Balancing the Prop Balancer

Ironically, the first thing you have to make sure is that your prop balancer itself is balanced. For this, you have to make sure that the rod that holds the propeller on the balancer sits horizontally as shown in the figure below:

ROD IS PERFECTLY HORIZONTAL



To do this, make sure that both the sides of the balancer are at the EXACT same level. You can use a wooden block or some other symmetrical object below each of the platforms one after the

other to check and get it to the same exact level



do not overlook this balancing step!

## Step 2: Balancing the blades

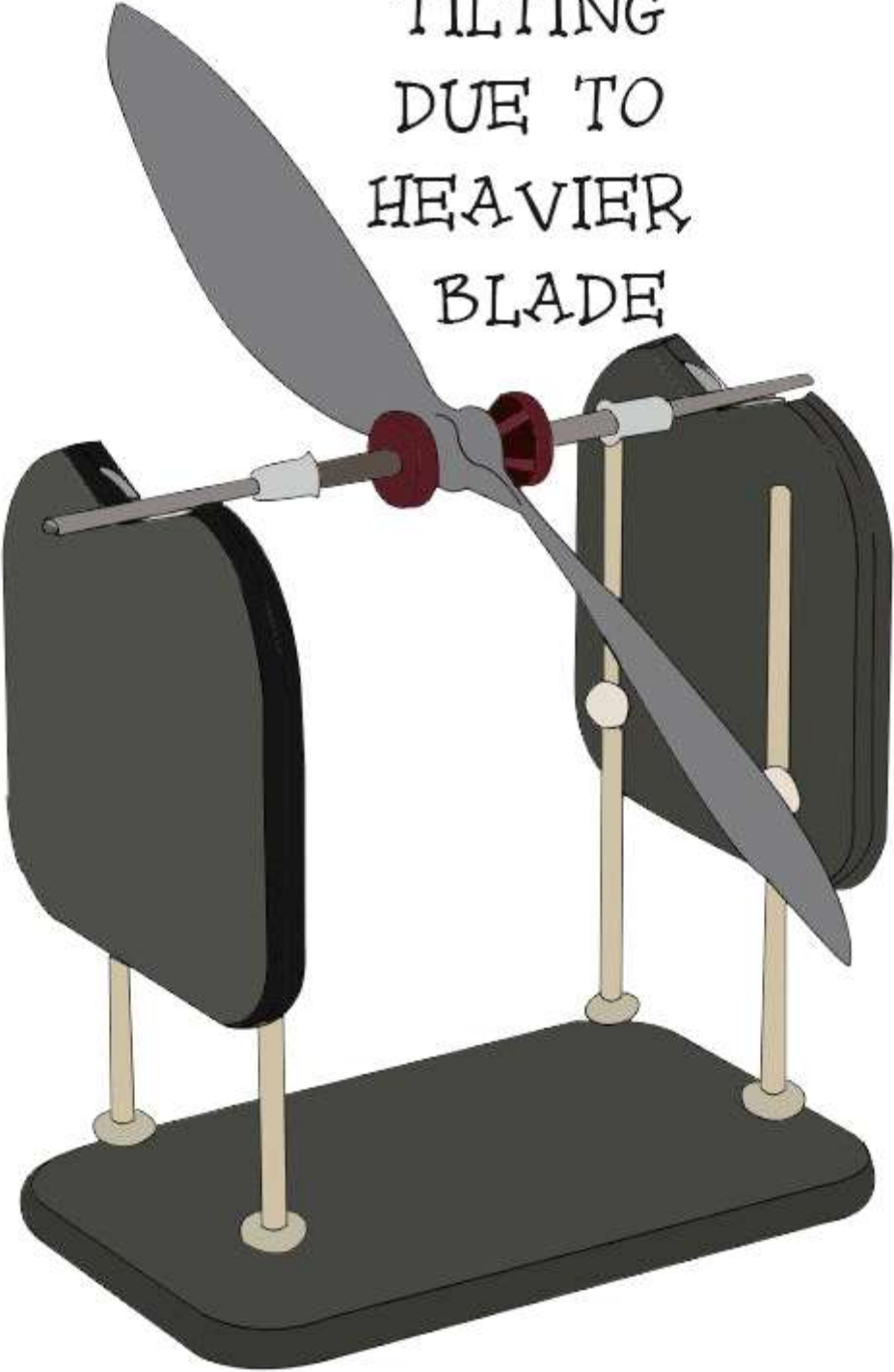
1. Check if the blades are unbalanced

You need to check if your blades are unbalanced in the first place. To do this, mount the propeller on the prop balancer.

Rotate the propeller around and if the propeller is unbalanced, you can easily see that the blade doesn't rest when you leave it alone. Instead, it will have a tendency to tilt.

When you try to keep it at a perfect horizontal line and the propeller tilts to one side, it suggests that the blade that goes down is probably heavier than the other blade. If it stays relatively stable, it is time to move onto the next step. If it is unbalanced, make sure to mark the side of the hub which was facing up when you tested for the imbalance. You will need this further in this step and for the next step.

TILTING  
DUE TO  
HEAVIER  
BLADE



## 2. Balancing the blades

Apply some tape on the lighter blade so that the weight of the lighter blade matches the heavier blade. If the relative weights are near even, then when you place the propeller back on the balancer, the propeller should align horizontally without tilting.



Make sure that the same side of the hub is facing up when you checked for the imbalance in the beginning of this step. If you don't, then the propeller will probably tilt even if the blades weigh even due to imbalance of the hub.

### Step 3: Balancing the hub

- Check if the hub is unbalanced

Like the previous step with the blades, you need to check if the hub is unbalanced. Balancing propellers will remain incomplete without this step. To do this, mount the propeller onto the balancer horizontally with the other side of the hub (the one that wasn't marked in the previous step) facing up. If the blades tilt, then it is a sign that the hub itself is unbalanced.

Another great way to check if the hub is unbalanced is to mount the propeller vertically. If the propeller doesn't stay that way and tilts, this is also a sign of an unbalanced hub.

In both tests, the heavier side of the hub tends to pull on the lighter side, causing the tilt.



- Balance the hub

To balance the hub, add weight to the side of the hub that is lighter. To do this, add some super glue onto the lighter side (be frugal) and wait for it to dry up. The added material should balance the lighter side with the heavier one.

You can also use tape for this, but due to the nature of the surface of the hub, tapes tend to fall off quickly.

## End result: **Balanced propeller**

Once you have balanced your propeller, no matter what way you mount it, it should stay balanced without tilting.

Remember that it doesn't have to be a 100% aligned at all times. A little bit of tilt is still okay. Just try and get it near perfect even if it isn't perfect.

As long as the propeller isn't moving as crazy as before, you should be good to go.

Don't rush. Take your time through the process. Balancing propellers might take a while, but I assure you that the end result will be worth it.

## Common Issues and solutions for it

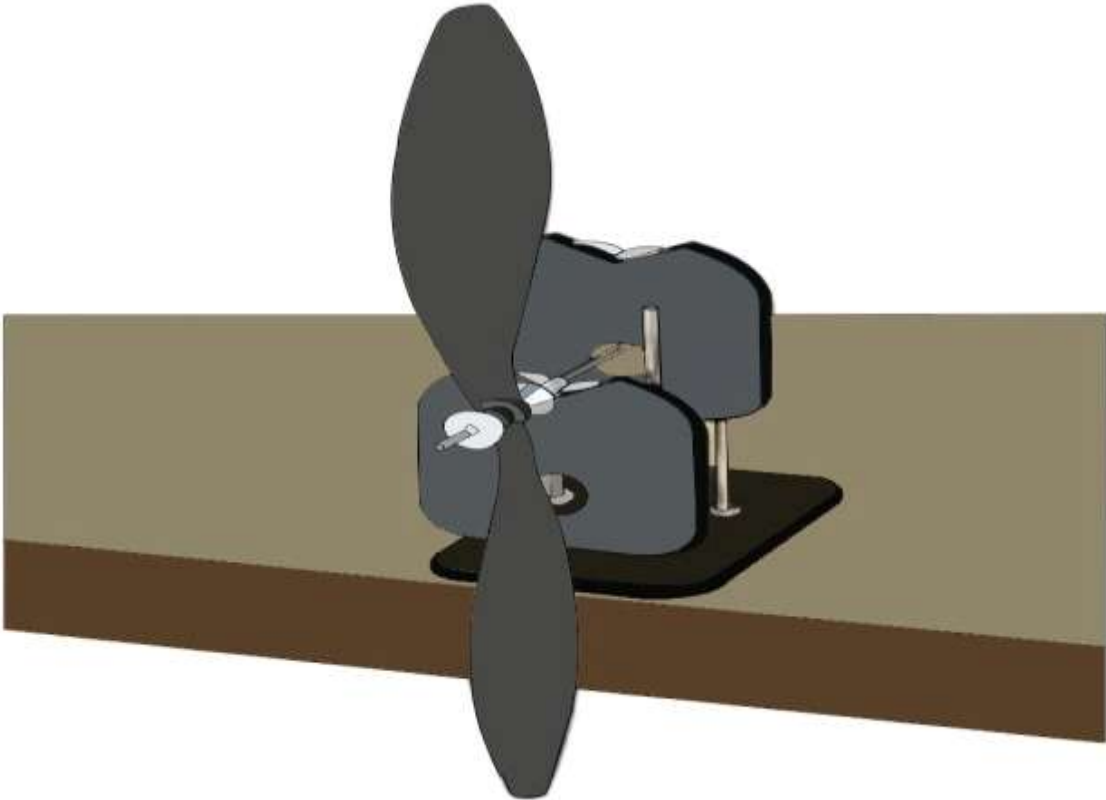
- Balancing propellers for large propeller

A common problem you might face with large propellers is that the rods of the balancer may not be long enough. Because of this, the propeller may hit the desk, limiting your testing for imbalance. To work around this, first get one of the platforms to the middle. That is, remove the rods which you would have placed at the ends of the balancer to the middle and mount the platform on top of the rods there.

Slide down the other platform to the bottom. Place the platform on the middle rods such that the hole of the platform aligns with the head of the other platform.

The rod that holds the propeller should now be perfectly horizontal .Mount the propeller and place the balancer it at the edge of the

desk to do your tests.



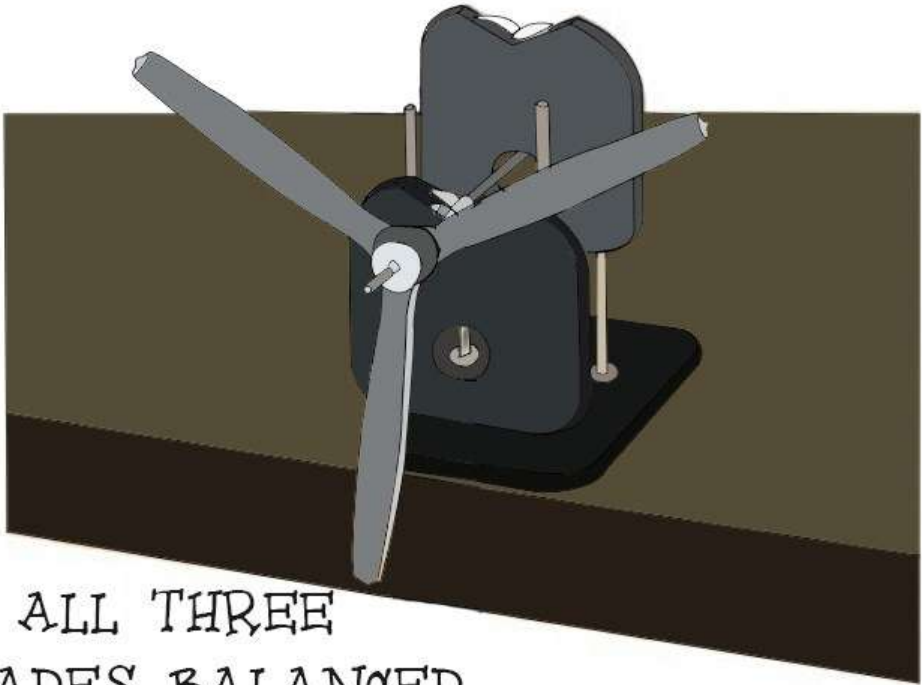
- Balancing propellers with 3 or more blades

You may own propellers that have 3 or more blades. The basic principle behind balancing 3 or more blade propellers is the same as balancing the regular 2 blade propellers.

With 3 or more blades (Lets name the blades X, Y, Z), usually the weights of the blade tend be  $X > Y > Z$  (X being the heaviest blade) when they are unbalanced.

Following similar principles laid out in the steps above, all you have to do is match the weights of the lighter blades to the heaviest blade by adding tape to it.

Since there are three blades, you might also have to use the balancer at the edge of the desk like the larger blades



ALL THREE  
BLADES BALANCED

When balanced, the propeller will stop tilting and moving, just like before.

# Fixing the flight controller and PID tuning made easy

We've covered some of the very basics of PID already. The theory is rather complicated but in this section, the goal is not to make you competent at physics or mathematics but to make it easy to understand so that you as a drone pilot will have the practical knowledge that you can apply to tune your flight controllers if they become out of tune.

We'll look at P, I and D separately and what they mean for you. Using knowledge of each, you can then test and experiment with your flight controller and tune appropriately. Note that the PID numbers and amounts are going to be different for each controller so you will have to check out the manual of your flight controller. If you are trying to tune a flight controller of a drone like the DJI Phantom, look up the DJI Nava flight controller series' manuals.

## Proportional

The job of the "proportional" is error correction. For example, if the multicopter is to stay at a fixed horizontal line and one of its side goes below that line, the job of the proportion then, is to get that side back in line.

The amount of “P” value you tune in and calibrate will determine how hard the flight controller will try to get back that side to that horizontal line. If the P is too low, it will not level it back to the horizontal level.

If the proportional is too high, the flight controller will try too hard to get back to that horizontal level and it might for example, overshoot that horizontal line and go above it, causing the other side to go down.

The vicious cycle of overdoing and underdoing will go on and on.

## Integral

Like the proportional, the integral also does the job of error correction. But at the same time, it also accounts for the duration and sustained difference.

The integral is what maintains the altitude in a multicopter. For example, if you are flying forward and the nose of the multicopter tends to go up, the sustained difference from the momentum is not being taken care of.

The integral accounts for this by putting in a bit more control onto the multicopter to get back to the level it is supposed to be, which is how the “smooth” tucking in of the nose occurs when flying forward.

## Derivative

D predicts the behavior of P and I and then improves the performance of them. It is the speed or rate at which P and I function.

## Testing the PID

### Testing the P

If your multicopter tends to wobble too much, then there is too much "P". As we have already discussed, too much proportional will have create a vicious cycle of over correcting. This is what causes the wobble.

The ideal setting for the P control is to increase the "P" to a point where the multicopter starts to wobble and then decrease it to just below it.

### Testing the I

Testing the I can be done simply by pitching your multicopter forward quickly. If the nose tends to go up instead of smoothly tucking down, then "I" value is probably too low. You have to increase it in this case

## Testing the D

The easiest way to check the D value is to change the altitude quickly by increasing the throttle. If the multicopter starts to quiver around as it comes to a stop and changes direction, you may need to increase the D value a little bit. If the quivering becomes worse, decrease the D.

## Things to keep in mind

- Use the standard, manual/rate mode while testing the PID. Do not use self-level mode.
- Start with P, then go on to I and then to D before going onto 'P' again. Continue iteratively until you have the correct, ideal settings.
- Every flight controller and version is different. The amount of PID varies from flight controller to flight controller and from version to version
- Copying another multicopter's PID settings more often than not, will not work.

# In closing

The field of quadcopters, autonomous robots and its applications are vast and extremely interesting. The knowledge you gained in this book is going to be a strong starting point for you if your goal is to try out various multirotor builds.

That being said, you should now have the skill and understanding to build and repair your own multirotors, as well as know the ins and outs should anything go wrong with your craft during a flying mission.