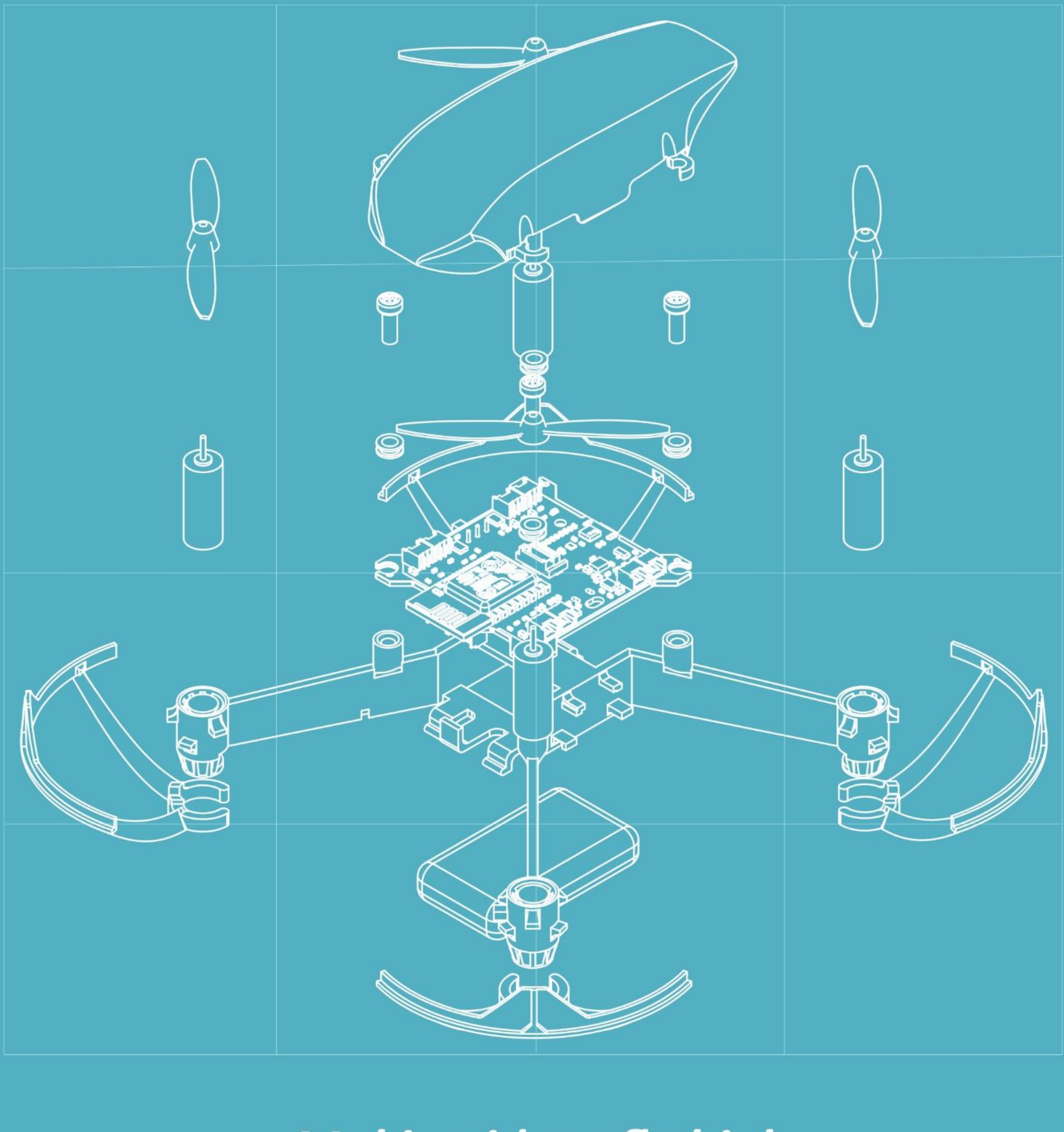
NITI Aayog

ATAL INNOVATION MISSION

ATL Drone Module

Get, Set, Fly!



Making ideas fly high

Message from Mr. R. Ramanan,

Mission Director & Additional Secretary, AIM, NITI Aayog

Atal Innovation Mission, housed at NITI Aayog, is Government of India's flagship initiative to foster a spirit of innovation and entrepreneurship across India in a holistic manner.

With the vision "To create One million Neoteric Innovators by 2020", AIM is setting up thousands of Atal Tinkering Labs (ATLs) where young innovators get access to resources and know-how of 21st century technologies, DIY kits, electronics and IoT tools, 3D printer, etc. AIM also envisions growth in the collaborative education ecosystem in the country where students, teachers, mentors, industry partners and experts work together to imbibe learnings and experiences from each other.

The idea of flying is always a fascinating concept for all young as well as old. And technology has made it a reality. In the age of the 4th industrial revolution, drones are one of the most promising technologies integrating the concepts of physics, maths, chemistry, engineering and sensor technologies creating a tremendous range of innovative solutions that can be developed using them. Recently, various Government bodies have expressed their interest and are working collaboratively to create an ecosystem for drone technologies in India. This will open new opportunities for innovators and entrepreneurs. Further, to enable students to leverage this emerging market, it is imperative that they are educated and informed on the same at an early age.

The ATL Drone Module, created in collaboration with Drona Aviation, is one such enabler for the ATL students to explore the world of drones and its possibilities allowing their imaginations to fly high. With the Drone module, Sky indeed is the limit for their creativity and innovation. Students will be able to connect this module to their academic subjects, especially physics and mathematics, and enhance their spatial problem-solving skills. I hope that the students find this Drone module interesting, imaginative and instructive.

NITI Aayog | ATAL INNOVATION MISSION

Message from Apurva Godbole,
CEO & Co-Founder, Drona Aviation

DRONA AVIATION

From time immemorial, humans have been fascinated by flight. The flying birds inspired the fancy of many, expressed in mythology (Vimana in India, Dragons in China) and in more recent times through superheroes from Superman to our very own Shaktimaan. It is this fantasy that that inspired the Wright brothers to make the first manned flight in US creating a technology development that revolutionised the world.

Similarly, the last 2-3 decades have seen the rise of unmanned flight technology accessible to the common man. This has sparked the imagination of innovators across the world. And who better to unleash the innovative power of drone technology than the tinkerers themselves. It is only by working with the tinkerers can we build an ecosystem for drone innovation that can help India rise to be the drone capital of the world.

The module aims to be the first step in helping learn unmanned aerial systems by building, flying, crashing and flying again.

Foreword

It is quite heartening to learn that our young children in high schools are giving life to their ideas, and building innovative solutions across multiple sectors, with the help of Atal Tinkering Lab. The Atal Tinkering Lab is a flagship initiative of Atal Innovation Mission, NITI Aayog, Government of India, to nurture 21st century skills of problem solving, teamwork, collaboration, critical thinking, design thinking and so on.

More than 5000 schools have been selected for establishing an Atal Tinkering Lab. As we continue our journey towards tinkering and innovation, we are adding several new dimensions to the program. We strongly believe in introducing young minds to future technologies of 3D printing, Internet of Tings (IoT), robotics, miniaturized electronics, drone technologies, artificial intelligence, virtual reality, and so on, towards building a new and transformed India. Drone technology is one of the many promising technologies that will eventually have a huge impact on education, agriculture, weather forecasting, healthcare, disaster management, defence and other sectors.

The ATL drone module: Get Set Fly, will introduce our young generation to the world of building drones and leveraging them for solving community problems. It teaches us about the science of flying, drone technology, how to build your own drone and important rules on safe drone flying in India. This module also contains references to external links, so that students can themselves kick-start their research and build drones, as per the Indian regulations. The module is primarily aimed at ATL teachers and mentors who would enable their students in building and flying drones, as per the Indian regulations. The module has been created in Do-It-Yourself (DIY) mode, so that students can conduct the activities and thereby self-learn. So, dear students, teachers, mentors and parents- get ready to make your ideas fly high with the ATL drone module.

Happy Tinkering 😊

- Dr. Ayesha Chaudhary,

Atal Innovation Mission, NITI Aayog,

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Note:

This document contains several weblinks and associated QR codes. The relevant documents and videos can be accessed either by clicking the weblink or by scanning the QR code using a QR code scanner application, which can be downloaded on any smartphone via the application store.

Towards the end of each chapter, a summary and an exercise are added for students to check their learnings and further refine their knowledge.

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Chapter 1

Key features of Drone Regulations 1.0

1.1 Notification of Final Regulations for Civil Use of Remotely Piloted Aircraft System (RPAS)[1]

The Directorate General of Civil Aviation has issued the Civil Aviation Requirements (CAR) for civil use of Remotely Piloted Aircraft System (RPAS) commonly known as drones. The regulation was developed after extensive consultations among various stakeholders, and will be effective from 1st December, 2018.

As per the regulation, there are 5 categories of RPAS categorized by weight, namely nano, micro, small, medium and large.

1.1.1 Operational/ Procedural Requirements:

All RPAS except nano and those owned by NTRO, ARC and Central Intelligence Agencies are to be registered and issued with Unique Identification Number (UIN).

Unmanned Aircraft Operator Permit (UAOP) shall be required for RPA operators except for nano RPAS operating below 50 ft., micro RPAS operating below 200 ft., and those owned by NTRO, ARC and Central Intelligence Agencies.

The mandatory equipment required for operation of RPAS except nano category are:

a. GNSS (GPS)
b. Return-To-Home (RTH)
c. Anti-collision light
d. ID-Plate
e. Flight controller with flight data logging capability
f. RF ID and SIM/ No-Permission No Take off (NPNT)

As of now, RPAS to operate within visual line of sight (VLoS), during day time only, and unto maximum 400 ft. altitude.

For flying in controlled Airspace, filing of flight plan and obtaining Air Defence Clearance (ADC) /Flight Information Centre (FIC) number shall be necessary.

Minimum manufacturing standards and training requirements of Remote Pilots of small and above categories of RPAS have been specified in the regulation.

[1] Source: http://pib.nic.in/newsite/PrintRelease.aspx?relid=183093

1.1.2 No Drone Zones

The regulation defines "No Drone Zones" around airports; near international border, Vijay Chowk in Delhi; State Secretariat Complex in State Capitals, strategic locations/vital and military installations; etc.

1.1.3 Operations through Digital Platform:

Operations of RPAS to be enabled through Digital Sky Platform. The RPAS operations will be based on NPNT (No Permission, No Take off). The details including links for the digital sky platform shall be available in DGCA website from 1st December, 2018. There will be different colour zones visible to the applicant while applying in the digital sky platform, viz, Red Zone: flying not permitted, Yellow Zone (controlled airspace): permission required before flying, and Green Zone (uncontrolled airspace): automatic permission.

1.1.4 Enforcement Actions:

The enforcement actions are, (a) suspension/ cancellation of UIN/ UAOP in case of violation of regulatory provisions, (b) actions as per relevant Sections of the Aircraft Act 1934, or Aircraft Rules, or any statutory provisions, and (c) penalties as per applicable IPCs (such as 287, 336, 337, 338, or any relevant section of IPC).

1.2 RPAS regulation document

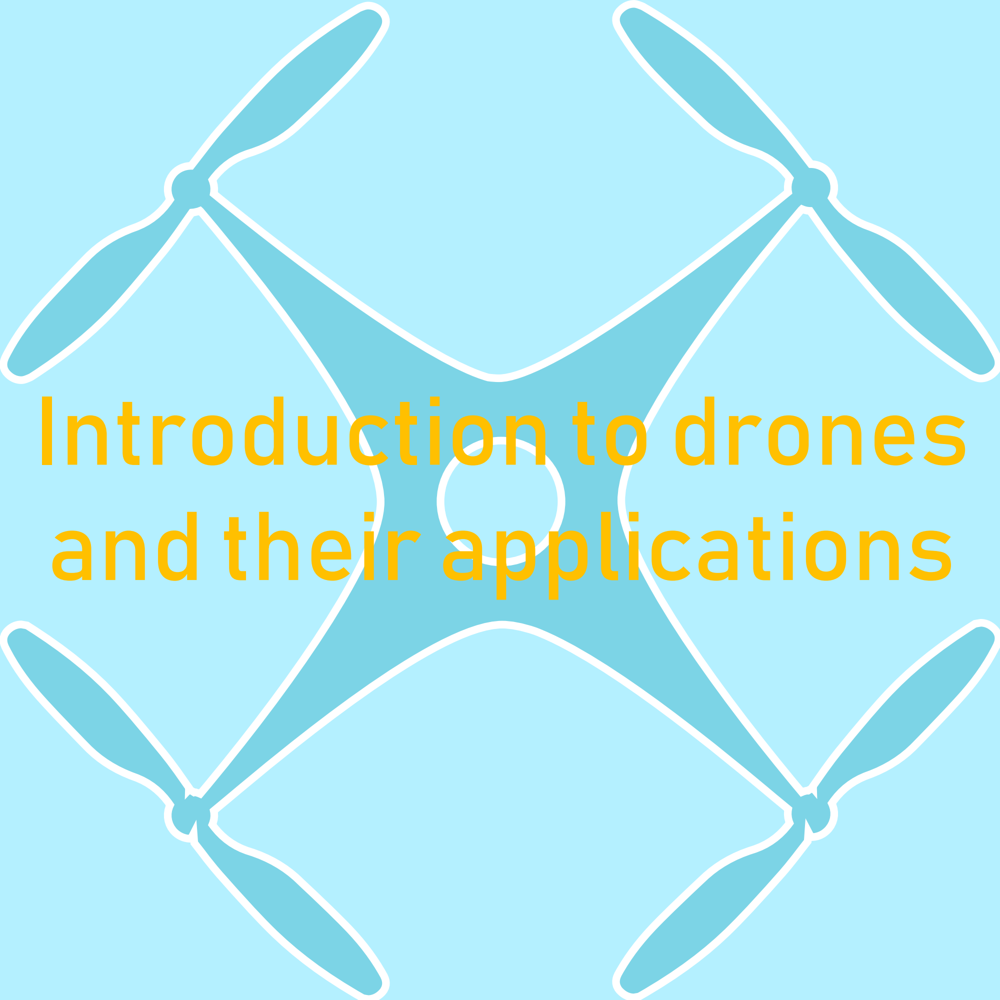
The RPAS Regulation document by the Director General of Civil Aviation, Government of India can be accessed as below:

RPAS Regulations 1.0 (1st December, 2018)
Requirements for Operation of Civil Remotely Piloted Aircraft System (RPAS)

Source : http://dgca.nic.in/cars/D3X-X1.pdf

Chapter 2

Introduction to drones and their applications



Objectives

The objectives of this chapter are to understand:

- Introduction of drones
- Classification of drones
- Applications of drones

2.1 Definition of drones

Drones also known as UAV is an abbreviation of Unmanned Aerial Vehicle, meaning aerial vehicles which operate without a human pilot on board. UAVs are commonly used in both the military and police forces in situations where the risk of sending a human piloted aircraft is unacceptable, or the situation makes using a manned aircraft impractical. In modern times drones are gaining popularity in day to day applications, you can see examples of them in the later part of the module

2.2 History of drones

Wars have generally wreaked havoc on countries that have been a part of it. As societies and civilisations evolved, the number of wars waged in different parts of the world went down and we are probably living in one of the most peaceful times ever on the planet. There is however one (and probably the only one) advantage of wars - technology innovations that come out into the world. Many innovations - the GPS, nuclear energy, IC Engine, Satellites and a bunch of others - came from defence necessities. Drones had a similar beginning.

The first drone was built for a war. In the year 1849, Austrians were attacking Venice. They had already besieged the city to try and starve it off food. They launched large pilotless balloon with the explosives attached to it to fly into the city. However, the winds started blowing in opposite direction and exploded right above the Austrians.

Since then, there were incremental innovations that were happening over the period of a century and a half. Drones came in form of large pilotless planes and weapon-delivery systems. In the late 1990s, drones started becoming smaller in size. In With the advent of the BLDC motors and high energy density lithium polymer batteries, the efficiencies improved and the costs came down. That is the time the drone revolution started taking birth on this planet.

Even then, the applications of drones were very focused on the military. The drones slowly started bringing cameras with better cameras and image stabilisation technologies. That is when drones started being used for their first non-military application - aerial photography and cinematography. And as software for image processing and data gathering improved, drones started being used for newer applications. These included precision agricultures, land surveying, mapping and a bunch of other such ideas. In the next phase, as the battery technology improves further (think of fuel cells), we will see more usages in form of payload deliveries and very high endurance.

2.3 India and drones

The Unmanned Aircraft System ("UAS") market in India is projected to touch US$ 886 million by 2021, while the global market is likely touch US$ 21.47 billion. With such a growing economy, it becomes important for India as country to foster drone innovations.

Countries across the world realise the potential of drones and are investing in the growth of drone innovations. But they also understand the risks posed by unfettered usage of drones and have laid down rules for drone usage. The first body to bring this out was the FAA of the USA. Soon, other countries followed suit. India's DGCA has also brought out its own set of rules to govern the Indian skies via RPAS regulations.

2.4 Tinkering and drones

The human race strives because they are curious. The ability to ask questions is one of the most fundamental reasons of human evolution. And this can be seen throughout the history of human evolution. Explorers first conquered the land till they reached a shore. To cross the blue oceans, they created the 'Ship' and conquered the planet. Then the explorers looked up and saw the blue sky, eventually creating 'space-ship'.

During one's lifetime, a human being is the most curious at childhood. And as natural explorers, we tend to like the idea of flying, solely because it gives us an opportunity to expand our horizons and see the unknown. Tinkering, is an output to the curious mind and flying objects foster the idea of exploration. Thus, a need was felt to create a module to connect Tinkering and drones.

The drone technology has proven to be one of the most promising technologies of the 4th industrial revolution. And it is imperative that a platform is created to enable students to explore this technology early in their life and in a collaborative environment, like an ATL environment in schools. In school, students learn various concepts of physics and mathematics during their daily curriculum-based classes, and further get an opportunity to work them out in real life with the help of the ATL and this module. This authentic hands-on experience will result in students creating their own innovations at a grassroot level.

Throughout this experience, students will be empowered to understand various concepts, for e.g Mathematics - algebra and calculus; physics - Laws of Motion, Force, Mechanics and Electronics; geometry - 3D geometry and spatial problem-solving skills.

This module can be used by young innovators as a tool to start their innovative journey and at the same time have fun by making their own drone.

2.5 Do's and Don'ts

It is important to use technology holistically and responsibly. Readers are requested to take note of the regulations issued by the Government of India, in public interest.

Following is a list of Do's and Don'ts for flying drones[2]:

2.5.1 Do's:

- Ensure your drone (except Nano in uncontrolled airspace upto 50 feet) is Digital Sky "No Permission- No Take off" (NPNT) compliant.
- Obtain Unique Identification Number (UIN) from DGCA for operating in controlled airspace (where the ATC services are active) and affix it on your drone.
- Obtain Unmanned Aircraft Operator Permit (UAOP), if applicable from DGCA for commercial operations and keep it handy.
- Obtain permission before each flight through Digital Sky Platform which are available on DGCA website from December 1, 2018.
- Keep an eye on interference which can be from mobile devices or blockage of signals.
- Fly only during daylight (after sunrise to before sunset).
- Fly in good weather: Good weather lets you not only fly your drone better but also keep track of it in the air.
- Fly in visual line of sight (VLOS): Always be within visual range of your drone.
- Be aware of airspace restrictions/ no drone zones and respect privacy of people.
- Keep local police informed about your drone flying activity. If you are ever approached by police provide all requisite information.
- Do log your flights and intimate concerned authorities (like DGCA, local police etc.) of any incidents/ accidents.

[2] Source: https://www.livemint.com/Technology/sBsvTm7ueplDHk2OsNt5oJ/The-dos-and-donts-of-flying-drones-under-new-regulations.html

2.5.2 Don’ts:

- Don’t fly Nano drones above 50 feet from the ground level.
- Don’t fly Micro drones above 200 feet from the ground level.
- Don’t fly drones more than 400 feet from the ground level.
- Don’t fly drones near other aircraft (manned or unmanned).
- Don’t fly drones in areas specified as ‘No Fly Zones’.
- Don’t fly drones near airports and heliports.
- Don’t fly drones over groups of people, public events, or stadiums full of people without permission.
- Don’t fly drones over government facilities/military bases or over/ near any no-drone zones.
- Don’t fly drones over private property unless permission is given.
- Don’t fly drones in controlled airspace near airports without filing flight plan or AAI/ADC permission (at least 24 hours before actual operation).
- Don’t drop or carry hazardous material.
- Don’t fly drones under the influence of drugs or alcohol.
- Don’t fly drones from a moving vehicle, ship or aircraft.

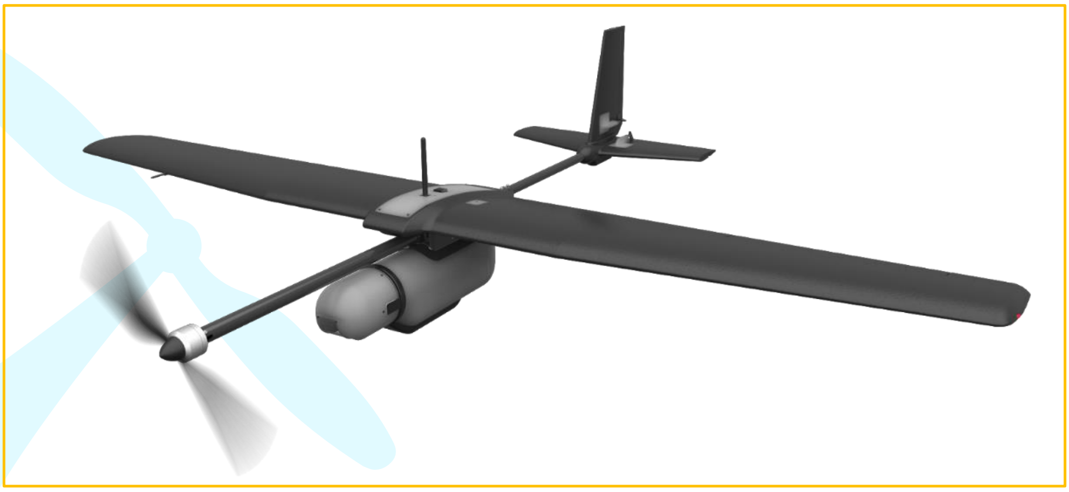
Note:

- A permit is required for commercial drone operations (except for those in the Nano category flown below 50 feet and those in the Micro category flown below 200 feet).
- Permission to fly in controlled airspace can be obtained by filing a flight plan and obtaining a unique Air Defence Clearance (ADC)/Flight Information Centre (FIC) number.

2.6 Classification of drones based on structure

Based on the structure drones are classified into following:

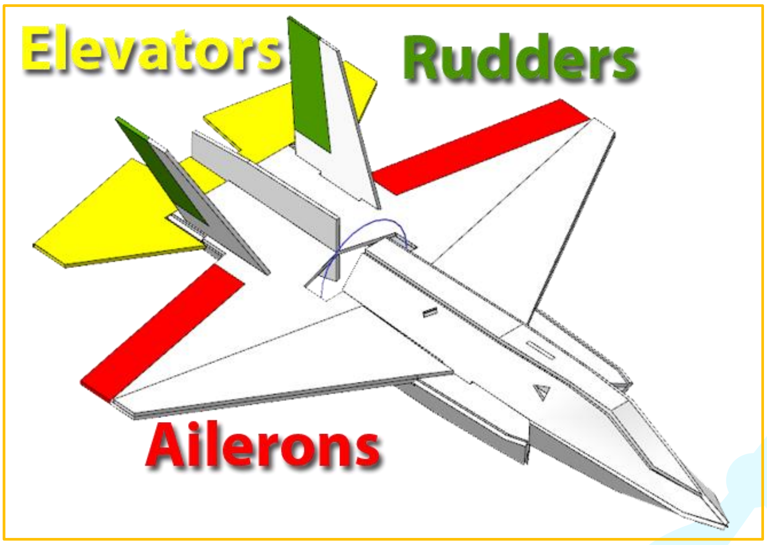
2.6.1 Fixed Wing Structure:



Img 2.1 Cygnus

Fixed wing drones as the name suggests have two fixed wings along the lateral axis of the aircraft. Fixed wing UAVs consists of a rigid wing that has an aerofoil shape which make flight capable by generating lift caused by the UAV's forward airspeed. This airspeed is generated by forward thrust usually by the means of a propeller (explained in later modules) being turned by an internal combustion engine or electric motor.

Control of the UAV comes from control surfaces built into the wing itself, these traditionally consist of ailerons an elevator and a rudder. They allow the UAV to freely rotate around three axes that are perpendicular to each other and intersect at the UAV's centre of gravity.



Img 2.2: Control Surfaces

Advantages:

- Comparatively Simple Structure
- Comparatively simple maintenance/repair process
- Aerodynamically stable system
- Better energy efficiency - High operational flight time at lower energy and cost

Disadvantages:

- Need a runway or launcher for take-off and landing. Thus, comparatively more land/floor area is required. To eradicate this issue, solutions like VTOL (vertical take-off/landing) and STOL (short take off/landing) solutions are very popular.

- To generate lift, fixed wing aircraft require air movement through the wings. Thus, these must stay in constant forward motion and cannot hover at a single location like a multi-rotor UAV can. Thus, fixed wing solutions are not best suited for stationery applications, for e.g inspection work and static video recording.

2.6.2 Lighter than air systems

Img 2.3: Airship

Aircrafts such as balloons and blimps are designed such that when filled with a gas lighter than air (eg. hot air, Helium, Hydrogen), the aircraft displaces the atmospheric air apart and floats in the air like a wooden plank floats in water. The difference in density of gas inside and outside the aircraft creates the lift in these aircrafts.

Advantages:

- Incredibly light and manoeuvrable
- Capable of quickly changing direction both during motion or stationery
- Low fuel consumption
- Ideal for stationery hovering application for long duration of time over a specific area, e.g – sports event, border area surveillance.

Disadvantages:

- Highly difficult to operate in difficult weather situations like typhoon, storm, thunder, rain, snowfall, hail, etc.
- Large surface area makes it difficult to operate in windy condition.

2.6.3 Rotary-wing Aircraft

A rotorcraft or rotary-wing aircraft is a heavier-than-air flying machine that uses lift generated by wings, called rotary wings or rotor blades, that revolve around a mast. A rotor is a setup of 2 to 8 blades mounted on a mast. The mast is a shaft connected perpendicular to the rotation plane of the rotor blades, connected to a power source(engine).

Rotary-wing aircraft are of two types:

a. Single rotor
b. Two rotors
c. Three rotors
d. Multi-rotor (four and above)

Img 2.4: Single Rotor

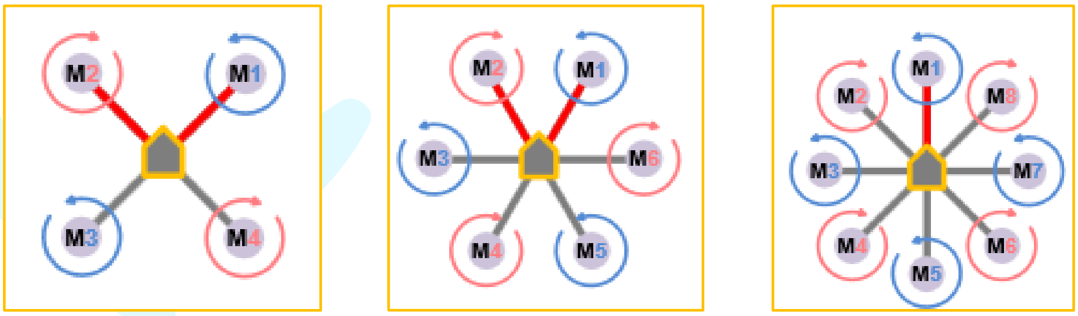
Rotor based aircrafts works under the same principle as a fixed wing. However constant aircraft forward movement is not needed to produce airflow over the blades. Instead the blades themselves are in constant movement which produce the required airflow over their aerofoil to generate lift. The major interest of this module is on multi-rotor aircrafts/drones.

A multi rotor aircraft is a mechanically simple aerial vehicle whose motion is controlled by speeding or slowing multiple downward thrusting motor/propeller units. The most common multi rotor aircraft/drone is a Quadcopter.

Img 2.5: Multi-rotor drone (Quadcopter)

Multi Rotor are further sub classified based on number of rotors:

a. Quadcopter (4 rotors)
b. Hexacopter (6 rotors)
c. Octocopter (8 rotors)
d. Decacopter (10 rotors)
e. Dodecacopter (12 rotors)



Img 2.6 : Diagrammatic representation of Quadcopter, Hexacopter, Octocopter

Advantages:

- Vertical take off and landing (VTOL) ability
- User can operate within a smaller vicinity with no requirement of takeoff/landing area
- Ability to hover and perform agile manoeuvring tasks
- Precision flying

Disadvantages:

- Comparatively complicated structure and programming
- Aerodynamically unstable system, thus it requires an on-board computer (flight controller)
- Low energy efficiency compared to fixed wing counterparts

2.7 Applications of Drones

With the ability to reach inaccessible places and its agility, drones are helping humans to expand their horizons. Following are some of the major drone application areas:

Defence	Emergency and Disaster management	Urban Planning
Surveillance	Marketing and Advertising	Aerial cinematography
Agriculture	Healthcare	Weather forecasting
Mining	Tele-communications	Logistics

Summary

With the advancements in technology in general, countries started to develop drones in the recent past. Much advanced UAVs have been utilized by the military around the world. In the civil world, drones have just begun to fascinate people and this has encouraged them in building more and more applications using drones. Young students are interested in not just studying theoretically, but want to explore the practical world and they have been given an extraordinary facility through ATL. This module aims at providing the beginning to the endless journey in the world of drones.

There are three types of flying machines based on the structure:

a. Fixed Wing drones: The fixed wing drone gets the thrust by a propeller which is turned by an internal combustion engine or a motor. It can fly at high speeds but cannot hover at a place. Its control systems include elevators, rudders and ailerons.
b. Lighter than air: The lighter than air system uses gases like hot air, helium, hydrogen, etc. it can hover at a place but becomes difficult to operate during poor weather conditions.
c. Rotary wing drone: Rotary winged drones use propellers fixed on motors to generate thrust. These drones can take off vertically and can hover at a place.

Drones have a large number of applications in the fields of defence, surveillance, marketing, logistics, telecommunications, etc.

Exercise:

1. What do the following important abbreviations stand for?

    a. UAV
    b. DGCA
    c. UAS
    d. RPAS
    e. NPNT
    f. UIN
    g. VLOS
    h. VTOL
    i. STOL

2. Which of the following UAV cannot hover at a place?

    a. Rotary wing aircraft
    b. Fixed wing structure
    c. Lighter than air systems

3. Match the columns:

Column A	Column B
a. 6 rotors	i. quadcopter
b. 12 rotors	ii. octacopter
c. 4 rotors	iii. decacopter
d. 8 rotors	iv. dodecacopter
e. 10 rotors	v. hexacopter

4. Activity: Can you think of any future applications of drones?

Chapter 3

Dynamics of an aerial system

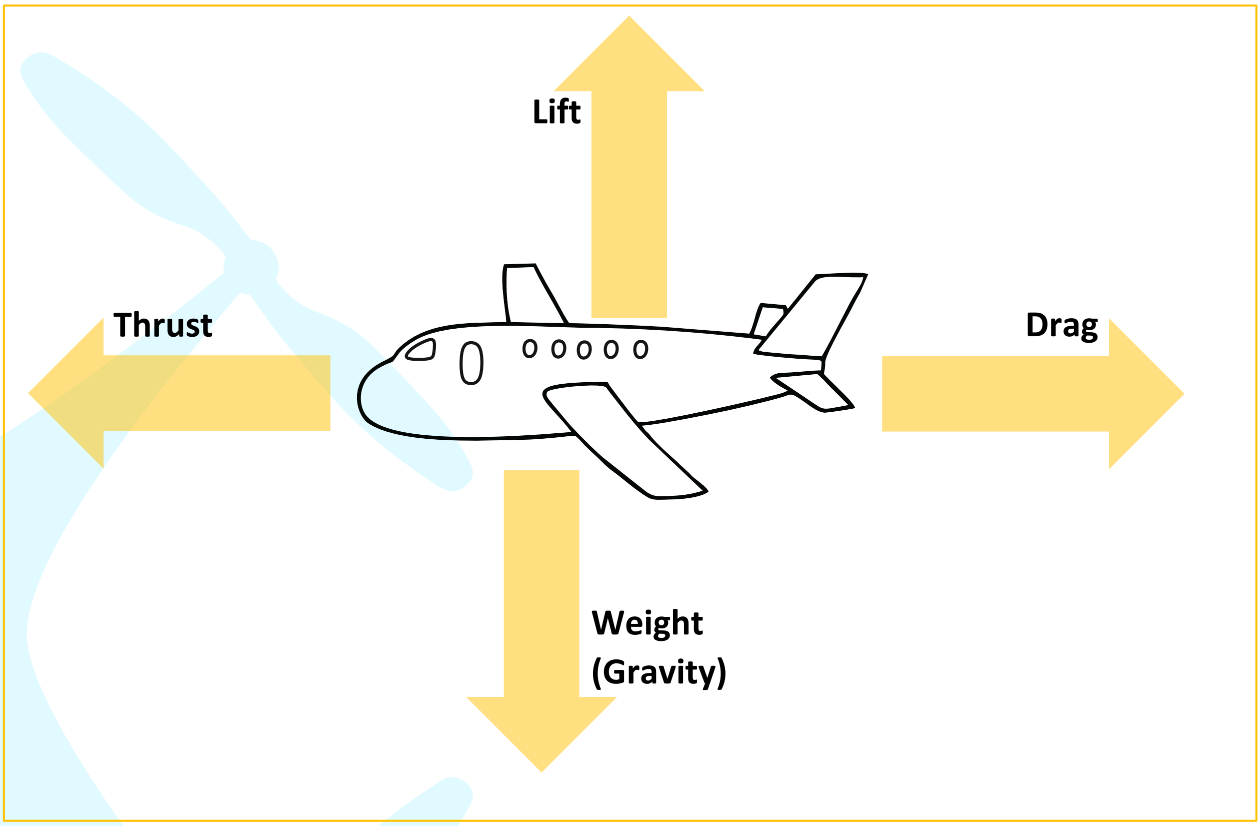
Objectives

The objectives of this chapter are to understand:

- Forces working on a Flight
- Principal axes and rotation of aerial systems

3.1 Forces of flight

Every particle in the universe is subject to force. Each particle attempts to reach its stable position, by balancing out various forces acting on it. In case of flight, there are 4 such forces, as follows:



Img 3.1 : Forces of flight

Weight: Weight is the force of gravity. It acts in a downward direction—toward the center of the Earth.

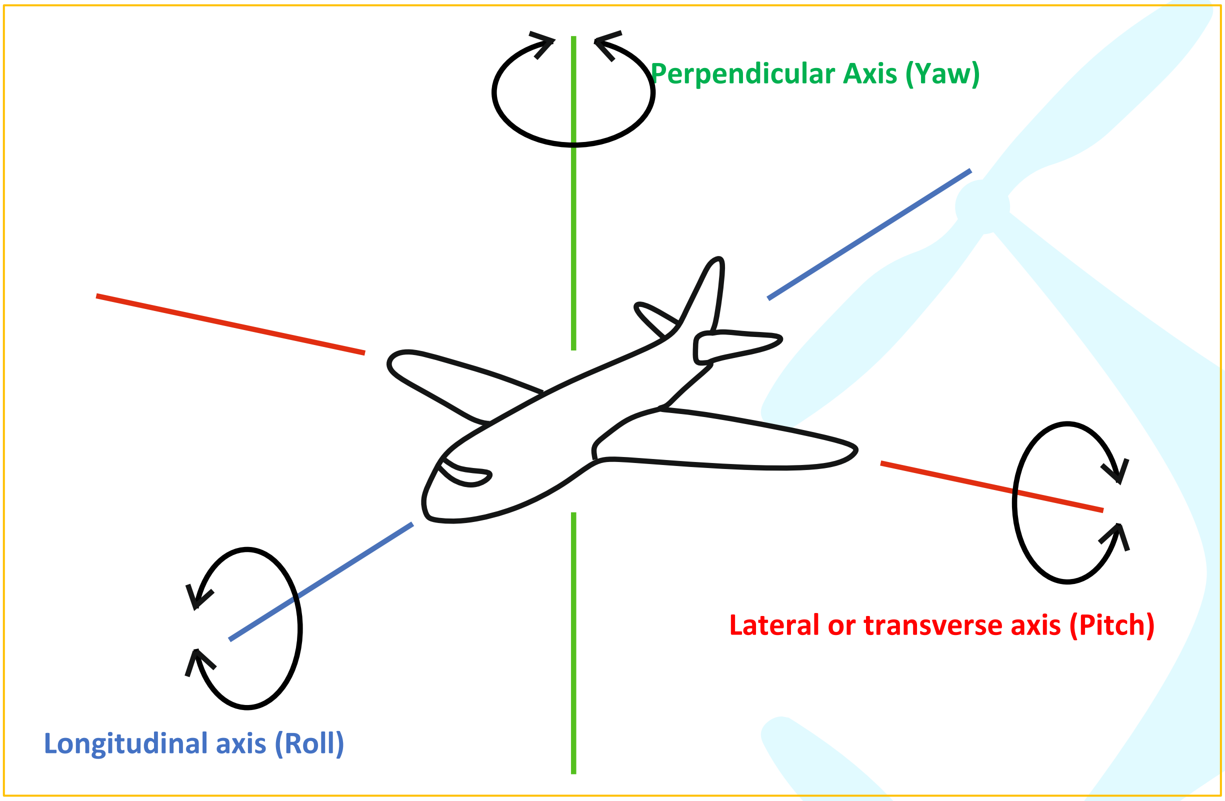
Lift: Lift is the force that acts at a right angle to the direction of motion through the air*. Lift is created by differences in air pressure above and below the wing of airplanes.

Thrust: Thrust is the force that moves the flying machine in the direction of motion. Engines produce thrust with the help of propeller, jet engine or rocket.

Drag: Drag is the force that acts opposite to the direction of motion. Drag tends to slow down the flying machine. It is caused by friction and difference in air pressure.

3.2 Principal axes and rotation of aerial systems

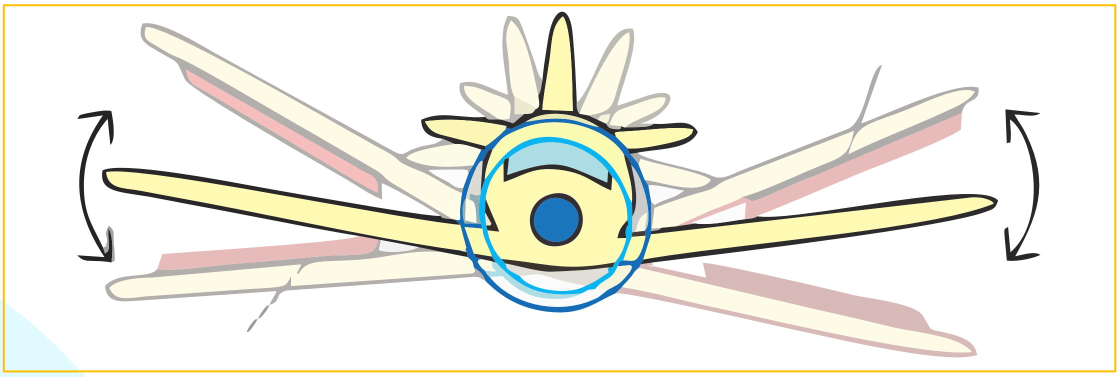
An aircraft/drone in flight is free to rotate in 3 dimensions of space. These rotations are produced by moment/torque about the principal axes. These rotations are intentionally produced by moving control surfaces of an aircraft. This results in variation on net force, enabling the user to maneuver the aircraft/drone They are explained as follows:



Img 3.2: Principal axes of aerial system

3.2.1 Longitudinal axis:

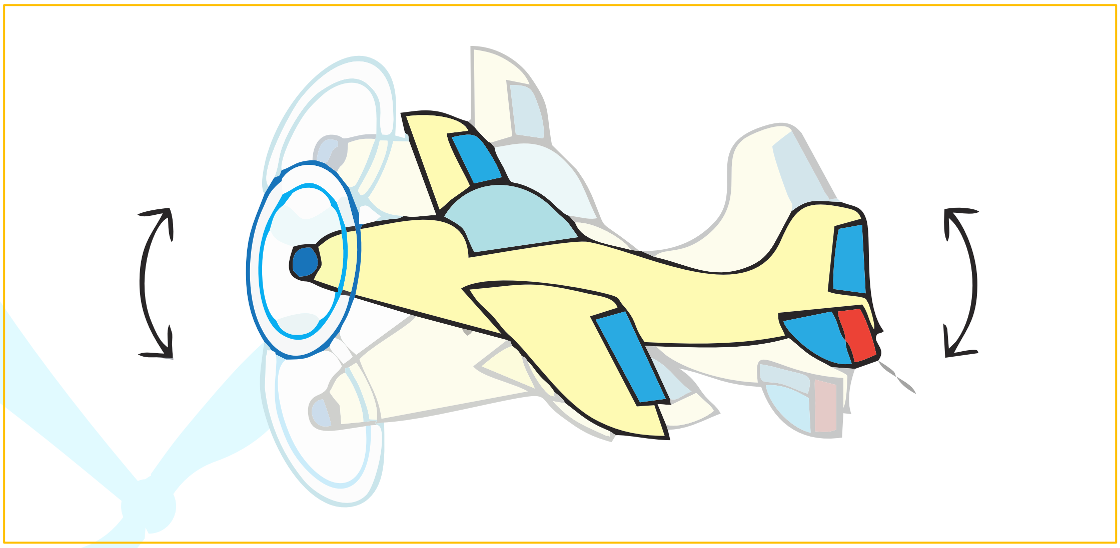
The axis along the length (front - back direction) of the aircraft, usually passing through its center of gravity. The rotation of the aircraft along the longitudinal axis is called as **'Roll'.** This is caused by moving the ailerons.



Img 3.3: Roll

3.2.2 Lateral (transverse) axis:

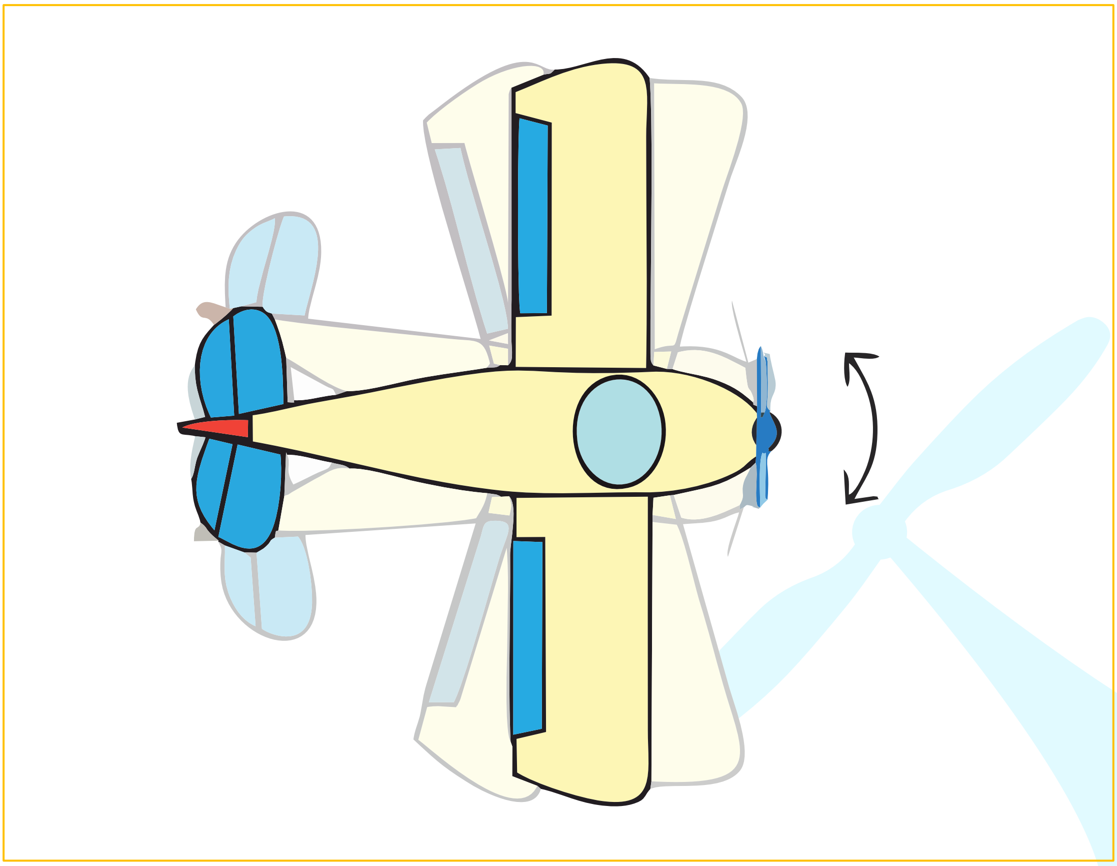
The axis that runs below the wing, from one wingtip to another (left - right), passing through the airplane's center of gravity. The rotation of the aircraft along the lateral axis is called as **'Pitch'**. This is caused by moving elevators.



Img 3.4: Pitch

3.2.3 Perpendicular axis:

The axis perpendicular to the wings and body of the aircraft (up - down), passing through the airplane's center of gravity. The rotation of the aircraft along the perpendicular axis is called as **'Yaw'.** This is caused by moving rudders.



Img 2.5: Yaw

Activity :

Let us understand the effects of the four forces of flight on a flying body with the help of a visual representation, as follows:

The effects if one of the four forces of flight

Link : http://howthingsfly.si.edu/activities/forces-flight

Summary

There are four forces which act on a flight, WEIGHT, which acts downwards and brings your flight downwards, LIFT, which acts upwards and lifts the flight upwards, THRUST, which moves the flight in the forward direction and DRAG, which acts backwards to resist thrust. The movement of aircraft is controlled by rotating it along three mutually perpendicular axes. These axes are longitudinal axis/ ROLL axis which is along the front-back direction, lateral/PITCH axis which is along left-right direction and perpendicular/YAW axis which is along the top-bottom direction. A combination of movement along these three axes results in the movement of the aircraft.

Exercise:

1. Fill in the blanks:

   a. There is a total of ______ forces acting on an aircraft.

   b. The force which opposes thrust is called _______.

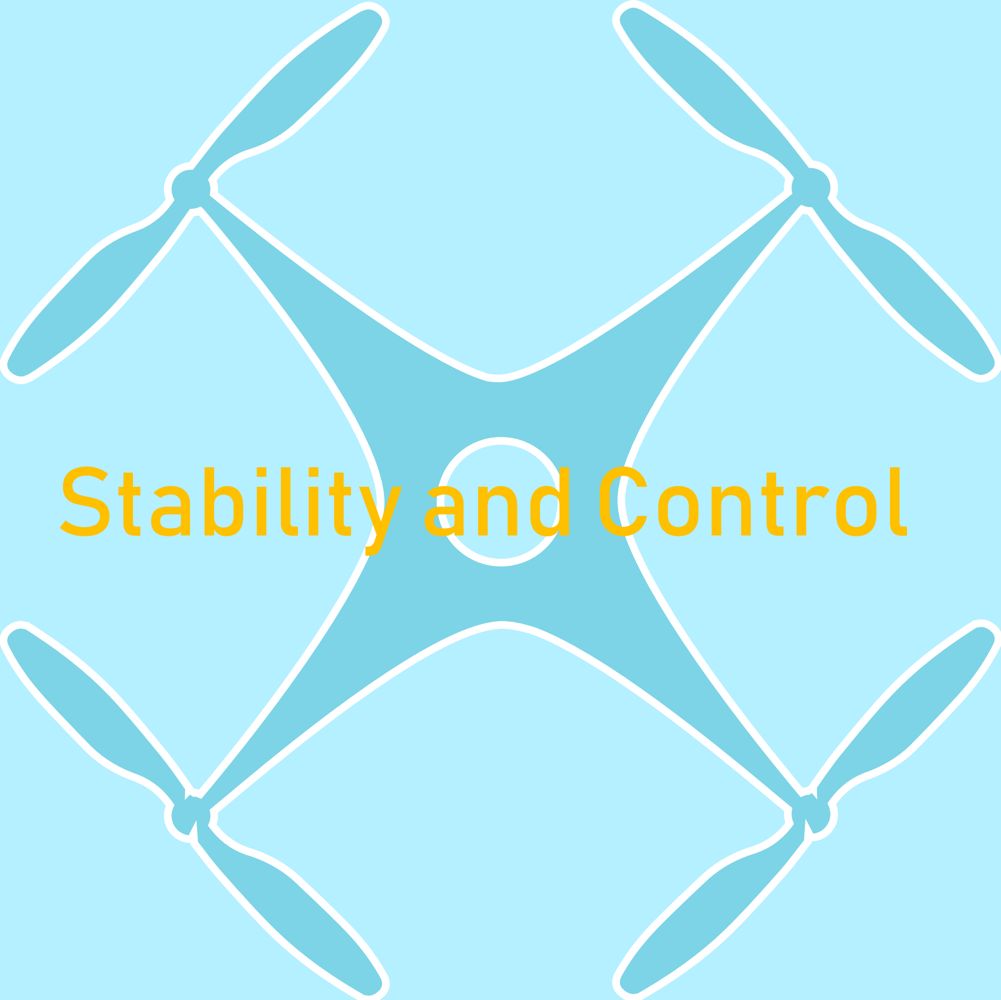
   c. The forces which opposes ______ is called weight.

2. Match the columns:

Column A	Column B
a. Rudders	i. Roll
b. Ailerons	ii. Pitch
c. Elevators	iii. Yaw

Chapter 4

Stability and Control



Objectives

The objectives of this chapter are to understand:

- Stable, unstable and neutral systems
- Control
- How to move your drone (roll, pitch and yaw)

4.1 Equilibrium:

Any object or body always experiences a number of forces from various directions. When the resultant of all these forces acting on the body is zero, the body will remain in the state of equilibrium. Even due to a small change in the acting forces, the body will shift away from the state of equilibrium.

4.2 Stability:

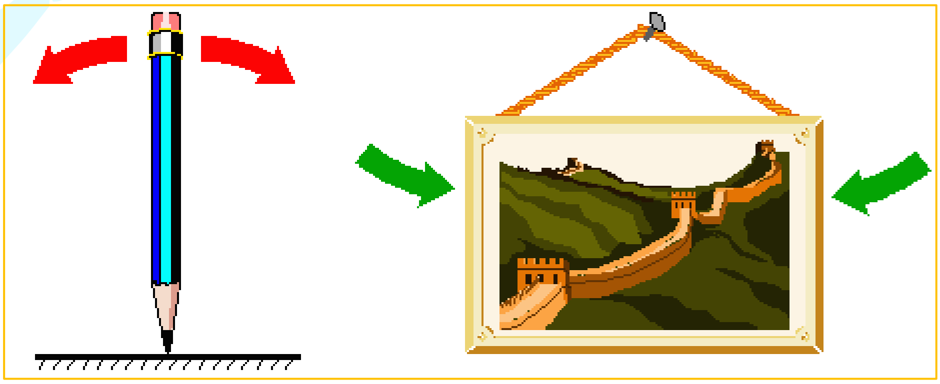
When a body experiences unequal external force, it is displaced from its original position. This displacement could be in terms of position, inclination or a combination of both. Depending on the behaviour of the body, it can be either of the three types of systems.

4.2.1 Stable system:

If the body returns to its original position after being displaced, it is said to be a stable system. For example, when you push a swing in the garden, the swing will return to its original position after a few oscillations. Such a system is called as stable system.

4.2.2 Unstable system:

If the body does not return to its original position after being displaced, it is said to be an unstable system. For example, if you balance a pen on its tip on a table, it will start to tilt downwards by the slightest application of external force and it will keep on tilting until it completely falls down. The body does not return to its original position but keeps on moving further away. Such a system is an unstable system.



Img 4.1 showing unstable and stable systems

4.2.3 Neutrally stable system:

If the body does not return to its original position and does not even keep on moving away from it but stays in the new position, it is said to be neutrally stable system. For example, keep a spherical ball on a horizontal table. Move it by your hand to a new position and leave it. The ball will now neither return to its original position nor will it move further. It will stay in this new position. Such a system is called as neutrally stable system.

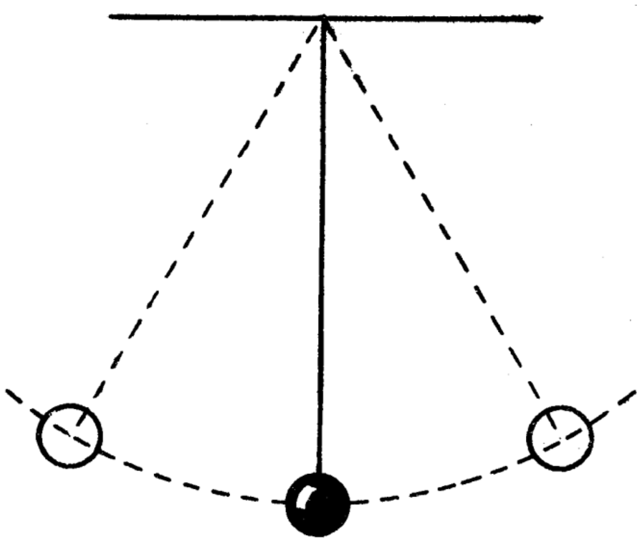
A drone without any sensors equipped is a neutrally stable system. When a drone is dropped from a height without applying any force, the angle at which it is dropped will remain same till it touches the ground. Hence, neither the angle goes back to its original inclination nor does it deviate further but remains same.

It is interesting to know that stability is measured with respect to a certain parameter. Like in the case of a drone falling from a height, it is a neutrally stable system when it comes to the angle. However, if you consider the position of the drone, then it becomes an unstable system.

Additional Information

Multi-rotors are neutrally stable system which is stabilized with the help of sensors, microcontroller and motors. Thus, if one is to drop quadrotor without arming, it would fall in the same orientation as it was left in. Assuming that we apply no torque on the drone while dropping it.

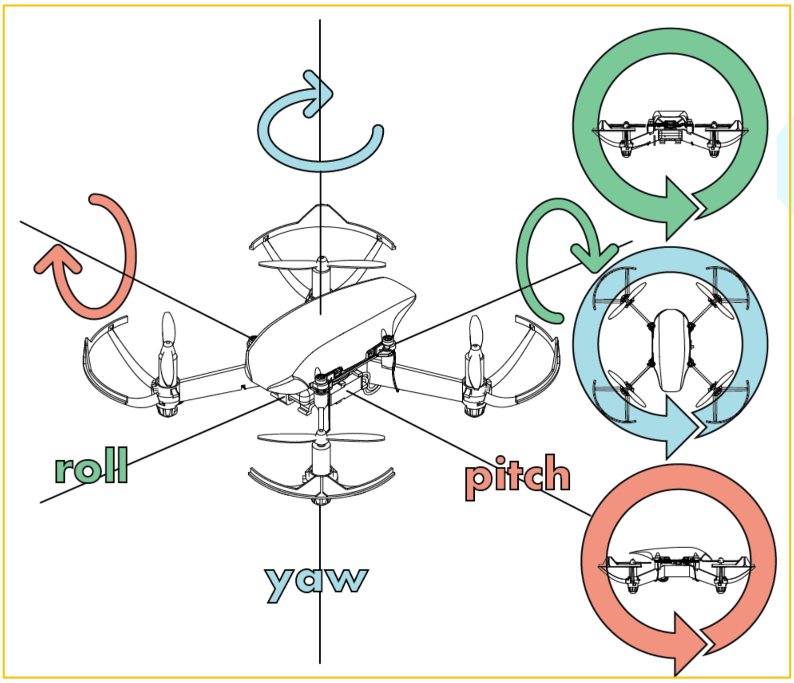
Example:



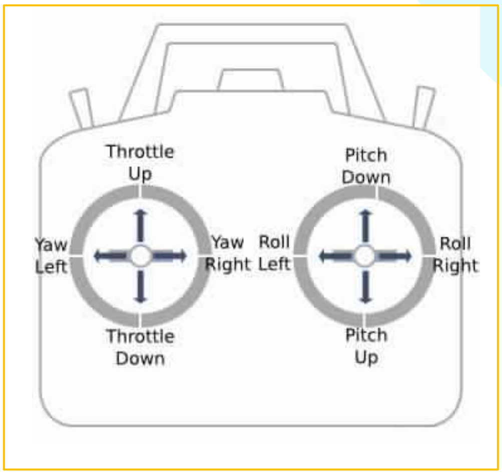
Consider this pendulum at rest (equilibrium). When it is swung to the right, for it to return back to the equilibrium, a restoring torque is provided. This restoring torque is provided by gravity itself. In the case of a pendulum, the C.G (center of gravity) is situated in the center of the bob and the axis of rotation is above it that is above the C.G. this particular arrangement is what makes the pendulum a stable system.)

4.3 Control

In order to take care of the inherent neutral stability of the drone, it's necessary to use sensors and control its behavior. Note that it is extremely difficult to fly a drone without sensors, but an aircraft can be. Thus, Control of drone is a very important aspect. A user controls the drone via a wireless remote-control hardware over radio or Bluetooth. Here is how it works:



Img 4.2: Drone controls

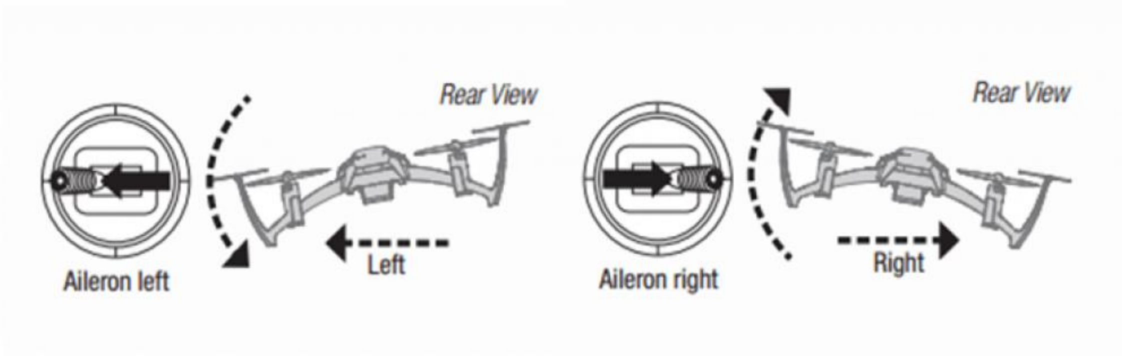


Img 4.3: RC Joystick control diagram

4.3.1 Roll:

Done by pushing the right joystick to the left or right. Literally rolls the quadrotor, which maneuvers the quadrotor left or right.

Working Principle:



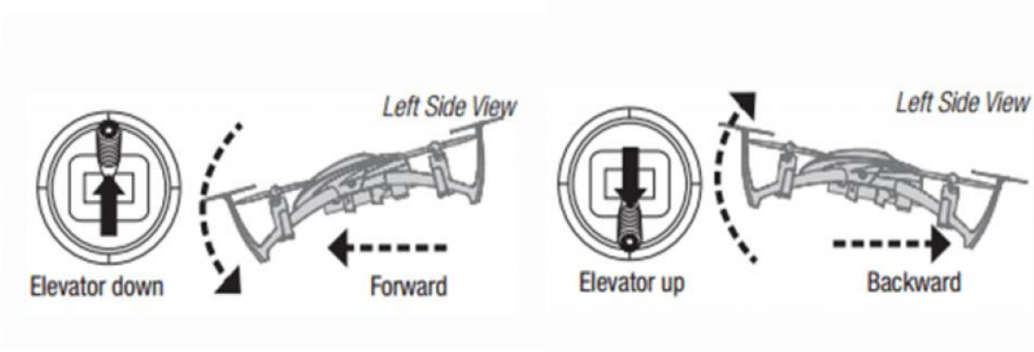
Img 4.4: Roll controls

a. For a quadrotor to roll, it needs a torque about the center of gravity along lengthwise (front - back) direction.
b. To roll the quadrotor towards the left, we need a counterclockwise torque. That means the thrust on the right pair of rotors should be more than the thrust on the left pair of rotors.
c. This is attained by increasing the speed the of pair of rotors on the right to create more thrust on the right side as compared to the left side and the required torque is generated.
d. Similarly increasing the speed of left pair of rotors creates more thrust on the left side as compared to the right side and quadrotor rolls to right with this torque.
e. After rolling the drone on either side the thrust on the rotors generates a lateral force which then translates to the acceleration moving the quadrotor to left/right.

4.3.2 Pitch:

Done by pushing the right joystick up or down. Tilts the quadrotor, which maneuvers the quadrotor forwards or backwards.

Working Principle:



Img 4.5: Pitch controls

a. For the quadrotor to move along any direction, in this case forward or backward, we need to generate torque. Thus, to perform a Pitch movement it needs to generate torque at the center of gravity along the Lateral axis(wing-wing)
b. To facilitate forward movement, rotors at the back of the drone need to provide additional torque. This requires the respective motors to provide more force by running the back motors at extra speed.
c. Similarly, for backward movement, the forward motors need to run at extra speed.

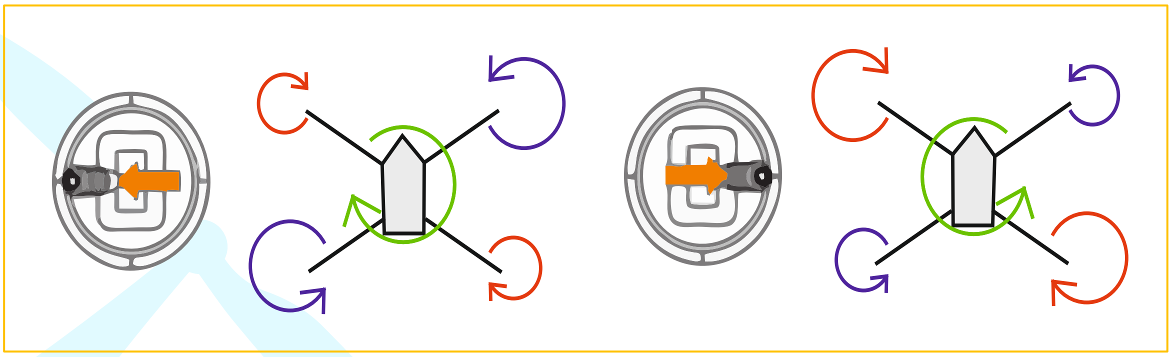
4.3.3 Yaw:

Done by pushing the left joystick to the left or to the right. Rotates the quadrotor left or right. Orients the front of the drone in different directions and helps with changing directions while flying.

Working Principle:

a. Unlike roll and pitch, yaw is the effect of the rotors on the frame of quadrotor.
b. When a propeller turns clockwise it generates counterclockwise torque on the frame to equalize the torques.
c. Diagonally opposite rotors generate torque in the same direction (Clockwise or Counter/Anticlockwise).

d. If one of the pairs of diagonally opposite rotors generate more torque than the other pair, then the frame will have a resultant torque acting in one of the directions (opposite of the propeller rotation). This helps the quadrotor to yaw



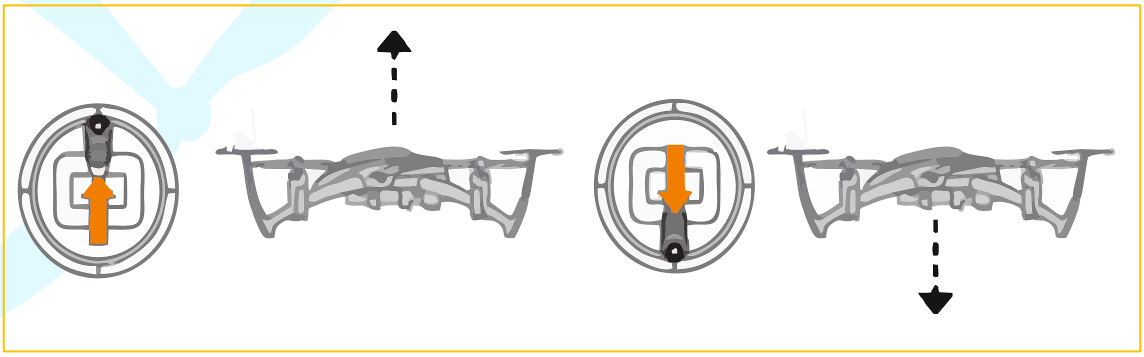
Img 4.6: Yaw controls

4.3.4 Throttle

To increase, push the left joystick up. To decrease, pull the left stick down. This adjusts the altitude, or height, of the quadrotor.

Working Principle:

Throttle up/down basically means controlling the quadrotor to go higher/ lower. Throttle up is achieved by increasing the speed of all rotors at the same time (and vice versa for throttle down). This causes propeller to increase the thrust generated that help the drone go higher.



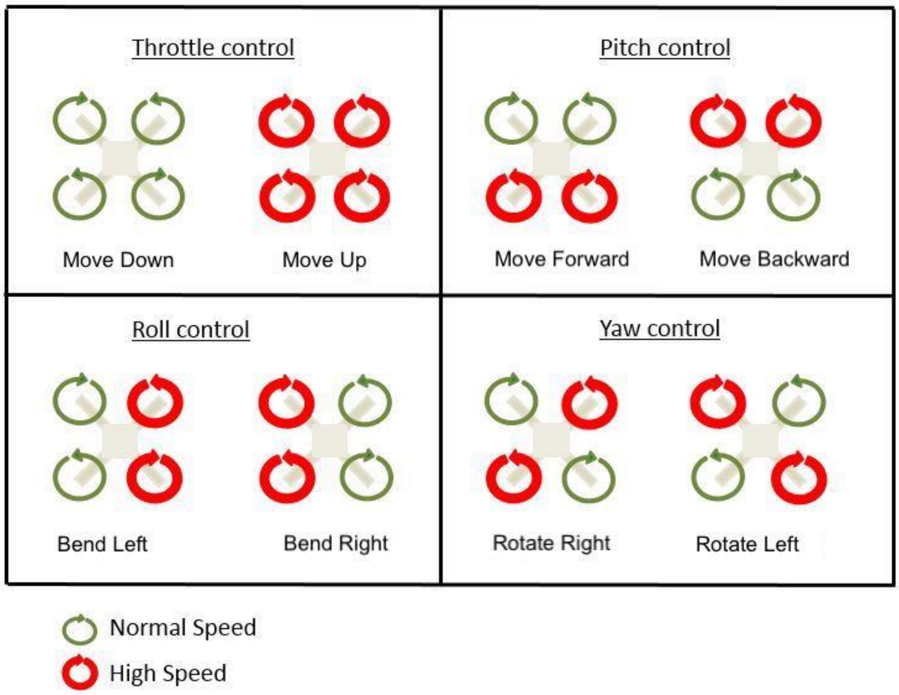
Img 4.7: Throttle controls

In order to understand the manoeuvres of a drone by roll, pitch and yaw in a better way, you can check out the following videos:

Understanding the three axes (Roll, Pitch and Yaw)
and the movements along them for an aircraft
Link : https://www.youtube.com/watch?v=5IkPWZjUQlw

How to control roll, pitch, yaw and
throttle movements in a quadcopter.
Link : https://www.youtube.com/watch?v=R_ekdXcDQHw

The mechanisms behind the motion of a quadcopter can be summed up in the given diagram:



Img 4.8 showing speed of motors for different motions of a quadcopter

Summary

Each and every object or a body or a system is either stable, unstable or neutrally stable. The behaviour of the body by a simple application of force causing displacement in a certain parameter like position or inclination defines the type of stability it has. When the body returns to its original position, it is called to be a stable system. When the body does not return to the original position but deviates further from it, it is called unstable system. When the body does not return to the original position but remains in the new position without deviating further, it is called as neutrally stable system. Drones are inherently neutrally stable systems.

In order to control this nature of a drone, it is necessary to mount sensors and use them to control the movement of drone. The controls of roll, pitch, yaw and throttle are done by varying the speeds of motors as required.

Exercise:

1. Categorise the following systems into stable, unstable or neutrally stable systems:

   Balloon, kite, birds, a ball kept on a flat surface, parachutes, missiles, passenger aeroplane, fighter jets, housefly, drones.

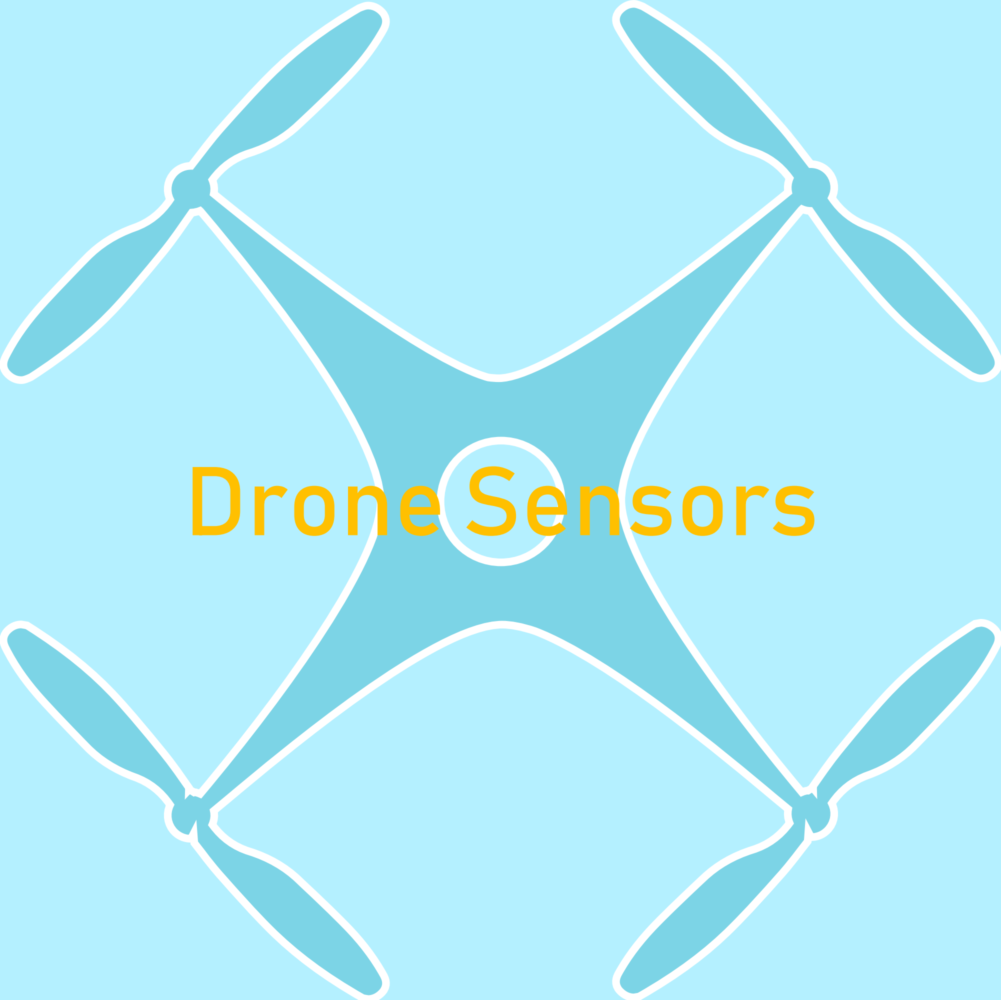
2. Activity: If a pendulum is an example of a stable system, then what type of system will an inverted pendulum be?

3. Which set of motors should have higher and lower speeds for the following manoeuvres:
   a. Pitch front
   b. Yaw clockwise
   c. Roll right
   d. Pitch back
   e. Move down
   f. Roll left
   g. Yaw anticlockwise
   h. Move up

4. Activity: is human being standing on the feet a stable, unstable or neutrally stable system?

Chapter 5

Drone Sensors



Objectives

The objectives of this chapter are to understand:

- What are sensors and why are they used in drones
- Types of sensors used in drone and their functioning

5.1 What is a sensor and what is it supposed to do?

A sensor is a device that detects and responds to some type of input from the physical environment. The specific input could be light, heat, motion, moisture, pressure, or any one of a great number of other environmental phenomena. It converts physical data to electronic data.

Following are the four major sensors in a drone:

Accelerometer	Barometer
Gyro Sensor	Magnetometer

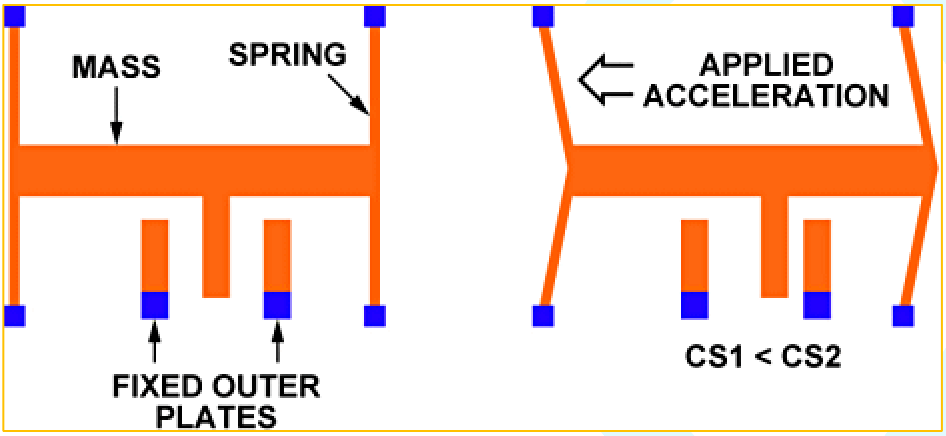
All these sensors are developed using micro-electro-mechanical system (MEMS) technology.

A video explaining about MEMS system can be found here:

https://www.youtube.com/watch?v=Vld-5Z1YGVM

5.1.1 Accelerometer

- Accelerometers are used to determine the orientation of the drone in flight
- Accelerometer measures the proper acceleration
- Accelerometer values help determine the roll and pitch movements of the drone
- Accelerometer measures the change in the acceleration due to gravity along X axis (forward and backward) or along the Y axis(sideward)
- The accelerometer uses the above data to calculate roll and pitch of the drone
- This is MEMS form of an accelerometer. Here the mass attached to the spring can move in a particular direction when it experiences acceleration. The movement of the mass will cause change in capacitance between the fixed plates on the outside.
- This change in capacitor is measured and converted to appropriate voltage values that are used in the circuit.



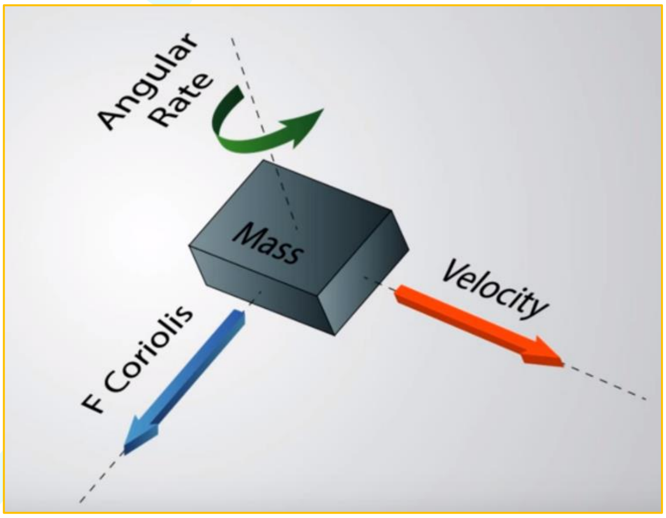
Img 5.1: Accelerometer

5.1.2 Barometer

- Barometer measures air pressure. This air pressure is used to measure the height of the drone above the MSL. As we move to higher altitude, the air pressure decreases. (Remember P=ρgh?)
- The barometer measures the air pressure and calculates the relative height of the drone
- This data is used with Kalman Filters to provide Altitude Hold (Althold) for the drone

5.1.3 Gyro Sensor

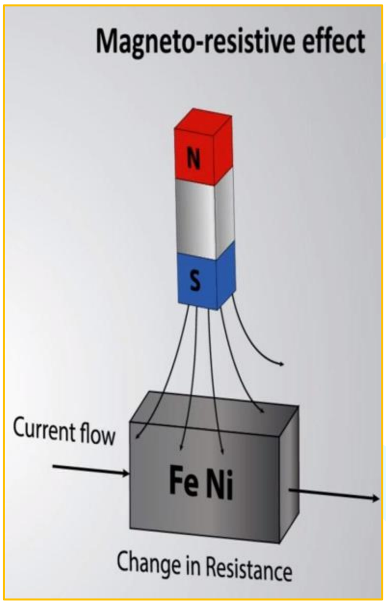
- Gyro sensors, also known as angular rate sensors or angular velocity sensors, are devices that sense angular velocity
- Gyro sensors work according to the Coriolis effect that is a force that acts on objects that are in motion relative to a rotating reference frame.
- A body of a certain mass moving with a certain velocity will experience the Coriolis force when observed in a rotating frame of reference.
- The next image depicts the MEMS form of a gyro sensor and this will help explain how the change in velocity and angular velocity of a body leads to change in the capacitance.
- The relevant change in voltage values because of the corresponding change in capacitance values is used to measure the Coriolis force and thus the angular velocities along different axes.



Img 5.2: Gyroscope

5.1.4 Magnetometer

- A magnetometer is an instrument that measures magnetism—either magnetization of magnetic material like a Ferro magnet, or the strength and, the direction of magnetic field at a point in space.
- Magnetometer measure the earth's magnetic field by using the Hall Effect or the magneto resistive effect.
- The onboard sensor works using the magneto resistive effect, wherein materials like FeNi are used. Such materials when subjected to magnetic fields change their resistance and we measure this resistance to calculate magnetic field.
- This way, the magnetometer is used as a digital compass that helps identify the magnetic north. This helps in obtaining more precise readings for headings.



Img 5.3: Magnetometer

5.2 Other sensors

The four major sensors mentioned above help in the stabilization of the drone. Apart from these, there are various other sensors which can be equipped on a drone. These sensors require different types of data input as they perform different tasks on a drone. Depending on the purpose of the drone, one can equip the sensors as required. Following are some other sensors that can be used on a drone:

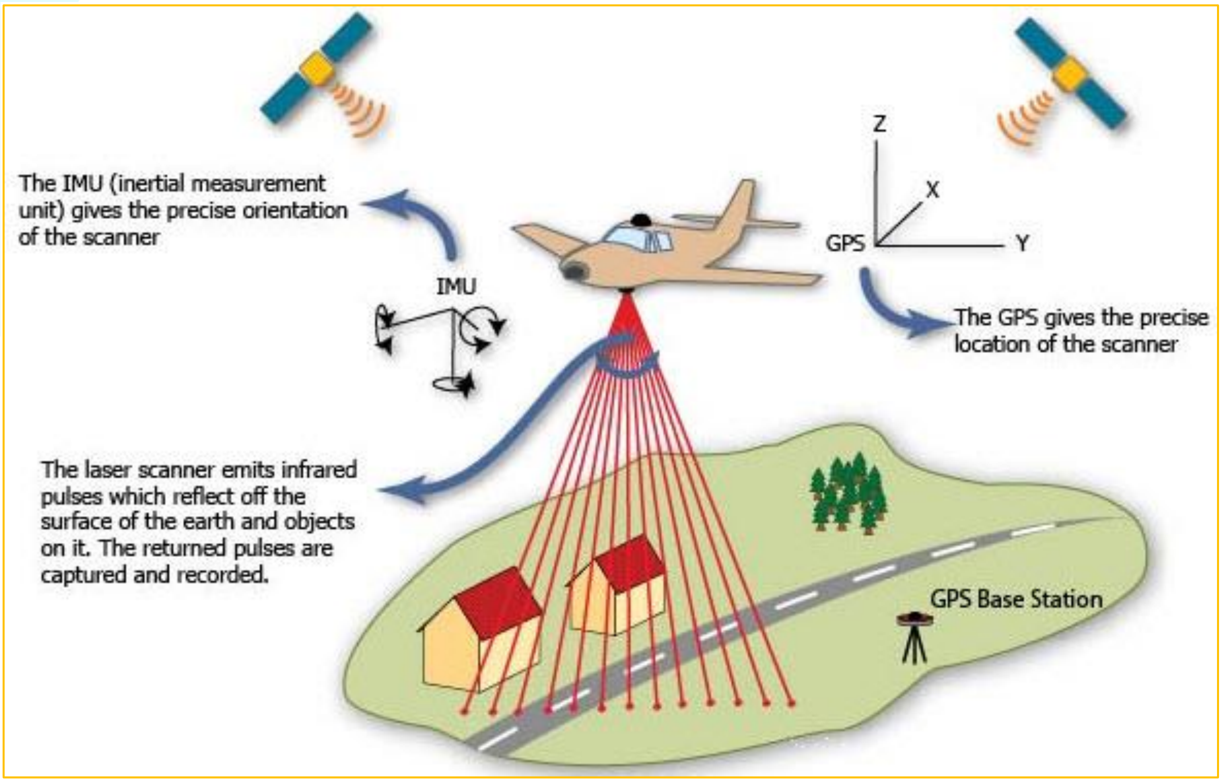
5.2.1 Distance Sensors [3]

Distance sensors can be used for various purposes. One can design a GPS enabled drone which can reach a specific location. Collision avoiding drones also use distance sensors, to determine the obstacle in their path. Following are some of the distance sensors:

5.2.1.1 Light-Pulse Distance Sensing (Laser)

A Laser Range Finder (LRF) sends out a laser beam at certain intervals. When these beams bounce off of objects, the LRF detects the time at which it takes for these beams to return to the drone to reflect the distance between the object and the drone.

Light Detection and Ranging (LiDAR): LiDARs create an LRF spin, which is especially useful for producing 3D constructions and surveillance required for aerial surveys and navigation purposes.



Img 5.4 showing principle of LiDAR

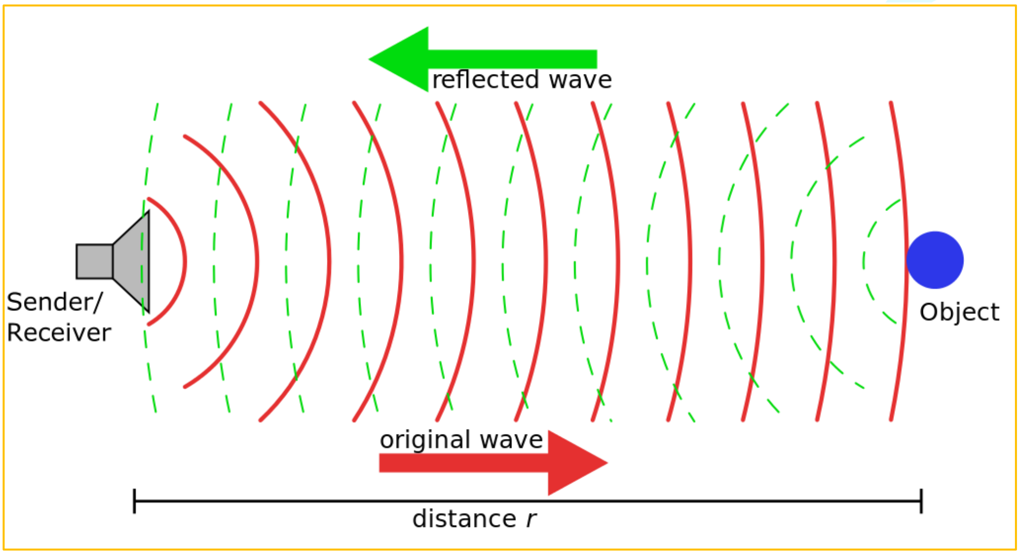
[3] https://www.azosensors.com/article.aspx?ArticleID=1149

5.2.1.2 Radio Detection and Ranging

The frequency shift between a transmitter that emits a particular signal and the receiver antenna on the drone that detects its Eco is used to determine the speed and direction of the object in relation to the drone.

5.2.1.3 Sonar-Pulse Distance Sensing (Ultrasonic)

By sending out a sound wave at a specific frequency, the drone measures the distance by which a sound wave bounces off the object and back to the drone.



Img 5.5 showing principle of SONAR

5.2.2 Time of Flight (ToF) Sensors (Range Imaging)

Depth sensors of the ToF camera sensor emits a short infrared light pulse. The pixels of the camera sensor measure the time in which the infrared light pulse returns back to the drone.

ToF cameras are lightweight sensors that provide users with useful information on the distance between the sensor and an object at a sub-millimeter depth resolution. ToF sensors can be used on drones for gesture recognition, track objects, virtual reality, counting of objects or people, enhanced 3D photography and much more[4].

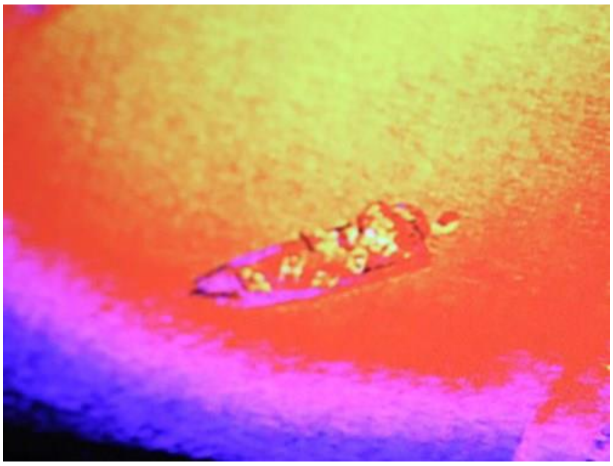
[4] https://www.dronezon.com/learn-about-drones-quadcopters/best-uses-for-time-of-flight-tof-camera-depth-sensor-technology-in-drones-or-ground-based/

Img 5.6 showing a Time of Flight Sensor

5.2.3 Thermal Sensors

Detects the heat that is radiating from almost all objects and materials to transform this data into images and videos. Thermal Sensor Cameras are capable of capturing a wide variety of objects and organisms, as almost every source on the planet, as well as within the Universe, radiates some level of thermal energy. These include, but are not limited to, living species, buildings, planes, electrical sources, machinery, land, rocks, liquid, gas, etc.

By using thermal sensors on a drone, it can be used for various operations involving extreme heat, such as in firefighting, tracking forest for fires, tracking volcanos, etc. Thermal sensor enabled drones help in inspection of chimney stacks, power stations and other such locations much quicker. There have been various instances where thermal drone has helped in rescue operations.



Img 5.7 showing thermal image of a boat during a rescue operation using thermal drone

5.2.4 Chemical Sensors

These types of sensors are particularly useful for the detection of chemicals present in environmental, industrial and emergency response situations. The use of chemical sensors on drones is especially critical in preventing the potential exposure of workers to the unknown chemical present in these situations.

Img 5.8 showing use of drone during fire fighting

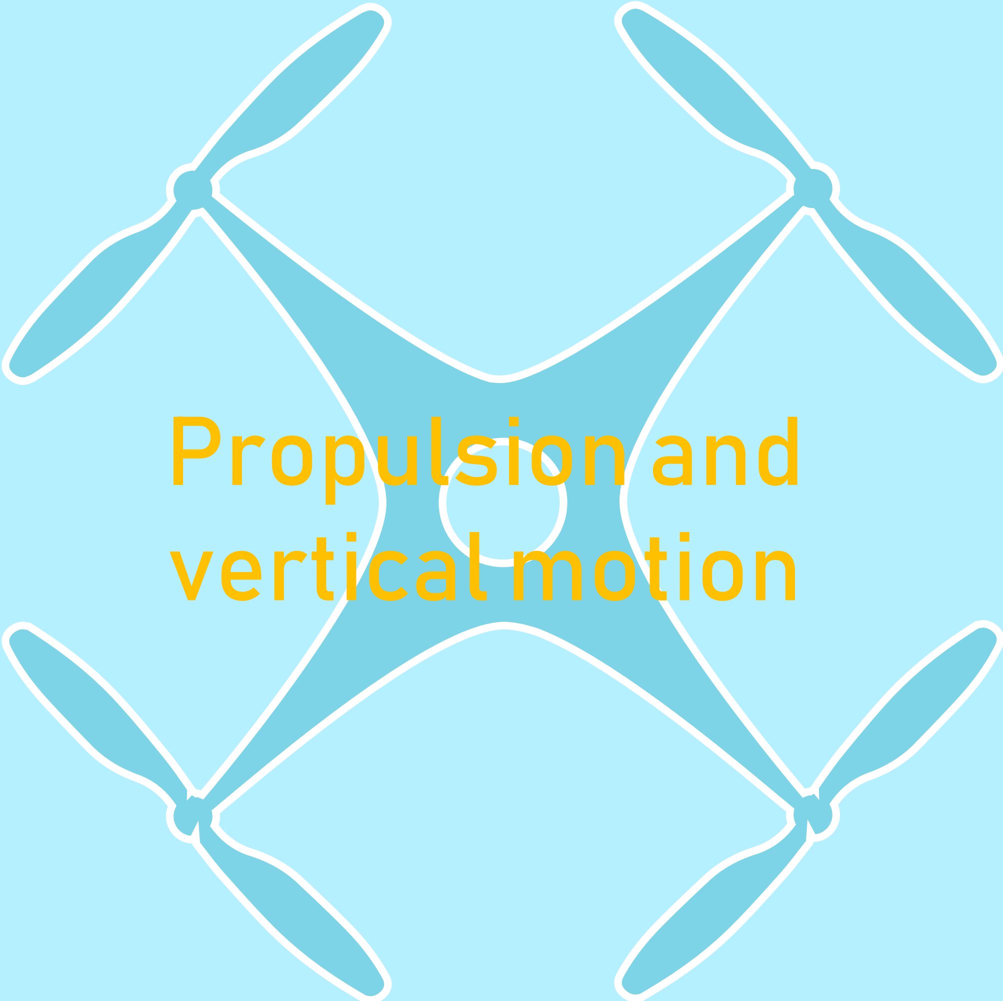
Summary

Sensor is one of the most important components of any drone as it helps in its stabilization. A sensor detects the current condition of the drone (position, orientation, speed, etc) by means of some particular environmental phenomenon. Accelerometer, gyro sensor and magnetometer help in determining the orientation of the drone by measuring different phenomena and converting into useful data. Barometer helps in determining the altitude of the drone. There are various other sensors which can be mounted on a drone for different purposes. These include distance sensors like LRF, LiDAR and SONAR, ToF, thermal sensors and chemical sensors.

Exercise:

1. What are the four major sensors used in a drone?
2. Which sensor is used to measure the altitude of a drone?
3. Which of the following sensors can be used to measure distance?
   a. LiDAR
   b. Thermal sensor
   c. Chemical sensor
4. Which sensor(s) can be used if the purpose of the drone is to assist a team of volcanologists?
5. ACTIVITY: think about a new application of drone and list down all the sensors required.

Chapter 6



Propulsion and vertical motion

Objectives

The objectives of this chapter are to understand:

- Concept of propulsion
- Motors used in drones
- Propellers

6.1 Propulsion

Propulsion is the act of moving or propelling the object in forward direction. In an airplane, the engine is part of the propulsion unit along with the blades (propellers).

If you consider a jet engine of an airplane, it has blades that spin at high speeds and compress air which are then sprayed with fuel and an electric spark lights the mixture. This burning gas expands and blasts through the nozzle at the back of the engine and thus the airplane is propelled forward with high speeds. The aircraft achieves vertical motion with its aerofoil shaped wings.

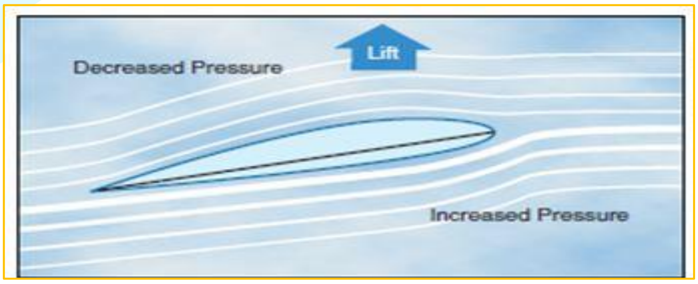
In a quadrotor, we can't attach jet engines, so we use motors and propellers as our propulsion unit to provide propulsion.

6.2 Propeller

The spinning propellers on motors generate thrust. The design of the propeller is significant in this thrust generation. The cross section of a propeller is an aerofoil whose aerodynamic shape helps in generating thrust.

A video explaining about working mechanism of an aerofoil:

Link: https://www.youtube.com/watch?v=w78JT6azrZU



Img 6.1 showing aerofoil design and pressure difference causing lift

6.2.1 Parameters of a standard propeller

1. Diameter of a propeller: The end to end distance of the propeller is called the diameter of the propeller.

2. Pitch: Propeller pitch is a linear dimension usually expressed in inches, feet, millimetres, or meters, and is equal to the advance of the propeller in one revolution.

6.2.2 Propeller Materials:

The materials used in the manufacturing of a propeller plays a significant role in the durability of the propeller and the thrust produced by it.

Propellers were predominantly manufactured in fibreglass reinforced plastics. This material makes the propeller to become very stiff for their light weight and this allows the propeller to keep the correct and most efficient shape regardless of how fast it spins. However, when it hits something like the ground or a branch, that stiffness means it will shatter and the quadcopter can no longer fly. This means you have to replace the propellers, increasing the maintenance cost.

In recent times, propellers are being made using polycarbonate, a type of plastic that has good stiffness but will bend rather than break if it hits something hard. This means that if you crash, a propeller may bend but it can quite often be bent back into shape rather than having to replace the propeller altogether. There are other materials used in propellers but polycarbonate or PC as it is often referred to is generally considered to be the best.

The plastics used for manufacturing propellers are mainly thermoplastics. Hence, these propeller materials change properties depending upon the temperature.

If you are flying in winter or in a very cold climate, you might want to use a ABS propeller, as PC can become brittle and break more often. If you are flying somewhere very hot, you may need to use a glass fibre reinforced propeller as both ABS and PC can become very soft and less efficient/durable. For most pilots in most locations, PC propellers will be suitable and the most durable.[5]

[5] https://www.getfpv.com/learn/new-to-fpv/all-about-multirotor-fpv-drone-propellers/

Img 6.2 showing propellers made of different materials

Types of propeller used in Multirotor:

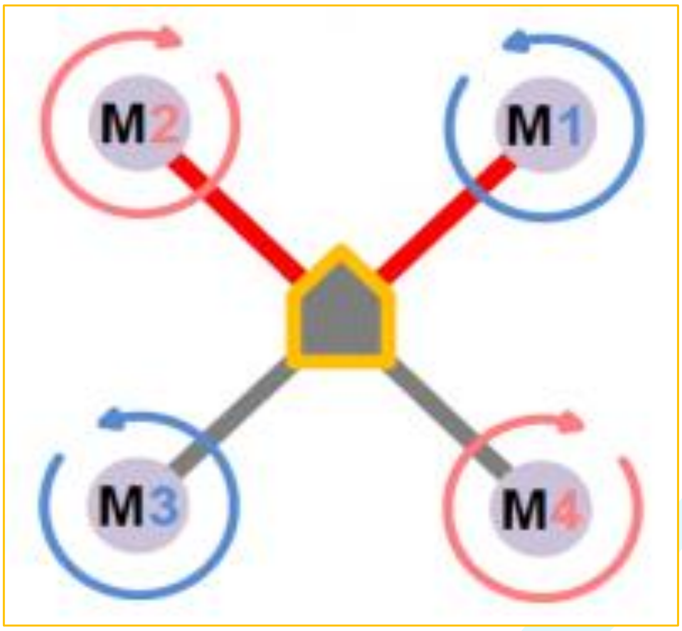
There are two types of propeller configurations. They are structurally the same with the only difference that they are mirror images of each other. This is because propellers move in the opposite direction/spin for stability purposes. The propellers ensure that they push the air down to generate and upward thrust.

For reference purposes in this module, we shall use the following:

Type ‘A’ – Clockwise rotating propellers.

Type ‘B’ – Counter-clockwise rotating propellers.

The propellers are positioned such that the ones with the same direction/spin are placed diagonally opposite to each other.



Img 6.3: Propeller direction/spin in a quadcopter

6.3 Motors

Motors are machines which convert electrical energy to mechanical energy. Drones require motors to create necessary thrust during flight. In drones, small Direct Current (DC) motors are used to achieve flight.

There are 3 types of DC motors:

- Stepper motor
- Brushless DC
- Brushed DC

The comparative advantages and disadvantages are as follows:

STEPPER	BRUSHLESS DC	BRUSHED DC
	Advantages	
Accurate position control	High efficiency	Economical and Simplest to use
Excellent low speed torque	Little to no maintenance	Speed linear to applied voltage
Long Life	High output power per frame size	Simple motor control
	Disadvantages	
Low efficiency	More complicated motor	High maintenance
Prone to resonance noise and cannot accelerate loads	Large initial costs	Short life span

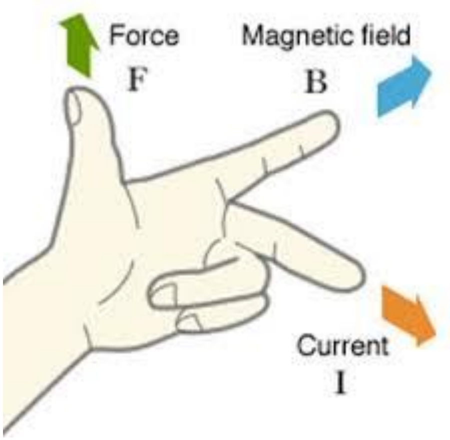
Additional Information

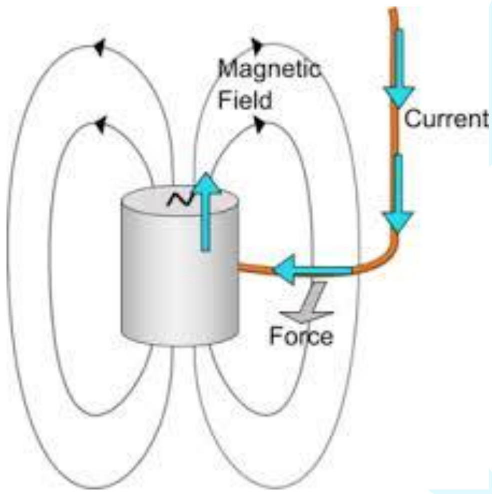
Working Principle of Homopolar Motor

A homopolar motor creates rotational movement (of wire) because of the Lorentz force.
In homopolar motor, the electric current is flowing from positive to the negative terminal of battery through a magnet. Here, the current is actually flowing from the edge of the magnet to its centre and then to the negative terminal of battery.

Notice that, the direction of current and the direction of magnetic field are perpendicular to each other. And when the direction of current is perpendicular to the magnetic field, Lorentz force is generated and is perpendicular to both current and magnetic field.

You can use left hand rule: Hold your left hand such that the index finger, thumb and middle finger are mutually perpendicular to each other. Your index finger is pointing in the direction of magnetic field and middle finger is pointing in the direction of current. In this case, your thumb will indicate the direction of Lorentz force and the wire will move/rotate in the same direction as the force.





Summary

In order to move an airplane in the forward direction, a large amount of force has to be provided which helps in propelling the aircraft. The lift is provided by the wings. In case of a multirotor drone, the propulsion and lift are provided by the propellers mounted on the motors. This happens because the propellers are aerofoil shaped. For selecting a propeller, one has to consider the pitch and the diameter of the propeller. Material of propeller also is significant as it affects the durability and speed of the drone. In most cases, polycarbonate propellers are used. Remember that propellers are of two types, clockwise and counter clockwise. Both of them are necessary in drones to provide stability.

Exercise:

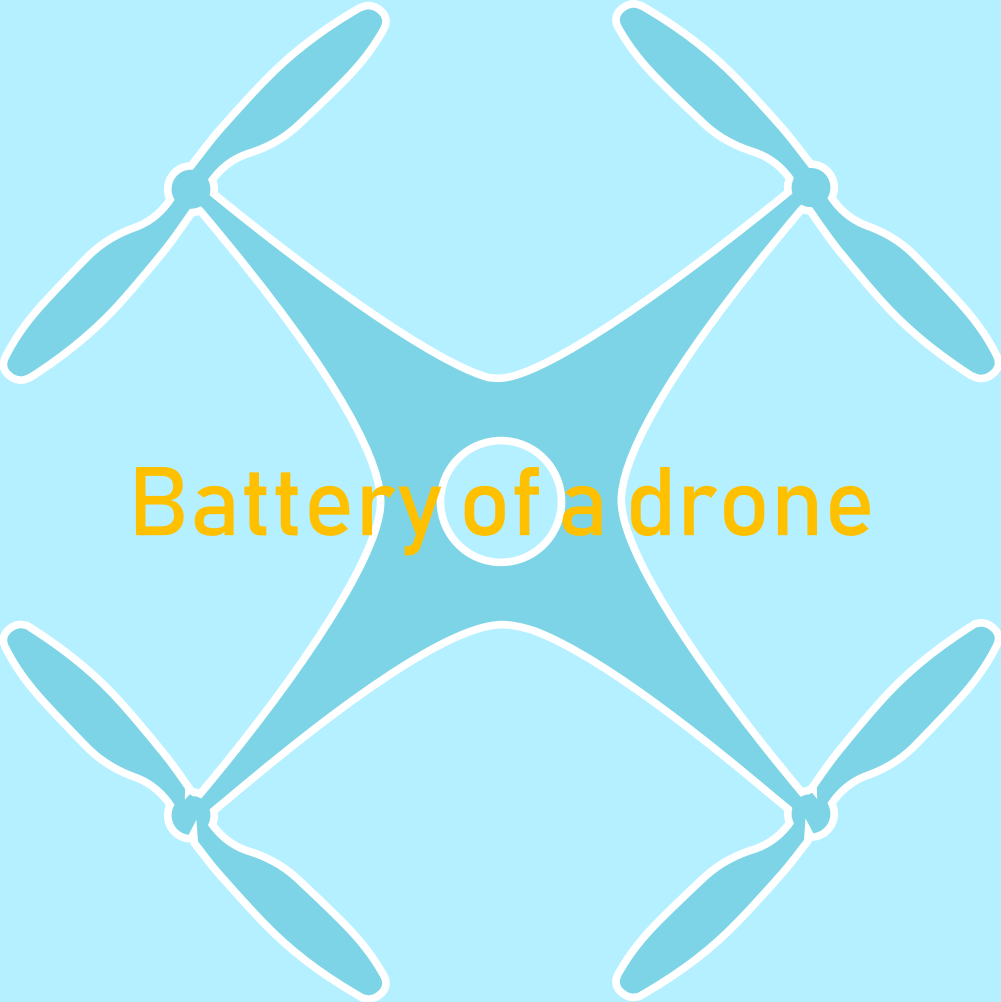
1. What is the name of the force which causes lift?
2. Which of the following can be used in a quadcopter to generate lift?
   a. Internal combustion engine and propeller
   b. Motor and propeller
3. What is the shape of the cross section of a propeller?
4. Which of the following statements is correct for a quadcopter?
   a. Like propellers are positioned side by side
   b. Like propellers are positioned diagonally opposite
5. Activity: Given are the weights of the components to be used in making a quadcopter.

Calculate the thrust required for each motor, keeping the thrust to weight ratio as 2.

Frame	:	150 gm
R/C receiver	:	15 gm
Batteries	:	150 gm
FPV camera and transmitter	:	50 gm
Motors	:	120 gm
ESC	:	35 gm

Chapter 7

Battery of a drone



Objectives

The objectives of this chapter are to understand:

What is a battery?

Which battery to use for a drone?

7.1 Battery

Batteries are devices that provide electricity by means of electrochemical cells inside them. Batteries are today utilized in every field, ranging from military to civil, industrial to agricultural, cars to drones.

A video explaining about the basic mechanism of a battery:

Link: https://www.youtube.com/watch?v=9OVtk6G2TnQ

7.2 Types of batteries

Batteries are of different types, made with different variety of materials. Some of these batteries are not rechargeable, such as alkaline batteries and some are rechargeable such as Li-ion, Ni-Cd, LiPo, Ni-MH, lead acid.

- Wet cell batteries:
  A wet cell battery generates power from an electrode and a liquid electrolyte solution. Eg. Lead Acid batteries, Ni-Cd batteries, etc.
- Dry cell batteries:
  A dry cell uses a paste electrolyte, with only enough moisture to allow current to flow. Eg. AA, AAA, Li-ion, LiPo, etc.

Examples:
Lithium ion Batteries: A lithium-ion battery is a type of rechargeable battery in which lithium ions move from the negative electrode to the positive electrode during discharge and back when charging.

Lead acid Batteries: Lead acid batteries are used in automobiles, AA and AAA batteries are used in common appliances.

For our purpose of providing current for a drone, LiPo batteries are a perfect fit.

7.3 Which batteries should we use for drones?

The battery used in a drone is a Lithium Polymer or LiPo battery. This battery has various advantages over other traditional batteries. The most important reasons for using LiPo batteries in drones are that they are energy dense and light in weight.

The weight of a battery is essentially due to the chemicals inside it which provide electric current. If you compare various types of batteries of equal weight, LiPo batteries provide a very high energy i.e. very high current. Hence, LiPo batteries have an ability to provide more current at very light weight, i.e. they are energy dense. This helps your drone to get high energy without much increase in overall weight.

Img 7.1 LiPo battery

Understanding the parameters that guide our decision around which battery to use for operationalizing a drone is critical. The motors, especially in a multi-rotor, consume a very high amount of power from the battery. The total weight of the system also needs to be very low to avoid spending a high portion of the energy in just getting the load up in the air. These parameters lead us to selection of the Lithium Polymer (LiPo) battery in our drones. Some of the reasons are:

1. **High Energy Density**
   LiPo batteries have a very high energy density i.e. they can carry the maximum amount of energy per unit of weight of the battery. This keeps the battery light and with sufficient energy to power an entire drone + its own weight.
2. **C-Rating**
   Another important factor in a LiPo battery is the C Rating of the battery. C-Rating of a battery refers to the maximum safe discharge current that a battery can provide (without exploding). C-Rating is calculated as: (Max safe current in mA) / (mAh capacity of the battery).
   Drone motors, especially multi-rotors, generally require a very high current to lift it up. To ensure this, the batteries require to be of a high C-Rating. Many drones use C-Rating between 15C to 25C.

3. **Voltage**
   The operational voltage of a single cell of a LiPo battery is 3.7V. We can get to different values of operational voltages by adding these cells in series and parallel combinations.
4. **Discharge Profile**

A fully charged single cell LiPo battery has a voltage of ~4.2 V. However, very quickly after starting to use the battery (at ~90% of the charge), the voltage falls to 3.7 V where it stays stable for most of the battery operation. When the battery charge reaches 20%, the voltage starts dropping sharply below 3.7V.

Summary

Battery is the source of electricity for many applications. There is a wide variety of batteries available in the market. Based on a particular application, one can select a particular type of battery. For the application of drones, Lithium Polymer batteries are most widely used. This is because of the high energy density and light weight.

Exercise:

1. What does LiPo stand for?

   a. Litmus Polymer

   b. Linux Polycarbonate

   c. Lithium Polymer

   d. Lithium Polycarbonate

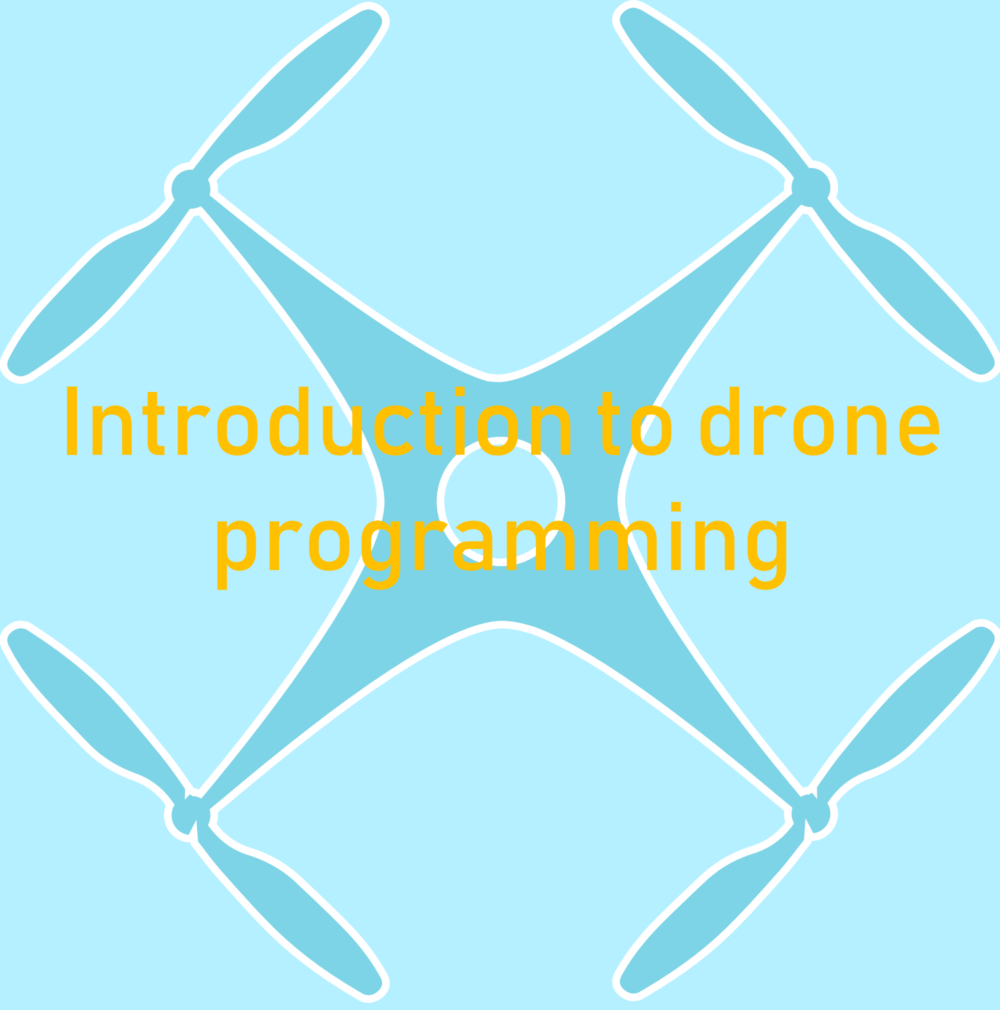
2. Energy density of LiPo batteries is?

   a. Low
   b. High

3. Activity: How can you connect the two batteries in series and in parallel? What will be the effect of each type of connection?

Chapter 8

Introduction to drone programming



Objectives

The objectives of this chapter are to understand:

- Introduction to logic and programming
- Drone programming basics

8.1 What is programming/coding?

Computers are complex machines built to perform complex tasks which only understand a particular set of instructions or a particular language. In order to make computers to do tasks and operations which we want, we have to give instructions which can be understood by it. Otherwise, the computer is just a box which will not be able to do any particular task.

Programming/coding is implementing our solution for the problem in a set of instructions or programming language for the computer to solve.

For this purpose of instructing the computer, we have different programming languages. These languages could have different syntax and different formats, but the core logic behind instructing the computer remains the same. Some of the programming languages are C, C++, Java and Python.

8.2 Logic in programming

As we know that there are various programming languages available. Any computer program can be written by following three constructs, irrespective of the language.

8.2.1 Sequential statement

These are the basic simple statements in the code. These statements are used for creating a variable, calling functions, assigning values, etc.

Example: In mathematics, we assign values to variables such as let x = 10. In the same way, while coding, we sometimes require too assign values to variables. In C++, it is done in the following way:

```
int k = 10;

myfucntion ();
```

8.2.2 Conditional statement

Sometimes, you want the computer to do a specific task by making a decision on its own, depending on the situation or condition. For example, you could write a program where in the computer asks the user to type a number and then the computer displays whether the number is positive or negative. In such a program, you could use a conditional statement, **if else**. The logic would be:

```
If (n < 0)
        cout << “the number is negative\n”;
else if (n == 0)
        cout << ”the number is neither positive nor negative\n”;
else
        cout << “the number is positive\n”;
```

Here, the program will first check the first condition. If the number (n) is less than zero, it will display that ‘the number is negative’. If the first condition is not satisfied, then the compiler will move on to the next condition and check if it is satisfied. If the condition that number is equal to zero is satisfied, it will display the concerned message. If the second condition is not satisfied, the compiler will move to the next condition. The interesting part is that you do not need to specify the last condition that the number should be greater than zero, because if the first two conditions are not satisfied, then the only remaining possibility is the third one. This is a very simple example of how you can instruct the computer to do tasks using simple logic.

8.2.3 Repetitive statement

The third important part of coding is repetitive or iterating statements. These statements are used where you want the computer to repeat the same set of codes again and again for a certain number of times or while a condition lasts. They are also called as loop statements. Let us take an example of a code where you want to print numbers from 1 to 10. In this case, the task for the computer remains the same, i.e. to print a specific number. Hence, the statement is going to be repeated. Here we can use a loop statement, **while**.

```
int k = 1;

while (k < 11)

{

        cout << "k, ";

        k++;

}
```

The above code will print: "1, 2, 3, 4, 5, 6, 7, 8, 9, 10, "

The working is pretty easy to understand. The first statement is a sequential statement which assigns the value 1 to the variable k. The next line in the code is a while statement. This statement checks the condition in the bracket, which is that the value of k should be less than 11. If the condition is satisfied, then it will go inside the loop, or else it will not go inside the loop and move on to the next block. For our case, the value of k is 1 in the beginning and hence the condition is satisfied. When it moves inside the loop, the statement is to print the value of k with a comma and a space. This prints "1, " on the screen. The next line of the code is k++, which means to increase the value of k by 1. Hence, the new assigned value to k is 2. The compiler then again checks for the condition in while. Since it is still satisfied, the same procedure will be repeated and the new value of k will now be 3. The entire loop will keep on repeating till the condition in the while is not satisfied, which will be when k = 11. Hence, it will print out numbers till 10 and then it will stop and move on to the next block. All the problems, simple or complex can be solved by these three parts as a solution. The number of times each of these parts is used in a code can vary, depending on the logic and the level of simplicity in the code.

8.3 What is C++?

C++ is one of the programming languages. It is an object-oriented language where you can create a class with functions and variables and access them by creating class objects. This feature makes the entire coding procedure modular. Links to resources are mentioned below:

C++ language tutorial (pdf)

Link: http://www.cplusplus.com/files/tutorial.pdf

C++ Language tutorial website

Link: http://www.cplusplus.com/doc/tutorial/

8.4 Integrated Development Environment (IDE)

An integrated development environment (IDE) is a software application that provides comprehensive facilities to computer programmers for software development. An IDE normally consists of at least a source code editor, build automation tools, and a debugger. Some IDEs, such as NetBeans and Eclipse, contain the necessary compiler, interpreter, or both; others, such as SharpDevelop and Lazarus, do not.

IDE provides a place to write the code with tools such as text editors, helps in completion of codes by providing suggestions and helps in finding errors and bugs in the code.[6]

[6] https://en.wikipedia.org/wiki/Integrated_development_environment

8.5 Application Programming Interface (API)

In computer programming, an application programming interface (API) is a set of subroutine definitions, communication protocols, and tools for building software. In general terms, it is a set of clearly defined methods of communication among various components. A good API makes it easier to develop a computer program by providing all the building blocks, which are then put together by the programmer.

An API may be for a web-based system, operating system, database system, computer hardware, or software library.

An API specification can take many forms, but often includes specifications for routines, data structures, object classes, variables, or remote calls. POSIX, Windows API and ASPI are examples of different forms of APIs. Documentation for the API usually is provided to facilitate usage and implementation.[7]

In order to program a drone, you can download a sample IDE and API document from the following link:

Cygnus IDE and API document can be downloaded from:
tinyurl.com/cygnusIDE

Eclipse IDE and API document can be downloaded from:
https://www.eclipse.org/ide/

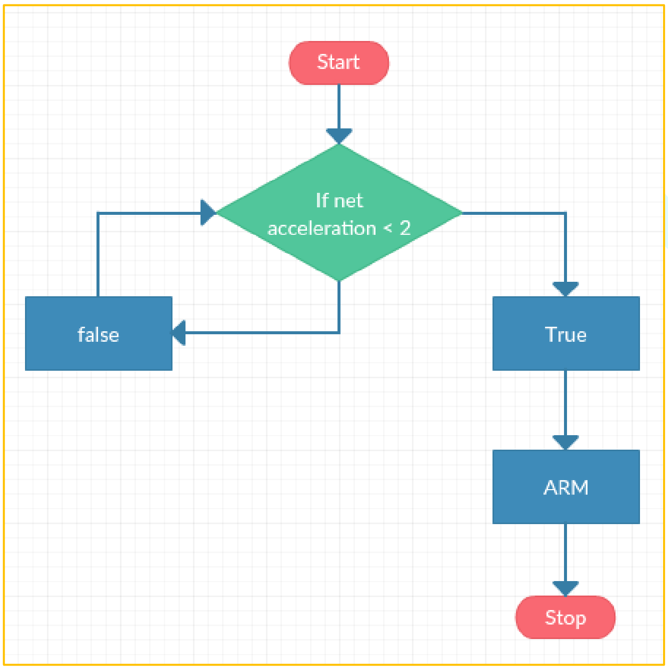
[7] https://en.wikipedia.org/wiki/Application_programming_interface

8.6 Programming a drone

A developer needs to think about the logic for a particular application. In our case of drones, we get the data about the orientation of drone through sensors. We can use these values obtained from sensors to make the drones perform tasks, as the drone is also a machine and programming helps us to instruct it.

In order to understand this, let us look at an example.

In our experiment, we want to program our drone for CHUCK TO ARM feature. This feature enables us to arm our drone by tossing the drone up in the air. In order to program this feature into the drone, we need a logic behind it. We know that the drone is armed when the propulsion system, i.e. the motors and propellers start spinning. In normal arming cases, pilot has to press a button for the propulsion system to start. In our experiment, we want to arm the drone by tossing it up in the air. When the drone is tossed upwards, it will go up for a fraction of second and then start falling downwards. As soon as it leaves your hand, the acceleration that is acting on the drone is gravity only and hence the accelerometer reading will show zero net acceleration in vertical or z axis. This data can be used in our program for the feature. Thus, our logic would be that when the accelerometer gives zero reading for net acceleration, drone should arm. Following flow chart will help you understand the entire logic in a better way.



Img 8.1 Flow chart

```
/* Name: ChuckToArm

 Author: DronaAviation */



// Do not remove the include below
#include "PlutoPilot.h"
#include "sensor.h"
#include "control.h"



//The setup function is called once at Pluto's hardware startup
void plutoInit()
{
// Add your hardware initialization code here
}



//The function is called once before plutoFly when you activate UserCode
void onPilotStart()
{
  // do your one time stuffs here

}



```

Img 8.2 Code for Chuck to arm

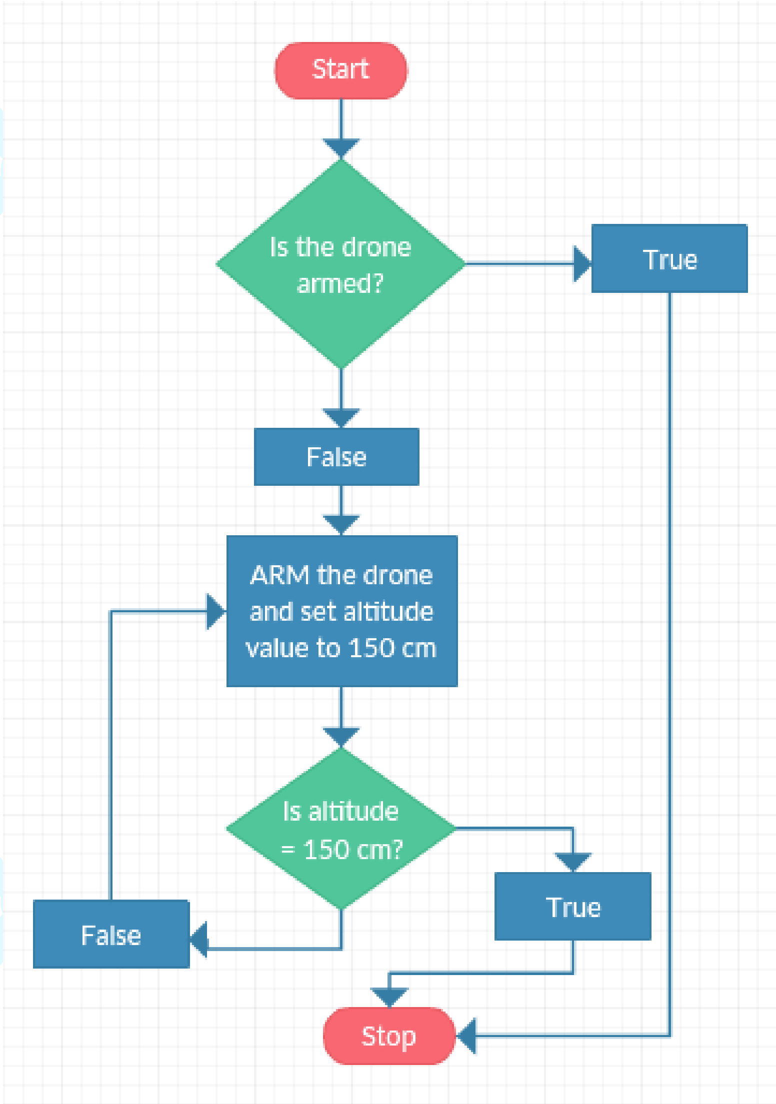
```
// The loop function is called in an endless loop
void plutoPilot()
{

//Add your repeated code here

        if(Accelerometer.getNetAcc()<2&&(!Control.checkFlightStatus(FS_Crash)))
                {


                Control.arm();

                }


}



//The function is called once after plutoFly when you deactivate UserCode
void onPilotFinish()
{

         // do your cleanup stuffs here

}
```

Img 8.3 Code for chuck to arm

Another feature that can be added into a drone by programming is: Auto take off

To take off, we need to arm the drone so that the motors and hence the propellers start spinning which would generate the required thrust. During manual take off, we control the amount of thrust to be given to the drone, and try to bring the drone to a suitable height above the ground before we start manoeuvring it. In many cases, people find this part difficult to control and hence aren't able to fly the drone. To simplify the flying experience, we can add AUTO TAKE OFF feature into a drone.

To add this feature, we need to think about the logic behind it that would enable us to program it. A drone is said to have taken off successfully if it reaches a satisfactory vertical height. Hence, the important aspects of this feature would be to arm the drone and let the drone reach a satisfactory altitude above the ground. The first part of the code can be to arm the drone. This can be done with the help of a button on the controller. After the drone is armed, it has to lift itself upwards till a suitable height. We know that the information about the altitude can be obtained by barometer sensor. Hence, we can program the drone to keep on flying upwards till a particular value is obtained from the barometer sensor, beyond which the drone will maintain its altitude by providing a constant amount of thrust.



Img 8.4 Flow chart

All it takes is to think about proper logic behind the feature you want to add into your drone. Once you have the logic, you can code it as per the syntax of the language and flash it onto your drone.

Summary

Coding is the mode of communication with a machine and in our case, the machine is a drone. In order to make a computer perform a specific task, we can write a set of instructions which can be understood by it. Every code requires logic. A coder has to think about the logic behind every task needed to be performed by the computer. If you learn the approach towards the thinking of logic behind tasks and coding in some specific language like C++, it opens an endless corridor towards building your own applications through drones. By coding you can make a drone do a variety of tasks. Tinkering will be limitless.

Exercise:

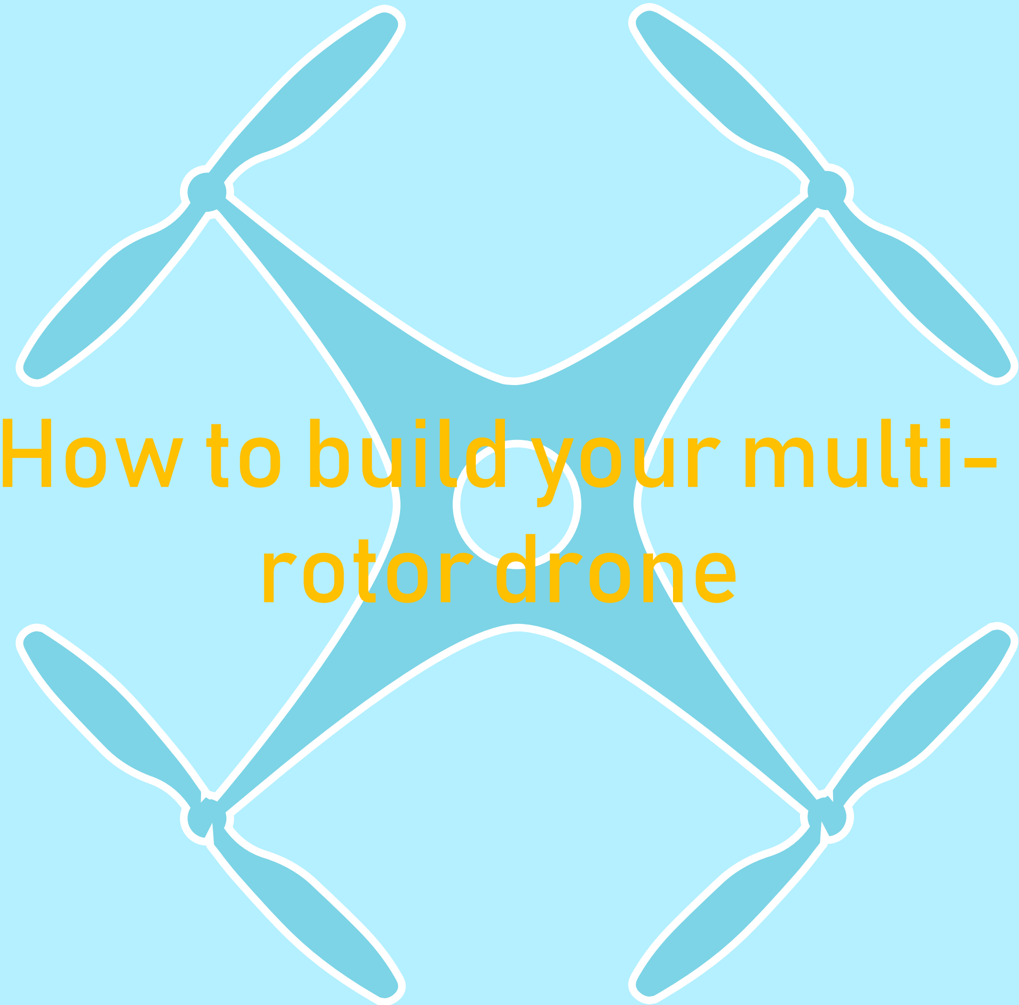
1. What are the different types of constructs in any programming language?

2. Activity: If you want to add a feature of flipping the drone when a button is pressed, what could be the logic for that code?

3. Activity: Think about different features that can be programmed into a drone and decide the logic behind the code.

Chapter 9

How to build your multi-rotor drone



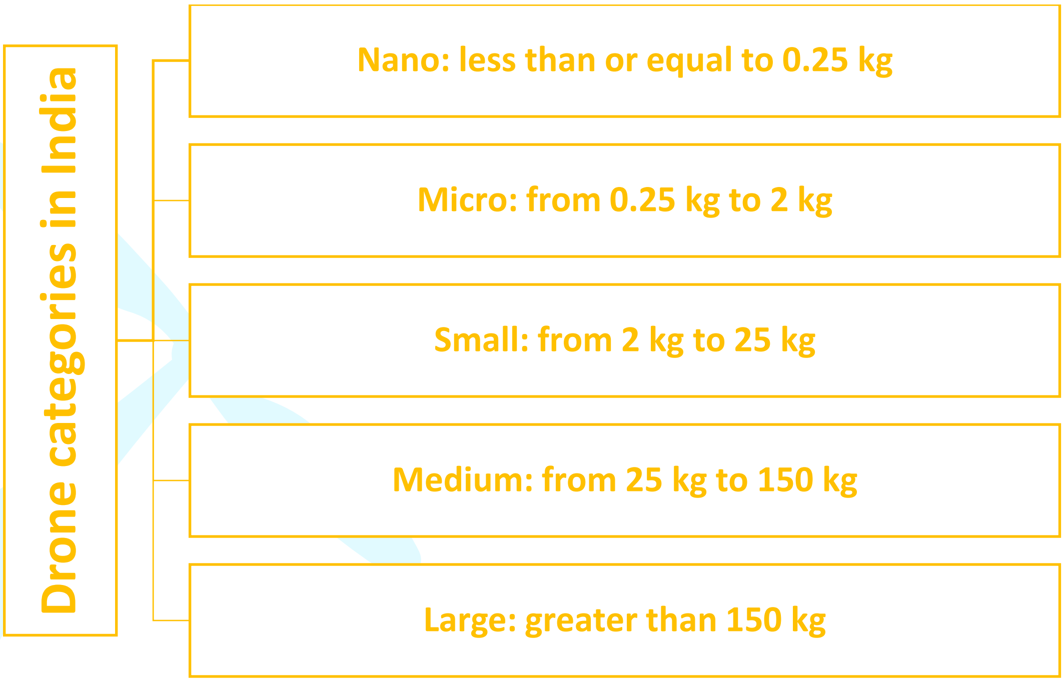
Objectives

The objectives of this chapter are to understand:

- Understanding rules of operating drones in India
- Components required to build a nano drone
- Steps to build a drone

9.1 Drone categories in India

Based on the weight, drones are divided into following categories:



Img 9.1: Drone Categories in India

9.2 Components required to build a nano drone

Following are the main list of components required to build your own Nano drone. Based on your purpose, size and design, you can identify your components and proceed.

9.2.1 Frame:

This is the structure which houses all the components, and supports all the components to remain in place during flight. The frame can build using Balsa Wood, Carbon fibre or can be even 3D Printed.

Common type of frame materials:

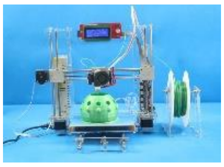
Picture	Material	Advantages	Disadvantages	Cost component
	Balsa Wood	Lightweight, easy to work	Low strength	Low
	PLA/ABS	Design can be 3d printed	Need 3D printer	Mid
	Aluminium	Strong and lightweight	Machining skills required	High
	Carbon fiber	Extremely tough and lightweight	signal interference	Highest

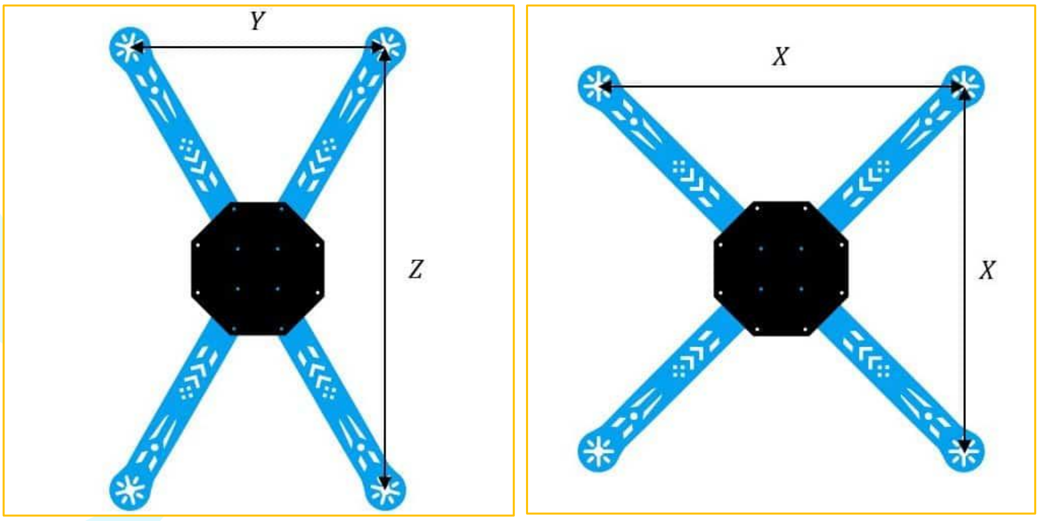
Table 7.1: Common type of frame materials

Sample STL files for drones

Link: https://tinyurl.com/FrameSTL

9.2.2 Propulsion system:

The first step in selecting a motor for your drone is knowing about the dimensions of your frame. The frame you are using will give you an idea about the size of the motor that can be fixed on it. Also, frame size will tell you about the size of the propeller that can be used. As a thumb rule, the radius of the propeller should be less than half of the smallest side of the drone. This is to avoid the overlapping of propellers with each other.



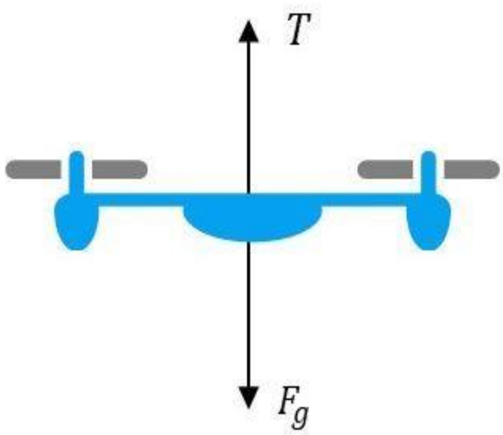
Img 9.2 showing size of frame to select the size of propellers

By knowing the size of propeller, you move one step ahead in selecting the motor for the drone.

The next step is knowing the weight of your drone. If your drone is not yet completed then add the weight of all the components which you will fit on the drone. Total weight of the drone will help you understand the amount of thrust required. Thrust is the force required to lift your drone up. Generally, it is 2 times the total weight of the drone. This is called as thrust to weight ratio.

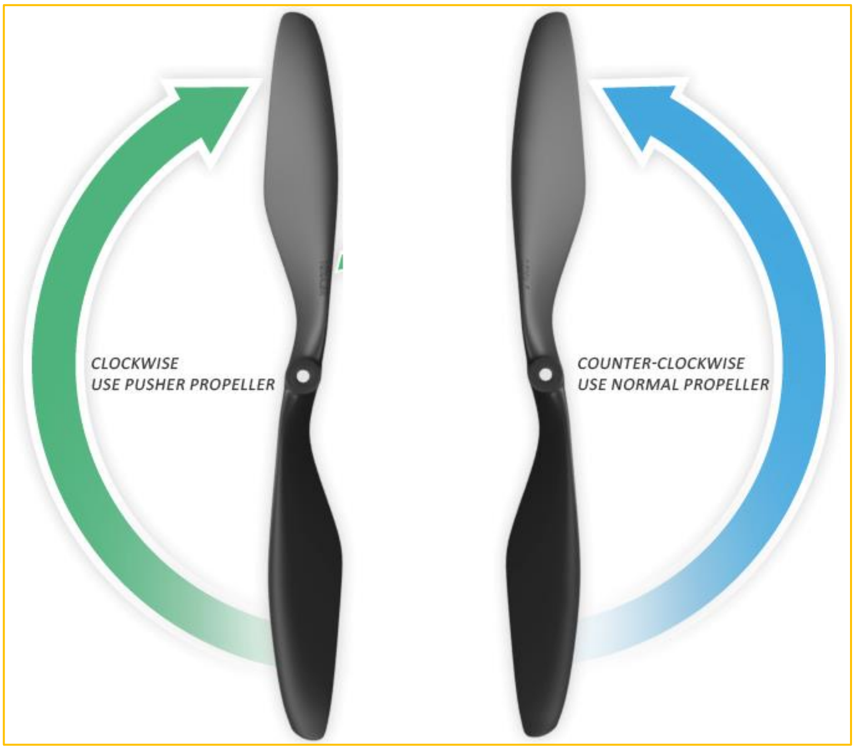
Divide the total thrust required among the number of motors you want for the drone. This will give you the thrust required from each motor. Most of the companies provide a thrust table which contain the specifications regarding the motors. Thrust table helps you choose the right motor for your requirement of thrust.

Among the available motors, you can select one based on the propeller size. Keep a note that the efficiency of the motor should be high, otherwise it will just result in the wastage of current and will lower your flight time as well.



$$T - F_g = ma_y$$

Img 9.3 showing thrust (T) and weight (Fg) acting on a drone.



Img 9.4: Top-view of Propellers

9.2.3 Propeller guards:

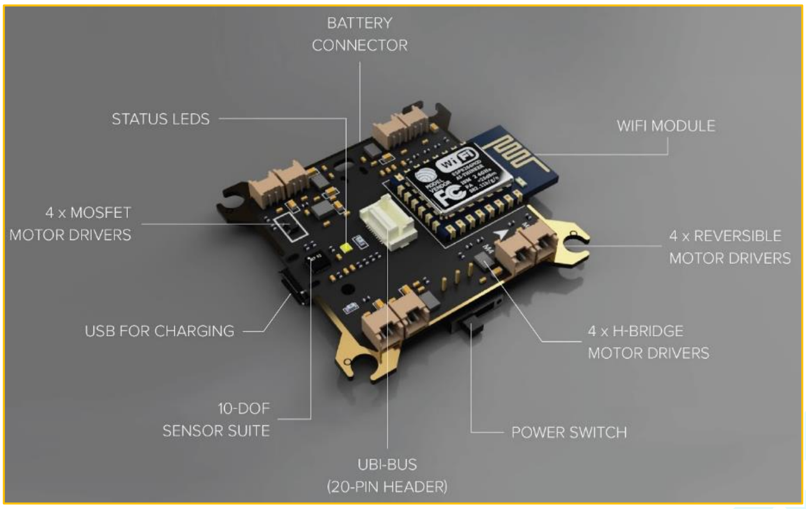
Since Nano Drones are operated at low heights it becomes very essential to attach propeller guards. They protect the propeller and motors from getting damaged. Also protects the humans from getting hurt in case of any mishap.

9.2.4 Drone controller:

To control the drone, you need an additional controller, it could be a RF controller or mobile app depending upon the type of flight controller used on the drone.

9.2.5 Flight controller:

This is the brain of the drone, the motors, sensors and battery is connected to the flight controller. Any of the open source flight controllers like Primus V3R by Drona Aviation, Crazyflie by Bitcraze could be used. These flight controllers come pre-programmed but their firmware could be tinkered using any open source SDK like Cygnus, BetaFlight or CleanFlight. The programming algorithm is explained in Module 8. Also depending on the controller you might need to add in additional sensors for a stable flight.



Img 9.5:Flight controller

9.2.6 Battery:

Selection of battery depends on various parameters such as:

a. Mass of the battery (grams)

Mass or weight of the battery should be as less as possible because its weight will increase the overall weight of the drone. If the weight increases too much, the thrust required for the motors will also increase which could ruin the combination of motor and propeller. If the battery is light in weight, the drone will be able to fly conveniently.

b. Capacity of the battery (mAh)

Capacity of a battery is measured in milliamp-hours. This parameter gives you an information about how long will your battery last. For this, you need to know the maximum current that could be drawn from your battery. For example, while designing a nano drone if your battery has a capacity of 600 mAh and if the maximum current drawn by the drone is 4 A, then the flight time can be calculated by: $0.6/4 \times 60 = 9$ mins

c. S value of a battery

A standard LiPo battery has a rating of 3.7V When more voltage is required, batteries are connected in series because series connection results in total voltage to be the sum of all the individual voltages. S value of a battery informs about the number of cells connected in series and thus it tells you about the voltage rating of the battery. 3S battery will have 11.1V and 4S battery will have 14.8V rating. Nano Drones generally use LiPo 1s/2s battery

d. C rating of a battery

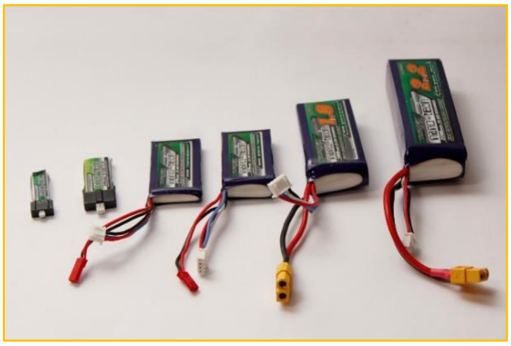
C rating of a battery is a measure of how quickly the current can be discharged from the battery. In other words, it gives you the maximum amount of current that can be drawn from the battery, without damaging it. So, for our example of 600 mAh battery, if the rating is 25C, then the maximum current that can be drawn can be obtained by multiplying the values:

$$0.6 \times 25 = 15A$$

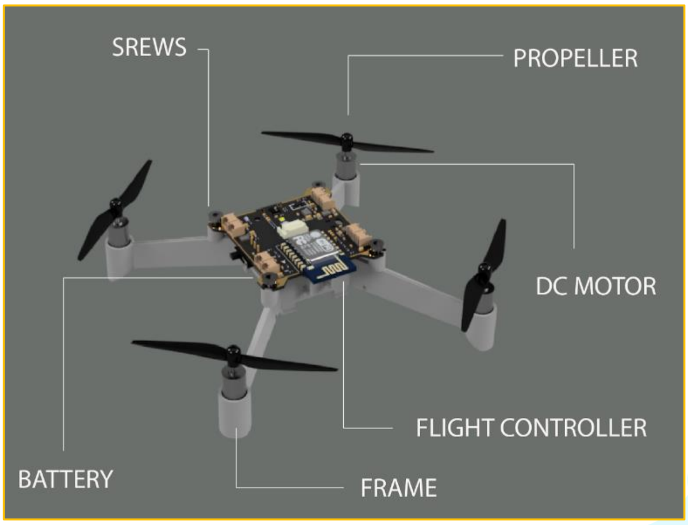
This rating is important because if the flight controller requires more current from the battery, it could damage the battery.

NOTE: LiPo batteries should be handled with proper care because when damaged, they can catch fire.

In conclusion, your battery should be light in weight, provide a good flight time and have a maximum discharge current above the normal requirement of the drone.



Img 9.6: Batteries



Img 9.7: Components of a drone

9.3 Examples of open-source nano drones:

Following are some of the examples of open source Nano drones you can build:

Arduino based Nano drone

Link:

https://www.instructables.com/id/Easy-Android-controllable-PC-Interfaceable-Relati/

Crazyflie by Bitcraze

Link : https://www.youtube.com/watch?v=TUskLT9ElDY

Pluto by Drona Aviation

Link: https://www.youtube.com/watch?v=Ya9RMPLPeM4

9.4 Steps to build your drone

STEP 1
Collect all the parts required to build your drone like frame, flight controller, motors, glue gun, propeller, propeller guard, screws, controller etc.

STEP 2
Create a plan of action and make sure every component is tested thoroughly. Start working on each component.

STEP 3
Assemble the frame.

STEP 4
Attach the Motors on the frame.

STEP 5
Programme the flight controller.

STEP 6
Attach the flight controller on the frame.

STEP 7
Attach the propellers and propeller guard on the motors.

STEP 8
Attach the motors to the flight controller.

STEP 9
Calibrate and Trim the drone.

STEP 10
Flight Test.

9.5 Build your own drone

Here is a simple activity to identify the requirements of your drone. Answer the following questions from your learnings and some online research.

Sr. No.	Technical requirement	Specs identified
1	Target Size of the Drone	
2	Number of rotors/Frame setup	
3	Frame material	
4	Landing gear	
5	Propellor	
6	Propellor Guards	
7	Shell - Yes/NO	
8	Material of shell	
9	Flight Controller	
10	Coding language	
11	Sensors	
12	Motor specs	
13	Battery	

References

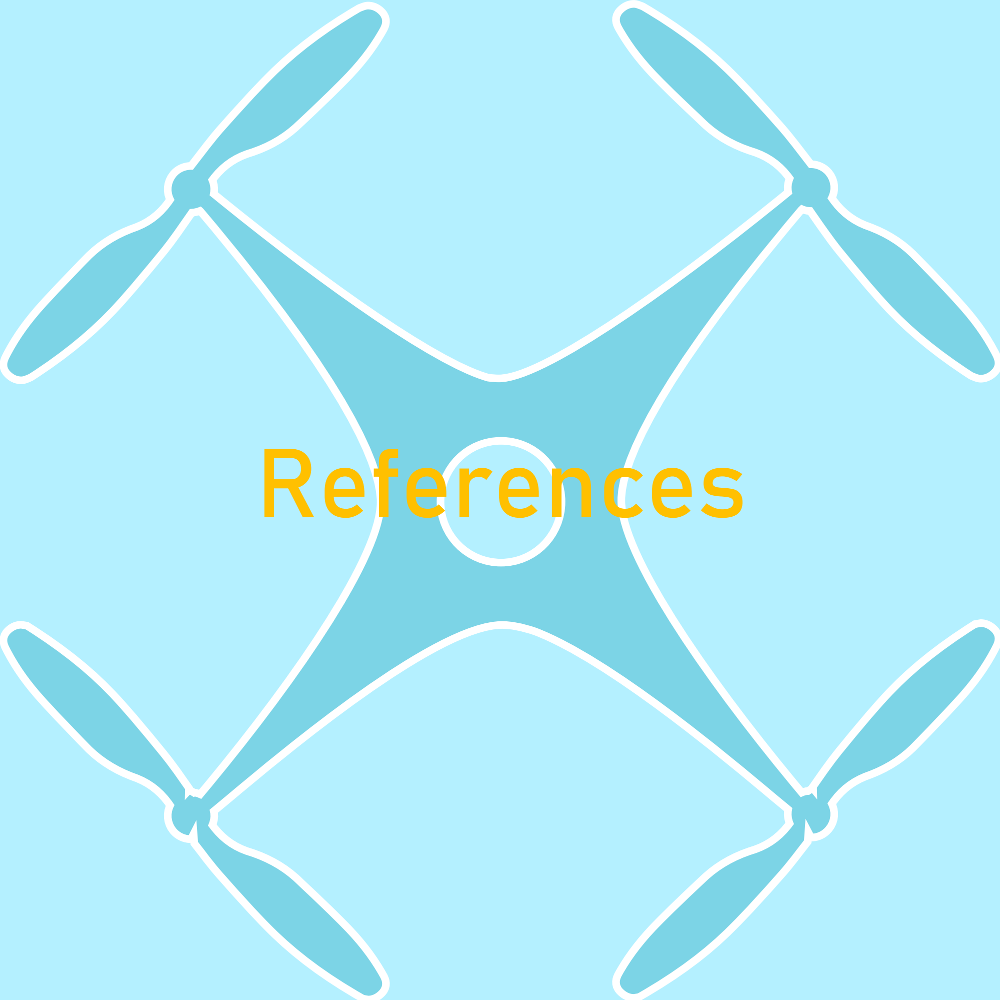


Image references

Img 2.1: https://www.asteria.co.in/

Img 2.3: https://www.aircharterserviceusa.com/about-us/news-features/blog/the-history-of-airships-and-airship-travel-in-commercial-aviation

Img 2.4: https://www.kisspng.com/

Img 2.5: https://www.dronaaviation.com/

Img 2.6: www.dji.com

Img 3.3, 3.4, 3.5: https://howthingsfly.si.edu/flight-dynamics/roll-pitch-and-yaw

Img 4.1 https://web.ma.utexas.edu/users/davis/375/popecol/lec9/equilib.html
Img 4.2: https://www.dronaaviation.com/

Img 4.3: http://dronenodes.com/how-to-fly-a-quadcopter-beginner-guide/

Img 4.4: https://uavcoach.com/how-to-fly-a-quadcopter-guide/

Img 4.8:
http://socialledge.com/sjsu/images/2/26/CmpE244_S14_Quadcopter_Quad_motion1.JPG

Img 5.4:
https://www.elprocus.com/lidar-light-detection-and-ranging-working-application/

Img 5.5: https://en.wikipedia.org/wiki/Sonar#/media/File:Sonar_Principle_EN.svg

Img 5.6 https://www.dronezon.com/learn-about-drones-quadcopters/best-uses-for-time-of-flight-tof-camera-depth-sensor-technology-in-drones-or-ground-based/

Img 5.7: https://www.aerosociety.com/news/life-saving-drones/

Img 5.8: https://www.mercurynews.com/2017/02/23/menlo-park-fire-district-drone-maker-partner-for-emergency-deliveries/

Img 6.1:

https://www.faasafety.gov/gslac/alc/course_content_popup.aspx?cID=104&sID=448

Img 6.2: https://www.getfpv.com/learn/new-to-fpv/all-about-multirotor-fpv-drone-propellers/

Img 7.1: https://hobbyking.com/en_us/turnigy-battery-5000mah-3s-40c-lipo-pack-xt-90.html?___store=en_us

Img 9.1: *https://www.arrow.com/en/research-and-events/articles/powering-a-battlebot*

Img 9.2: https://www.droneomega.com/drone-motor-essentials/

Img 9.3: https://www.droneomega.com/drone-motor-essentials/

Img 9.4: http://quadcopterforum.com/threads/newbie-to-drones.8707/

Img 9.5: https://www.dronaaviation.com/

Img 9.6: http://www.turnigy.com/batteries/nano-tech/

Img 9.7: https://www.dronaaviation.com/

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Answers:

Chapter 2

1. Full Forms:
    a. Unmanned Aerial Vehicle
    b. Directorate General of Civil Aviation
    c. Unmanned Aircraft System
    d. Remotely Piloted Air System
    e. No Permission No Take off
    f. Unique Identification Number
    g. Visual Line Of Sight
    h. Vertical Take Off/ Landing
    i. Short Take Off/ Landing
2. Fixed wing structure
3. a - v; b - iv; c - i; d - ii; e - iii
4. Activity

Chapter 3

1. Fill in the blanks:
    a. 4
    b. Drag
    c. Lift
2. a - iii; b - i; c - ii

Chapter 4

1. Stable systems:
   Kite, Birds, Parachutes, Passenger airplanes
   Unstable systems:
   Missiles
   Neutrally stable systems:
   Balloons, ball on flat surface, fighter jets, housefly, Drones
2. Unstable system
3. H - higher speed, L - lower speed
    a. Back motors - H, Front motors - H
    b. Anticlockwise motors - H, Clockwise motors - L
    c. Left motors - H, Right motors - L
    d. Front motors - H, Back motors - L
    e. All motors - L
    f. Right motors - H, Left motors - L
    g. Clockwise motors - H, Anticlockwise motors - L
    h. All motors - H
4. Unstable system.

The first thought about this question is always that humans are a stable system because if someone were to push you to a new position while you were standing, you would easily walk back to your original position. However, the essence of being stable or unstable or neutrally stable is in the natural tendency of the system to return to its original position or to deviate further or to stay at the new position. In case of human beings, consider a scenario where you are standing on your feet, your legs and hands are tied, and then someone pushes you. The only thing that will happen is that you will fall down, just like when you try to balance a pen or pencil on its tip. This proves that humans are in fact, unstable system. We are stabilised by the gyro sensors present in the form of inner ear fluids.

Chapter 5

1. Accelerometer, Gyro sensor, Magnetometer, Barometer.
2. Barometer
3. LiDAR
4. Apart from basic sensors required, we can use Distance sensors, Chemical sensors, Thermal sensors and others.
5. Activity

Chapter 6

1. Thrust
2. Motor and propeller
3. Aerofoil
4. Like propellers are positioned diagonally opposite.
5. Total weight of all components = 520 gm
   Thrust to weight ratio = 2
   Thrust required for four motors = 520 * 2 = 1040 gm
   Thrust required by one motor = 1040/4 = 260 gm

Chapter 7

1. Lithium Polymer
2. High
3. Series: by connecting the positive of first battery to negative of second. This connection will increase the voltage and current will remain the same.
   Parallel: by connecting the positive with positive and negative with negative. This connection will increase the current and voltage will remain the same.

Chapter 8

1. Sequential statement, Conditional statement, Repetitive statement.

सत्यमेव जयते
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