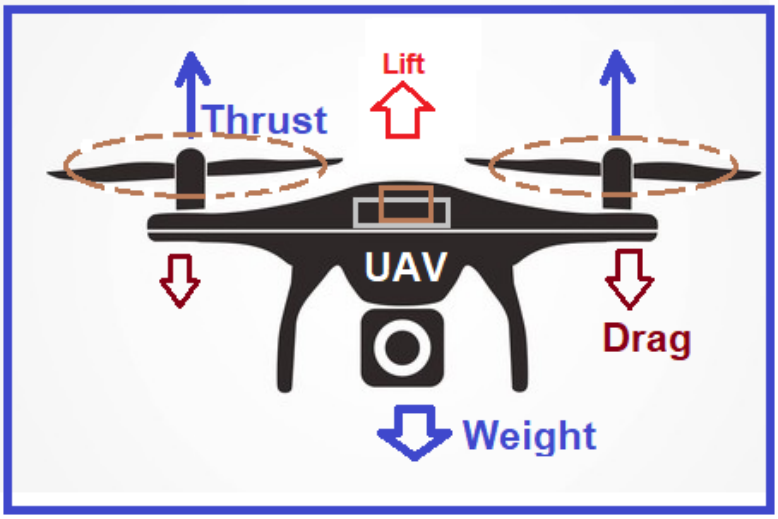
Working Principle and Components of Drone



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How do drones fly in air? Which drone is more popular?

by

Dr. Sharad Pachpute

Introduction to Drone or UAV

- Any aircraft or flying machine operated without a human pilot such machines is called an **unmanned aerial vehicle** (UAV). It can be guided autonomously or remotely by a human operator using onboard computers and robots.
- During surveillance or military operation, UAVs can be a part of an unmanned aircraft system (UAS), Drones are separately for air and water
- Drones have become increasingly popular in recent years. They are used for a variety of purposes, including photography, videography, surveying, inspection, and even delivery. But have you ever wondered how drones work? In this blog post, we'll take a look at the working principle of drones
- The basic components of a drone are the frame, motors, propellers, battery, flight controller, and sensors. Let's take a closer look at each of these components.
  - Frame
  - Battery
  - Flight controllers
  - Sensors
  - Motors and Propellers:

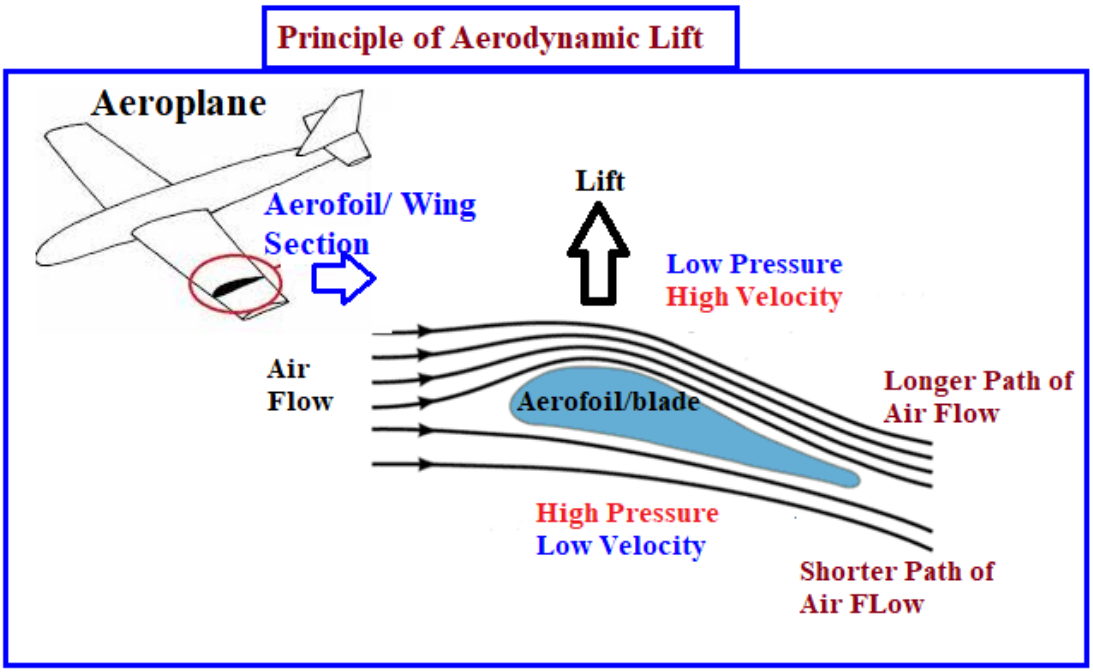
Subjects for Drone or UAV

Understanding and development of drones depend on many subjects. The design of drone for a particular application comprises many factors like the aerodynamic shape of propellors, strength and weight of drone parts, electric motor, electric speed controller, radio transmitter or receiver, and software interface on mobile or computer for monitoring and data analysis.

- **Fluid Dynamics or Aerodynamics:**
  - Fluid dynamics plays an important role to decide the forces acting on the body of a drone
  - The shape, size, and speed of the propeller and drone depending on the aerodynamics of propellers or blades
  - Computational Fluid Dynamics (CFD) modeling helps for flow dynamics of airflow over drones
  - CFD modeling of turbo-machinery) is essential to decide the amount of thrust generated by propellors
  - Wind tunnel testing of the aerofoil blade of the drone is still important for testing CFD results
- **Mechanical Design**
  - Rigid body dynamics to study the motion and forces acting on drones
  - Strength of materials
  - Low weight and rigid materials are selected for drone
- **Electronics and Electrical Components:**
  - Electric motor with and without brush is required to drive the propellors
  - Electronic Speed Controller
  - Flight controller unit and computer processors
- **Radio Communication:** transmitter and receiver for radio signals
- **Battery:** Low weight and high-power wattage battery is important
- **Software-based interface:** data collection and analysis using mobile or computer

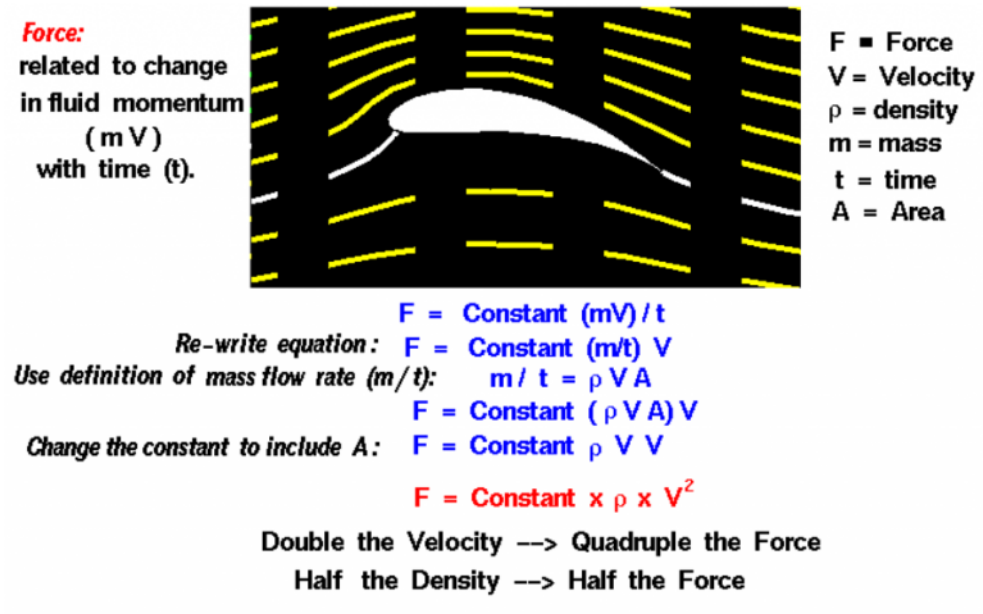
Working Principle of Drone and Flow Pattern

- The subject of Fluid dynamics plays a significant role in the design and development of aircraft and drones. This subject consists of the working principle of the aerodynamics of aircraft.
- A sufficient amount of upward force is required to lift the vehicle against gravity which is named Lift.
- A force created to move the vehicle or body in motion is called thrust. These forces can be studied using the kinematic laws of fluid flows

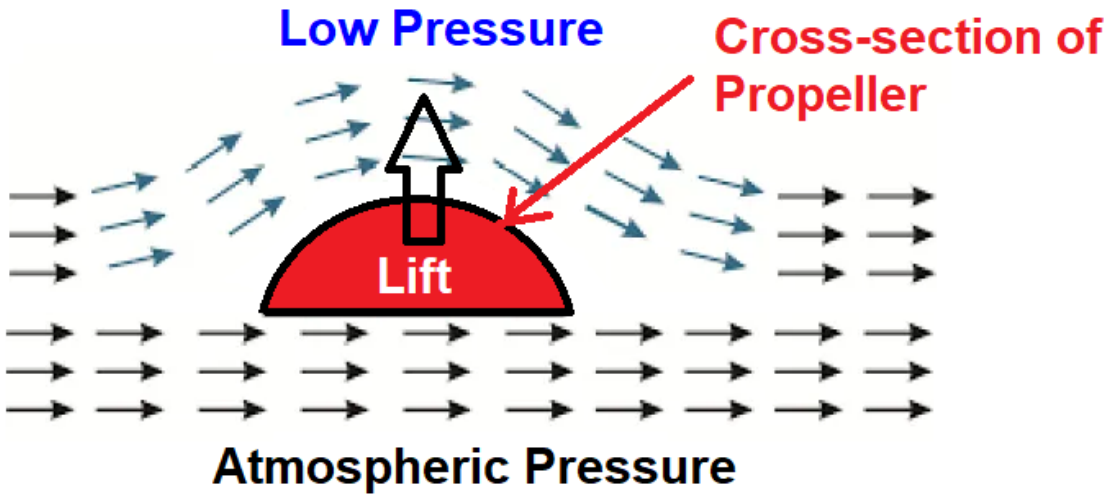


- When air flows over an aerofoil and pressure, viscous and drag force act on the profiles

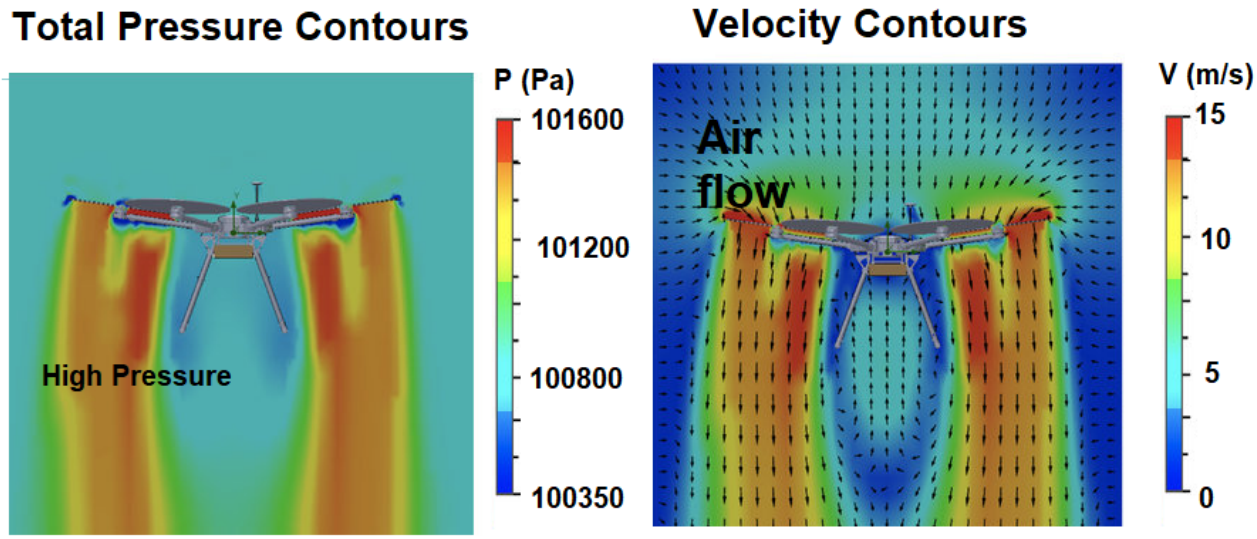
- Force is directly proportional to the velocity of air at the inlet



- The flow pattern around the cross-section of the aerofoil or propeller is shown below. High fluid pressure at the bottom and low pressure at the top of the propeller causes an upward force which is called a lift. This force is responsible for lifting the weight of an aero-plane or drone.
- The amount of lift force depends on the angle of inclination of the aerofoil or propeller.



- Based on the **principle** of conservation of energy in fluid flow (**Bernoulli's principle**, the sum of all forms of energy in a fluid is constant along the **streamline**
- When air flows over an aerofoil or wing, its velocity increases at the top portion. But the pressure of air decreases.
- In contrast, the air velocity decreases and pressure increase at the bottom side of the blade. The next pressure difference across the aerofoil results in an upward force which is called a lift
- CFD modeling of flow over an aerofoil has been important in many vehicular and aerospace industries



Types of drones based on the number of Propellors

A number of propellors are provided to drones. More propellors improve the stability of drones and load-carrying capacity but such drones need more battery power to drive more motors to get high power. A quadcopter is a more popular drone.

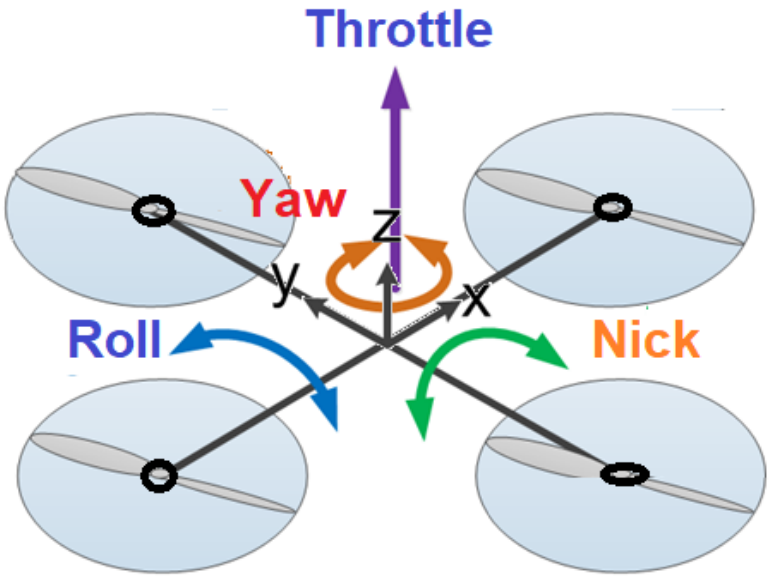
- **Bicopter (2 propellers)**
- **Triplecopter (3 propellors)**
- **Quadcopter (4 propellers)**
- **Hexacopter (6 propellers)**
- **Octacopter (8 propellers)**

Working Principle of Quadcopter

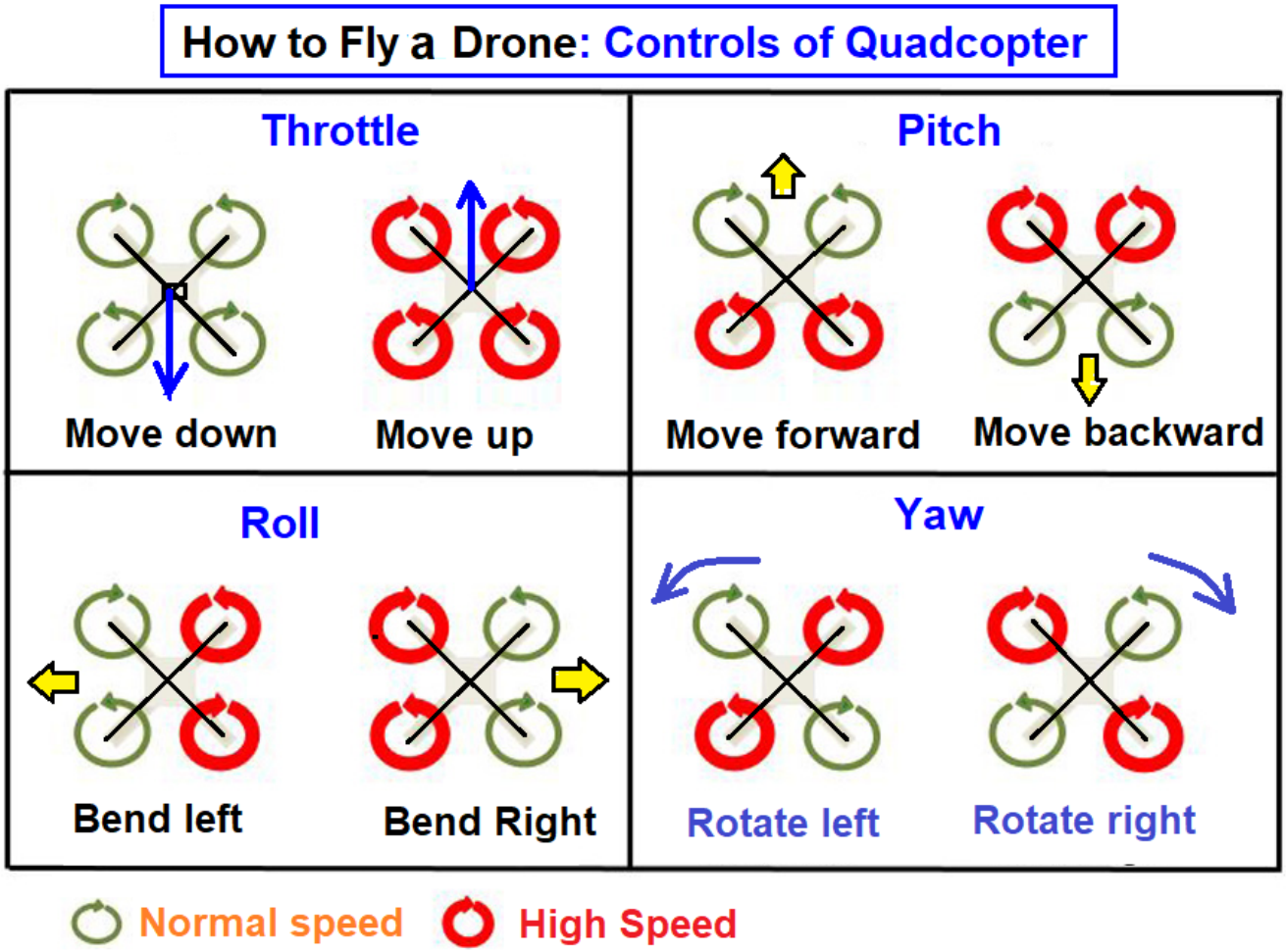
- A quadcopter has four propellors at four corners of the frame
- For each propeller, speed and direction of rotation are independently controlled for balance and movement of the drone
- In a traditional quadrotor, all four rotors are placed at an equal distance from each other
- To maintain the balance of the system, one pair of rotors rotates in a clockwise direction and the other pair rotates in an anti-clockwise direction
- To move up (hover), all rotors should run at high speed. By changing the speed of rotors, the drone can be moved forward, backward, and side-to-side

Quadcopter Dynamics

- The movement of drone are classified into four types based on the relation motion between four propellors: 1) throttle, 2) Pitch, 3) Roll, and 4) Yaw
- The details of quadcopter dynamics are explained in many references



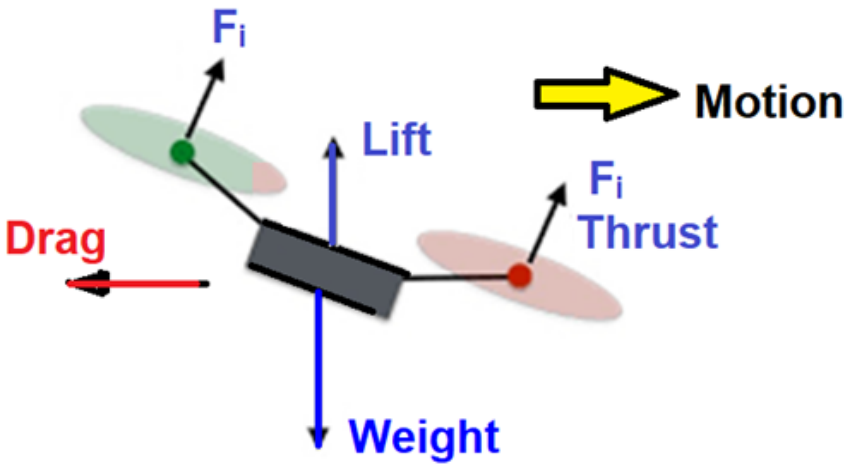
- **Throttle/ Hover:** up and down movement of the drone is called throttle
  - If all four propellors run at normal speed, then the drone will move down
  - If all four propellors run at a higher speed, then the drone will move up. This is called the hovering of a drone
- **Pitch:** movement of a drone about a lateral axis (either forward or backward) is called pitching motion
  - If two rear propellors run at high speed, then the drone will move in a forwarding direction
  - If two front propellors run at high speed, then the drone will move in the backward direction
- **Roll**: movement of a drone about the longitudinal axis is called rolling motion
  - If two right propellors run at high speed, then the drone will move in the left direction
  - If two left propellors run at high speed, then the drone will move in the right direction
- **Yawn:** the rotation of the head of the drone about the vertical axis (either the left or right) is called Yawning motion
  - If two propellors of a right diagonal run at high speed, then the drone will rotate in an anti-clockwise direction
  - If two propellors of a left diagonal run at high speed, then the drone will rotate in a clockwise direction



Forces and Moments Acting on a Drone

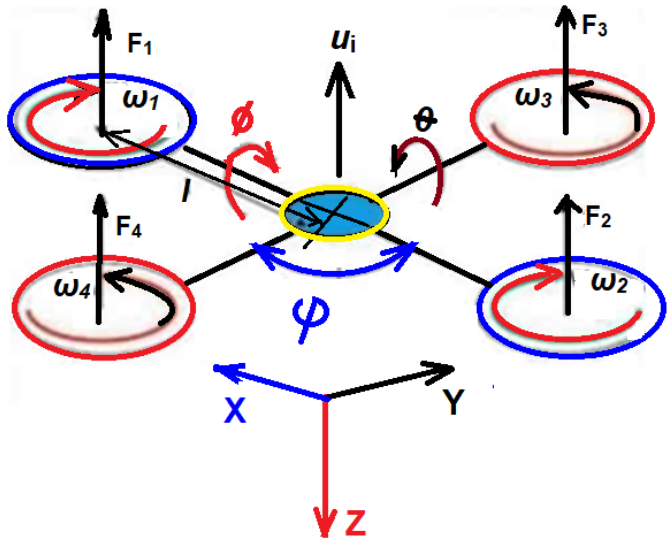
Major forces acting on a Drone

When a drone moves in the air, various forces act on it. The resultant force will decide its movement. There are major forces acting on a drone



- **Weight**
  - Due to the mass of the drone, the body mass force always acts in the direction of gravity
  - Higher the weight of the drone, more power is required to lift and move the drone
  - Weight of drone = mass of drone × acceleration due to gravity
- **Lift**:
  - The vertical force acting on the drone is called lift
  - This force is due to pressure differences across the drone (in the vertical direction). Hence, the speed, size, and shape of the propeller blade decide the amount of lift force
  - Lift is essential to lift the body against the gravity
  - To create this force, all four propellors run at high speed to lift the drone
- **Thrust**
  - The force acting on the drone in the direction of motion is called thrust. However, for drone dynamics, it is normal to the rotor plane.
  - During hovering, the thrust is purely vertical. If thrust is inclined then the drone will tilt forward or backward.
  - This force is essential to move the drone in the desired direction at equal speed
  - To get desired motion, two propellors have been given high speed
- **Drag**
  - The force acting on the drone in the opposite direction of motion due to air resistance is called drag
  - This may be because of pressure difference and viscosity of air
  - To reduce the drag, the aerodynamic shape of the drone is selected

Kinematic for Quad-copter



- The thrust produced by each propeller is perpendicular to the plane of rotation of propellors. It is directly proportional to the square of the angular velocity of the propeller

$$F_i = k_f \times \omega_i^2$$

- If L is defined as the distance between two motors or propellors for any diagonal of the drone, then the reaction moments about the X-axis and Y-axis

$$Mx = (F_3 - F_4) \times L$$

$$My = (F_1 - F_2) \times L$$

- **Newton's second law of motion**
  - For linear motion: Force = mass × linear acceleration
  - For rotational motion: Torque = inertia × angular acceleration

Hovering Motion

- **Equilibrium Conditions for hovering**

$$mg = F_1 + F_2 + F_3 + F_4$$

All moments = 0

- **Equation of motion**

$$m = F_1 + F_2 + F_3 + F_4 - mg$$

$$m = 0$$

Rise or Fall Motion (Throttle up)

- **Conditions for hovering (rise)**

$$mg < F_1 + F_2 + F_3 + F_4$$

All moments = 0

- **Conditions for Fall**

$$mg > F_1 + F_2 + F_3 + F_4$$

All moments = 0

- **Equation of motion**

$$m = F_1 + F_2 + F_3 + F_4 - mg$$

$$m > 0$$

Yaw Motion

- **Conditions for hovering**

$$mg = F_1 + F_2 + F_3 + F_4$$

All moments ≠ 0

- **Equation of motion**

$$mass * linear\ acceleration = F_1 + F_2 + F_3 + F_4 - mg$$

$$I_{zz} * angular\ acceleration @\ Z\text{-}axis = M_1 + M_2 + M_3 + M_4$$

Pitch and Roll Motion

- **Conditions for hovering**

$$mg < F_1 + F_2 + F_3 + F_4$$

All moments ≠ 0

- **Equation of motion**

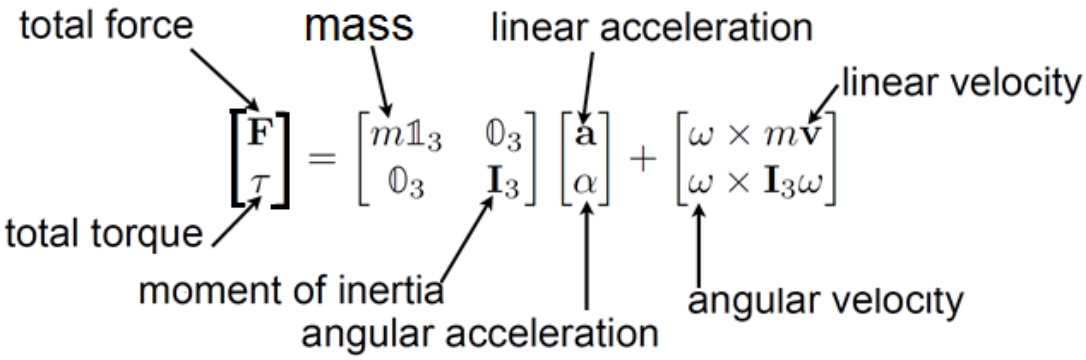
$$mass * linear\ acceleration = F_1 + F_2 + F_3 + F_4 - mg$$

$$I_{xx} * angular\ acceleration\ @\ x\text{-}axis = (F_3 - F_4) \times L$$

Rigid-body dynamics

- To calculate individual speeds and forces acting on drones, the three-dimensional rigid-body dynamics should be modeled

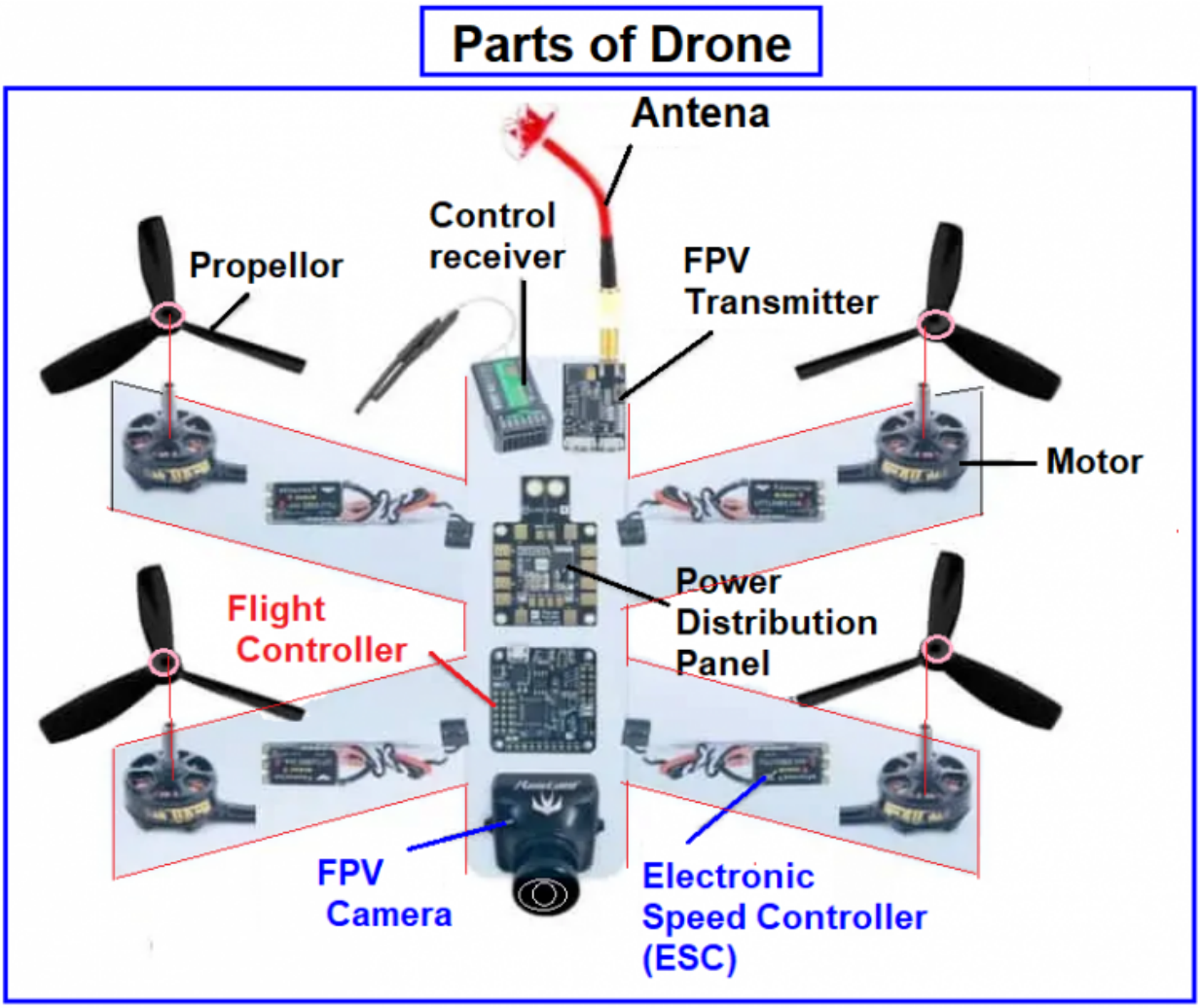
- The first step is to identify the reference coordinates, the direction of rotor speed and forces acting the drones
- For the rigid body, we have to consider the effect of aerodynamic, inertial, gravitational, and gyroscope
- **Aerodynamic Forces:** rotation of the propellors in air causes various forces such as friction and drag
- **Secondary aerodynamic effects**: blade flapping, ground effect, and local flow fields
- **Inertial counter torques**: gravitational forces acting at the center of drone affect the rotation of propellors
- **Gyroscopic effects**: change in the orientation of drone body and plane rotation of propellors.



- Based on Newton-Euler equations, all forces and moments acting on a quadcopter are combined and result in a complete model of the drone dynamics
- This physical model is useful to control the desired motion of the quadcopter

Major Components of Drones

The following are major parts of drones.



1. **Frame:**

- It should have sufficient strength to hold the propeller momentum and additional weight for motors and cameras
- Sturdy and less aerodynamic resistance

1. **Propellers:**
   - The speed and load lifting ability of a drone depends on shape, size, and number of propellors
   - The long propellors create huge thrust to carry heavy loads at a low speed (RPM) and less sensitive to change the speed of rotation
   - Short propellors carry fewer loads. They change rotation speeds quickly and require a high speed for more thrust.
2. **Motor**
   - Both motors brushless and brushed type can be used for drones
   - A brushed motor is less expensive and useful for small-sized drones
   - Brushless type motors are powerful and energy very efficient. But they need Electronic Speed Controller (ESC) to control their speed. These brushless motors are widely used for racing freestyle drones, traffic surveys and aerial photography drones.
3. **ESC (Electronic Speed Controller)**
   - ESC is used to connect the battery to the electric motor for the power supply
   - It converts the signal from the flight controller to the revolution per minted (RPM) of mc
   - ESC is provided to each y motor of the drone

4. **Flight Controller (FC)**
    - It is the computer processor which manages balance and telecommunication controls using different transmitter
    - Sensors are located in this unit for the accelerometer, barometer, magnetometer, gyrometer and GPS
    - The distance measurement can be carried out by an ultrasound sensor
5. **Radio Transmitter** sends the radio signal to ESC to pilot to control motor speed.
6. **Radio Receiver:** Received the signal from the pilot. This device is attached to the quadcopter
7. **Battery:** High-power capacity, Lithium Polymer (LiPo) is used for most drones. The battery can have 3S (3 cells) or 4S (4 cells).

- When the pilot or autonomous system gives the drone a command, the flight controller sends signals to the motors to spin the propellers
- The speed and direction of the motors and propellors are adjusted to achieve the desired movement. The sensors provide data to the flight controller, which uses it to stabilize the drone in the air and adjust its movement
- Drones can be controlled manually using a remote controller or programmed to fly autonomously. Autonomous drones use sensors and pre-programmed instructions to fly to a specific location, perform a task like taking photos or delivering a package, and return to their starting point.

How to operate a Drone

- Operating a drone can be a fun and rewarding experience, but it's important to know how to do so safely and legally
- Here are some general steps to operate a drone:

1. **Read the manual:** The first step is to read the drone manual carefully, as each drone model is unique and has its own set of instructions.
2. **Register your drone**: Depending on your location, you may need to register your drone with the appropriate authorities.
3. **Charge your drone battery**: Make sure your drone battery is fully charged before flying it.
4. **Find a suitable location**: Choose a location that is open, clear, and away from any obstacles like trees, buildings, or power lines.
5. **Check the weather**: Avoid flying your drone in windy or rainy conditions. Check the weather forecast before flying.
6. **Turn on the drone**: Turn on the drone and the remote control.
7. **Calibrate the drone**: Follow the instructions in the manual to calibrate the drone before flying.
8. **Take off**: Push the throttle stick slowly and smoothly to take off the drone.
9. **Fly the drone**: Use the remote control to maneuver the drone in the air. Keep it at a safe distance from people and property.
10. **Land the drone**: When you are ready to land the drone, slowly bring it down to the ground using the throttle stick.
11. **Turn off the drone**: After landing the drone, turn off the drone and the remote control.

Precautions During the Drone Use

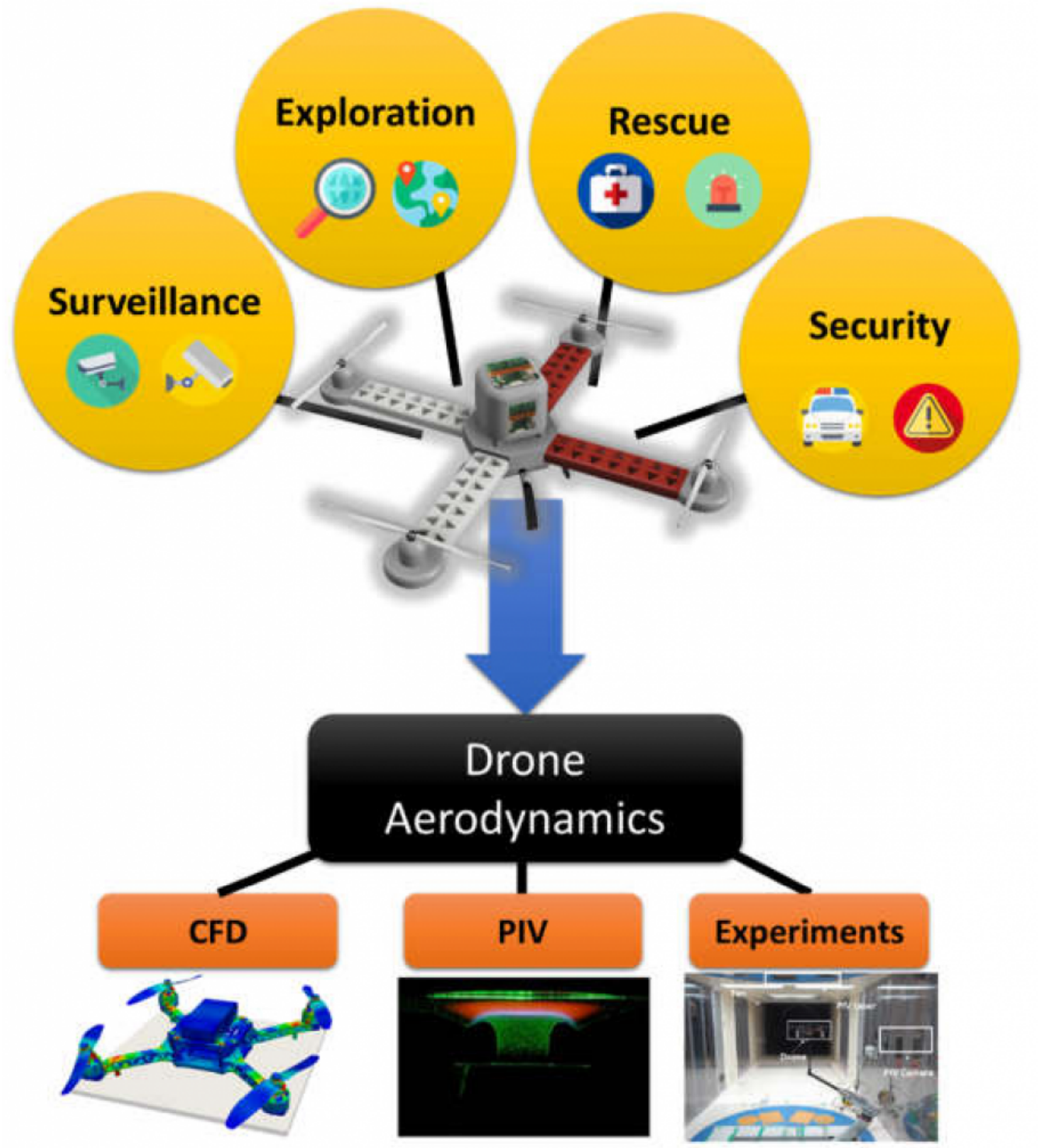
- Drones can be a fun and useful tool, but they can also be dangerous if not used properly. Here are some precautions to keep in mind when using a drone:

1. **Know the laws and regulation**s:
   - Before flying a drone, make sure you know the laws and regulations in your area
   - This includes any local, state, and federal regulations, as well as any restrictions on where you can fly your drone.
2. **Always keep your drone in sigh**t:
   - It's important to keep your drone within your line of sight at all times
   - This will help you avoid collisions with other objects or people.
3. **Fly in open areas**
   - Try to fly your drone in open areas away from people, buildings, and other obstacles
   - This will help you avoid accidents and crashes.
4. **Respect people's privacy**:
   - Don't fly your drone over private property without permission
   - Also, avoid flying your drone close to people's homes or in areas where people have a reasonable expectation of privacy.
5. **Avoid flying in bad weather**:
   - Drones are not designed to handle extreme weather conditions like strong winds, heavy rain, or snow
   - Avoid flying your drone in these conditions, as they can cause your drone to crash or become damaged.
6. **Keep your drone in good condition**:
   - Regularly check your drone for any signs of damage or wear and tear
   - Replace any damaged parts before flying.
7. **Practice safe battery us**e:
   - Always use the manufacturer's recommended batteries and charger
   - Avoid charging your batteries unattended and never use damaged or swollen batteries.
8. **Be prepared for emergencies**: Keep a first aid kit and a fire extinguisher nearby in case of emergencies. Also, be prepared to land your drone quickly if necessary.

- By following these precautions, you can help ensure a safe and enjoyable drone experience for yourself and others.

Application and Development of Drones

- Drones or UAE has a lot of application in space, defense, and military purposes, delivery of food items, and spraying of pesticides in farming
- Refer to the post for the application of drones in industries on this website
- **Application of drone and scope of CFD modeling**



Scope of CFD Modeling for Drone Aerodynamics

- Computational fluid dynamics (CFD) predicts the pressure gradient required for lifting a drone

- The following parameters decide the aerodynamic design of the drone
  - Payload of drone
  - Number and speed of propellors
  - Aerodynamics of propellors
  - Spacing between the propellors
  - Lift coefficient of drone
  - The thrust generated by the drone
- CFD modeling will help to optimize the aerodynamics and applications of drone

Summary

- The working principle of drones is similar to the flying of aero-planes
- The vertical lift force is created due to pressure difference across the rotating blades
- The drag and gravity forces act against its vertical motions
- By controlling the speed and directions of different rotors we can control the motion of the drone or UAV
- The drone consists of mechanical, electrical, and electronic components
- Drones have many applications in defense and military purposes, space, surveillance, agriculture, and many more.
- CFD modeling predicts the pressure gradient which is helpful for the aerodynamic design of the drone
- We have to understand the coordination of several components, including the frame, motors, propellors, battery, flight controller, and sensors
- The flight controller receives input from the pilot or autonomous system and sends signals to the motors to control the drone's movement
- Sensors provide data to the flight controller, which uses it to stabilize the drone in the air and adjust its movement
- With their versatility and range of applications, drones are likely to become even more widespread in the years to come.

10 thoughts on "Working Principle and Components of Drone"

tutorial

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info for me. And i'm glad reading your article. But wanna remark on some general things, The website style is ideal, the articles is really great :
D. Good job, cheers

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Good information.
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thanks for your explanatory content!!

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Thank you…

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Steven

Very nice content. Check grammatically or typo errors

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really Fantastic, precisely with advance idea, but i would like that you should put more detailed. love from Abdul

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A simple and well summed up article on principles and working of Drones. Keep it up

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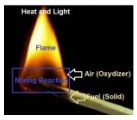
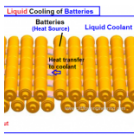


Working Principle of Biomass Combustion and Its CFD Modelling



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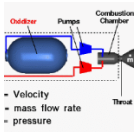

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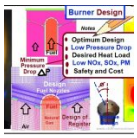

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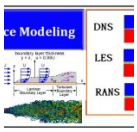
Industrial Burners : Parts, Applications, Types of burners



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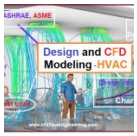

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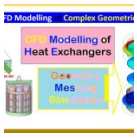

CFD Modeling of Heat Exchangers

Battery Thermal Flow and CFD Modeling

CFD Basic and Fluid Flow

Combustion and Emissions

Flow and CFD of Drone

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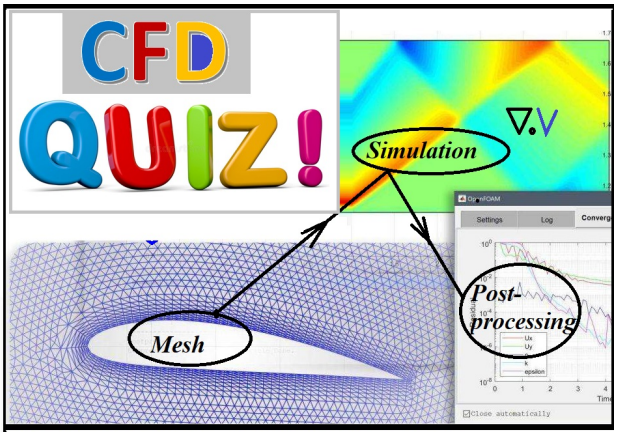

BASIC OF CFD AND FLUID MECHANICS -QUIZ

Basic of CFD and Fluid Mechanics will be examined

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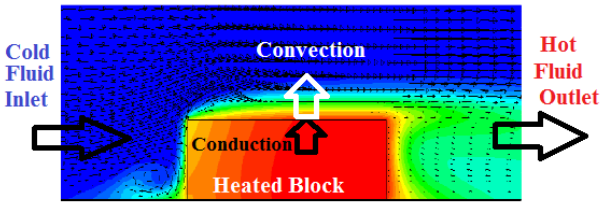

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