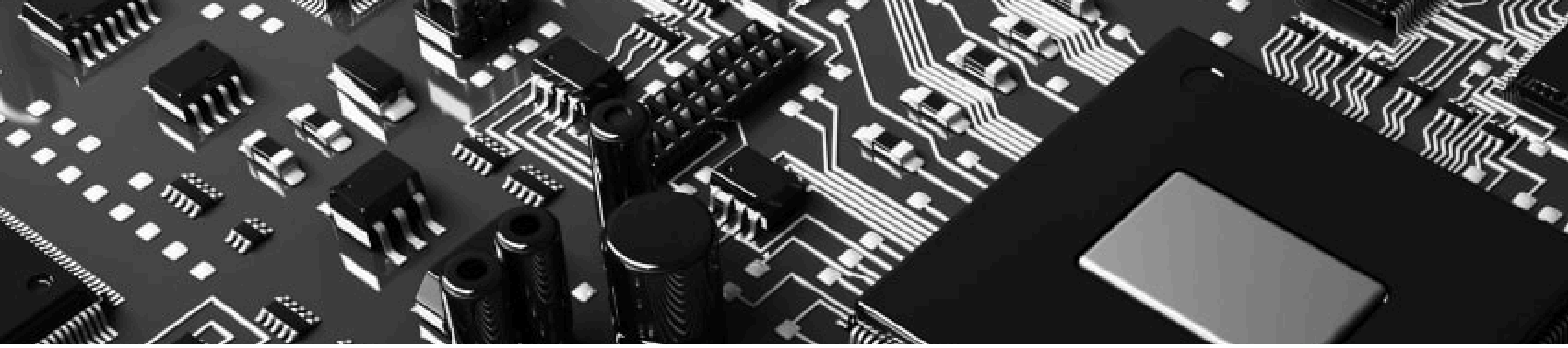


8 Aug 2025

Aviation Task Report

Krithik Kumar

TABLE OF CONTENTS

1. Introduction to Aerodynamics and Aircraft Structures

Objective

- Study Bernoulli's Principle, Newton's Third Law in aviation, and aerodynamic forces
- Understand lift, drag, thrust, weight, and stability
- Learn about primary and secondary control surfaces
- Do a study about the basic components like pitot tube & radio altimeter.
- Do a thorough study about the concepts of aviation present in the given resource articles

Learning

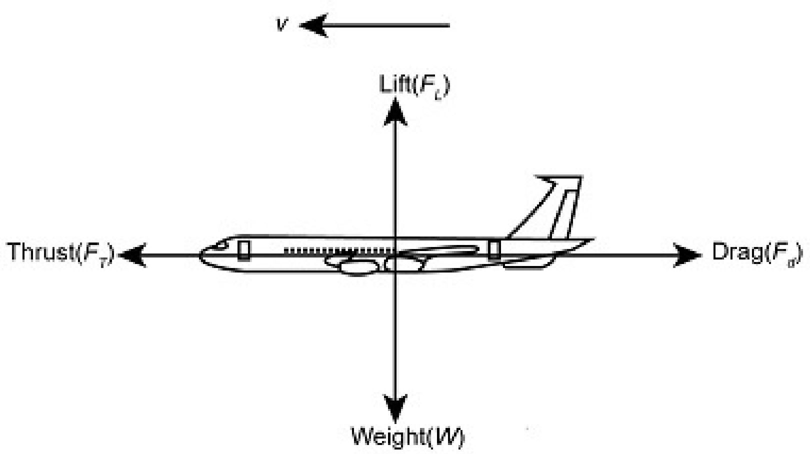
1.1 Bernoulli's Principle in Aircraft Wings

Bernoulli's Principle states that an increase in the speed of a fluid results in a decrease in pressure. In aviation, this principle explains how air moving faster over the curved top of an aircraft wing. The airfoil shape of airplane wings is designed so air travels faster over the top surface, creating lower pressure compared to the bottom. The pressure difference results in lift.. This pressure difference generates lift, helping the aircraft rise.

1.2 Newton's Third Law in Aviation

Newton's Third Law states that "For every action, there is an equal and opposite reaction" which is evident in how engines generate thrust. The expulsion of air or exhaust gases backward results in a forward motion of the aircraft. Similarly, the downward deflection of air by the wing leads to an upward lift force.

Free Body Diagram: Level Flight



Let's analyze a glider in level flight:
Weight (W) acts downward due to gravity.
Lift (L) acts upward, balancing weight.
Thrust (T) acts forward (from propeller or tow plane).
Drag (D) acts backward, resisting motion.

In level, constant-speed flight:
Lift = Weight and Thrust = Drag

1.3 Major Aerodynamic Forces

Every aircraft in flight is subject to four primary forces:

Lift: The upward force that counters weight, produced mainly by the wings.

Weight: The downward force due to gravity, acting through the aircraft's center of gravity.

Thrust: The upward force that counters weight, produced mainly by the wings.

Drag: The resistance force acting opposite to the direction of motion.

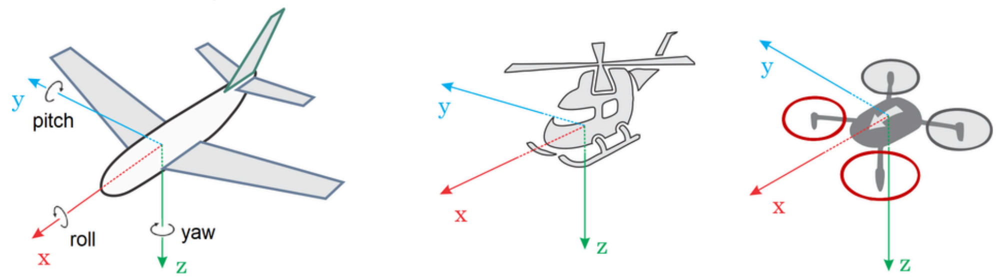
Proper flight requires a balance between these forces.

Force	Direction	Source	Effect on Aircraft
Lift	Upward	Pressure difference across wing	Keeps aircraft in air
Weight	Downward	Gravity	Pulls aircraft down
Thrust	Forward	Engine exhaust / propeller	Moves aircraft ahead
Drag	Backward	Air resistance	Slows aircraft down

1.4 Aircraft Stability

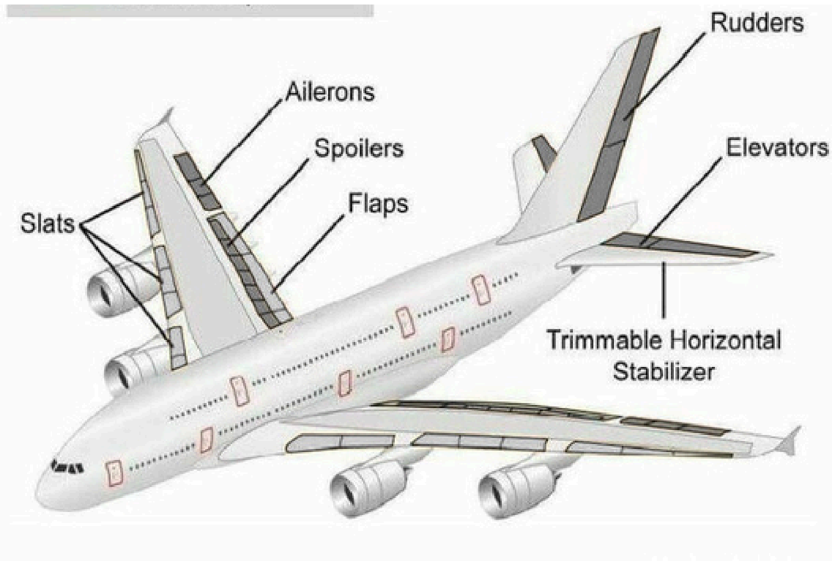
Stability refers to the aircraft's ability to maintain steady flight without constant control inputs. It is categorized into:
Static Stability – Aircraft's initial response to disturbance.
Dynamic Stability – Aircraft's long-term tendency to return to equilibrium.
Design features such as dihedral wings and horizontal stabilizers help maintain stability.

Types of Stability:



Longitudinal Stability (Pitch): Controlled by horizontal stabilizer.
Lateral Stability (Roll): Affected by wing dihedral and design.
Directional Stability (Yaw): Controlled by vertical stabilizer and rudder.
A stable aircraft returns to its original flight path after a disturbance, while an unstable one diverges and requires constant correction.

1.5 Control Surfaces in Aircraft



Control surfaces are movable parts of an aircraft's wings and tail that allow the pilot to control the aircraft's motion in the air. They work by changing the airflow around the aircraft, which creates forces and moments that move it in different directions. The three main control surfaces are ailerons, elevators, and rudder, which control roll, pitch, and yaw respectively. Additional surfaces like flaps, slats, and spoilers are used to improve lift or reduce speed during landing and takeoff.

Primary Control Surfaces:

Primary control surfaces include the ailerons, elevators, and rudder, which directly control the aircraft's roll, pitch, and yaw, making them essential for stable flight.

Surface	Location	Controls	Axis
Elevators	Tailplane (horizontal	Pitch	Lateral
Ailerons	Trailing edge of wings	Roll	Longitudinal
Rudder	Tail fin (vertical stabilizer)	Yaw	Vertical

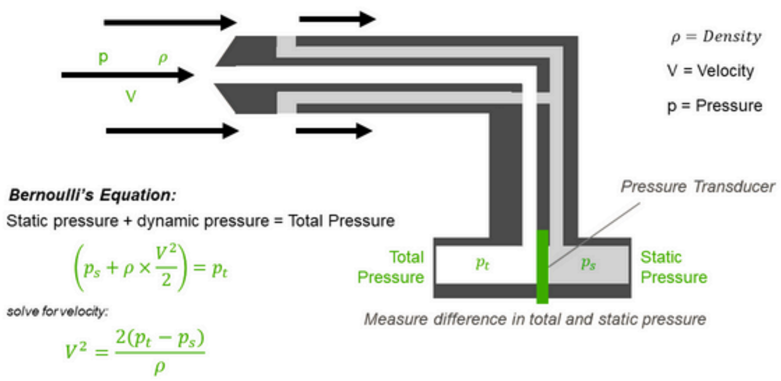
Secondary Control Surfaces

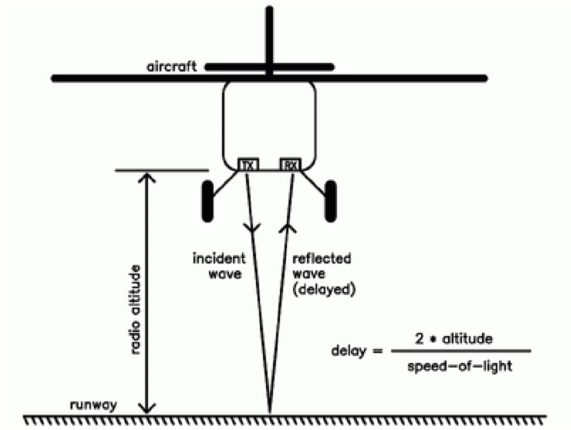
Secondary control surfaces such as flaps, slats, spoilers, and trim tabs assist the pilot by improving lift, reducing stall speed, controlling drag, and easing control forces

Surface	Function	Usage Scenario
Flaps	Increase lift and drag	Takeoff/Landing
Slats	Delay stall at high angles of attack	Slow-speed flight
Spoilers	Reduce lift and increase drag	Descending and braking
Trim Tabs	Minimize pilot input for stability	Long flights

1.6 Flight Instruments & Components

These are the essential tools in the cockpit that provide a pilot with critical information about the aircraft's position, movement, and performance.





1.6.1 Pitot Tube

A pitot tube is a device that measures airspeed by comparing static pressure and ram air pressure. It is a critical input for instruments like the airspeed indicator and is usually located on the aircraft's nose or wing.

1.6.2 Radio Altimeter

A radio altimeter measures the aircraft's actual height above ground level (AGL) using radio waves. Unlike a barometric altimeter, it gives precise low-altitude readings, which is crucial during takeoff, landing, and low-visibility operations

Instrument	Measures	Working Principle	Applications
Pitot Tube	Airspeed	Compares total (dynamic + static) and	Aircraft speed indication
Radio Altimeter	Height AGL (Above Ground Level)	Sends radio signals downward and calculates return time to measure altitude	Low-level flight, landing

Magnetic Compass:

The magnetic compass is the simplest navigation instrument, showing heading based on Earth's magnetic field. It is reliable but affected by turning and acceleration errors, so it is often used as a backup.

Heading Indicator (Directional Gyro):

The heading indicator provides a stable directional reference using a gyroscope. It avoids compass errors but slowly drifts and must be aligned with the magnetic compass.

VOR (VHF Omnidirectional Range):

VOR is a ground-based navigation system that gives aircraft their bearing from a station. It is highly accurate and widely used for following airways and flight routes.

GPS (Global Positioning System)

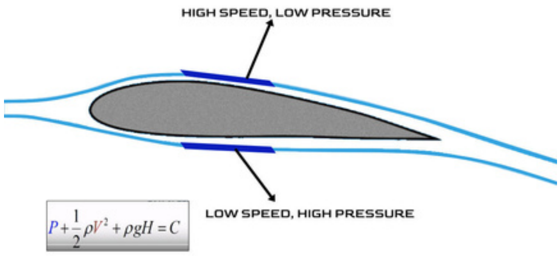
GPS uses satellites to give accurate position, altitude, and speed anywhere in the world. It has become the main navigation system in modern aircraft.

1.7 Concepts of Lift

Lift is the upward force that allows an aircraft to rise and stay in the air, counteracting the downward pull of weight (gravity). Without lift, an aircraft could not fly.

Lift is mainly generated by the wings due to the way they are shaped (airfoil design) and how air moves over and under them.

Airfoil Shape:



The airfoil shape is the cross-sectional design of a wing, tail, or propeller blade that allows an aircraft to generate lift efficiently. An airfoil typically has a curved upper surface and a flatter lower surface. This shape causes air to move faster over the top surface and slower underneath, creating a pressure difference according to Bernoulli's Principle. The higher pressure below the wing pushes upward while the lower pressure above pulls upward, together producing lift. The angle of attack, thickness, and curvature of the airfoil are carefully designed to balance lift, drag, and stability, making it a fundamental concept in aviation.

Angle of Attack (AoA):
The angle of attack is the angle between the airfoil's chord line (an imaginary line from the leading edge to trailing edge) and the oncoming airflow. Increasing AoA increases lift up to a certain point, but if it becomes too steep, airflow separates from the surface, leading to stall.

Curvature (Camber):
Curvature, also called camber, refers to how much the upper and lower surfaces of an airfoil are curved. A highly curved airfoil generates more lift at lower speeds, while a flatter one is designed for higher speeds with less drag.

Thickness:
Thickness is the maximum distance between the upper and lower surfaces of the airfoil. Thicker airfoils provide more lift and strength but also create more drag. Thin airfoils are faster and efficient but produce less lift.

Lift Equation:

$$L = \frac{1}{2} \times \rho \times V^2 \times CL \times S$$

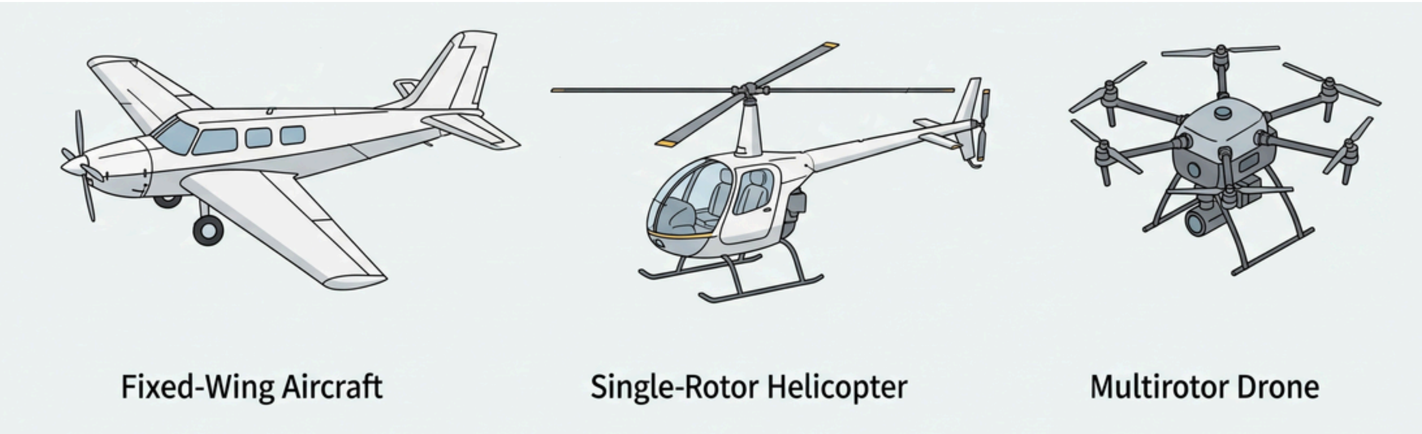
CL= Coefficient of lift (depends on airfoil shape and Angle of Attack)
ρ is air density
V is velocity
S is wing area

Key Observations:

- $L \propto V^2$ → Lift increases with the square of velocity (doubling speed gives four times the lift).
- $L \propto \rho$ → Lift increases with air density; higher at sea level, lower at high altitude.
- $L \propto S$ → Larger wing area produces more lift (gliders have long wings for this reason).
- Increasing Angle of Attack (AOA) increases lift, but only up to the critical angle, beyond which stall occurs.
- Wings with higher camber generate more lift at lower speeds, useful for short takeoffs and landings.
- For steady level flight, lift must equal weight; for climb, lift > weight; for descent, lift < weight.

1.8 Aircraft structures

Aircraft structures form the backbone of any flying machine, whether it is a fixed-wing airplane, a rotary-wing helicopter, or a multirotor drone. Their primary role is to carry loads, withstand aerodynamic forces, and provide stability while being lightweight and aerodynamically efficient.



Airplane (Fixed-Wing Aircraft)
An airplane is a fixed-wing aircraft that generates lift through the motion of its wings. The main structural components include the fuselage, which holds the cockpit, passengers, and cargo, the wings, which are designed with airfoil shapes to create lift, the empennage (tail unit) for stability, and the landing gear for ground support. The airplane works on the principle of Bernoulli's theorem and Newton's third law, where the curved upper surface of the wing causes air to travel faster above than below, creating a pressure difference that generates lift. The engines or propellers provide forward thrust, and the control surfaces (ailerons, rudder, elevator) manage roll, yaw, and pitch for controlled flight.

Helicopter (Rotary-Wing Aircraft)
A helicopter uses rotating blades instead of fixed wings to generate lift and thrust. Its key structural parts include the fuselage for crew and equipment, the main rotor system that provides lift, the tail rotor (or anti-torque system) for yaw control, and the landing gear (usually skids). The working principle is based on airfoil-shaped rotor blades, which, when spun by the engine, create lift in the same way as airplane wings but in a rotating manner. By adjusting the collective pitch of the blades, the helicopter can ascend or descend, while the cyclic pitch tilts the rotor disc to move forward, backward, or sideways. The tail rotor counters torque from the main rotor, ensuring directional stability.

Drone (Unmanned Aerial Vehicle Multirotor)
A drone is a lightweight aerial vehicle that relies on multiple propellers for lift and maneuverability. Its structure includes a central frame housing the flight controller, sensors, battery, and payload, with arms extending to hold motors and propellers. Unlike airplanes or helicopters, drones typically lack aerodynamic wings or control surfaces; instead, they work on the principle of variable thrust from multiple rotors. By increasing or decreasing the speed of individual motors, the drone can climb, descend, roll, pitch, or yaw. For example, to move forward, the rear motors spin faster than the front ones, tilting the drone forward. This precise control is managed electronically by the onboard flight controller, which balances inputs from sensors like gyroscopes and accelerometers to maintain stable flight.

Feature	Airplane (Fixed-Wing)	Helicopter (Rotary-Wing)	Drone (Multirotor UAV)
Lift Source	Fixed wings (airfoil shape)	Rotating main rotor blades	Multiple propellers
Main Body	Fuselage	Fuselage	Central frame/body
Control Surfaces	Ailerons, rudder, elevator	Collective & cyclic pitch, tail rotor	Flight controller (electronic mixing)
Landing Gear	Wheels/skids	Skids or wheels	Simple legs/skids
Materials	Aluminum, composites	Aluminum, titanium, composites	Carbon fiber, plastic, composites

1.9 Phases of Flight

1. Takeoff – Requires excess thrust and lift.
The aircraft accelerates along the runway until it reaches takeoff speed.
Pilots rotate the nose upward to increase lift and leave the ground.

2. Climb – Balance between thrust and drag.
The aircraft gains altitude while maintaining a safe airspeed.
Engines operate at high power to overcome gravity and drag.

3. Cruise – Efficient balance of lift, drag, thrust, and weight.
This is the longest phase, where fuel efficiency and stability are most important.
Aircraft fly at optimum altitude and speed to cover maximum distance.

4. Descent – Controlled reduction of altitude.
Pilots reduce thrust and adjust pitch to begin a smooth downward path.
Air traffic control guides the descent to ensure safe spacing with other aircraft.

5. Landing – Uses high-lift devices (flaps, slats) for low-speed safe approach.
Pilots carefully manage descent rate and alignment with the runway.
Brakes, spoilers, and thrust reversers are used after touchdown to stop safely.

2. Basic UAV Assembly & Components Familiarization

Objective

- Identify and understand flight controllers (Pixhawk, APM), ESCs, motors, propellers, and battery management
- Learn about LiPo, Li-ion, and NiMH batteries, their charge cycles, and safety
- List all the components required to build a quadcopter with a minimum thrust-to-weight ratio of 3:1, each of the components should be compatible with each other.
- Perform manual pen-and-paper calculations for flight time and thrust-toweight ratio using component datasheets
- Use E-Calc to verify the results

Learning

2.1 Flight Controllers

A Flight Controller (FC) acts as the brain of the drone, processing data from multiple onboard sensors and managing motor outputs. Modern FCs use MEMS (Micro-Electro-Mechanical Systems) technology to integrate mechanical and electrical components at a micro scale.

- **Pixhawk:** An advanced, open-source flight controller supporting PX4 and ArduPilot firmware. It offers multiple sensor inputs, GPS integration, telemetry, autonomous mission planning, and high precision for professional applications.
- **APM (ArduPilot Mega):** An older generation controller mainly used in early drones. It supports ArduPilot firmware but has limited processing power compared to Pixhawk. Today, Pixhawk is preferred for modern UAVs.

2.2 Sensor Unit

Modern drones rely on a variety of sensors to maintain stable flight, gather data, and interact with their environment. These sensors feed information to the flight controller, which makes real-time adjustments to motors and propellers for precise maneuvering.

1. Inertial Measurement Unit (IMU)

- Components: Accelerometer + Gyroscope (sometimes Magnetometer).
- Working Principle:
    - Accelerometer measures linear acceleration (change in speed along X, Y, Z axes).
    - Gyroscope measures angular velocity (rotation rates around roll, pitch, yaw axes).
    - Together, they provide orientation and movement data.
- Application: Keeps the drone stable, helps in leveling, and provides feedback for smooth movement

2. Magnetometer (Electronic Compass)

- Working Principle: Detects Earth’s magnetic field to determine the drone’s heading (North, South, East, West).
- Use in Drone: Provides accurate direction for navigation, especially in GNSS-based waypoint missions. Often used to correct drift errors from the gyroscope.

3. GNSS (Global Navigation Satellite System)

- Working Principle: Uses signals from multiple satellite constellations (GPS – USA, GLONASS – Russia, Galileo – EU, BeiDou – China, etc.) to calculate the drone's position (latitude, longitude, altitude).
- Use in Drone: Enables autonomous navigation, return-to-home (RTH) functions, and geofencing. Offers better accuracy and reliability than single-system GPS, especially in urban or obstructed areas.

4. Barometer (Pressure Sensor)

- Working Principle: Measures atmospheric pressure; since pressure decreases with altitude, it calculates height above ground level.
- Use in Drone: Maintains stable altitude (altitude hold feature), smoother takeoff and landing.

5. Optical Flow Sensor

- Working Principle: Uses a downward-facing camera and image processing to detect ground movement beneath the drone.
- Use in Drone: Provides position hold indoors (without GNSS), stabilizes hover by comparing changes in ground texture.

2.3 Parameters to Consider When Choosing a Flight Controller

1. Processor and Performance

The microcontroller unit (MCU) inside the FC determines how fast it can process flight data. Modern controllers often use ARM Cortex processors (e.g., STM32 series) with higher clock speeds (168 MHz, 216 MHz, or more) and larger memory for handling complex algorithms. A more powerful processor allows smoother control, better handling of GPS, advanced filtering, and running additional features such as autonomous missions, telemetry logging, and obstacle avoidance.

2. Sensor Suite (IMU, Barometer, Magnetometer, GPS Support)

A reliable FC must include high-quality sensors.
IMU (Inertial Measurement Unit): Consists of a gyroscope and accelerometer for measuring orientation and motion. Dual or redundant IMUs improve reliability.
Barometer: Measures altitude using air pressure; essential for maintaining stable flight levels.
Magnetometer (Compass): Provides heading information, critical for GPS navigation.
GPS/GNSS Support: Enables position hold, return-to-home, and autonomous navigation. Some controllers support multi-constellation GNSS (GPS, GLONASS, Galileo, BeiDou) for higher accuracy.

3. Number of Input/Output Channels

The number of PWM, UART, I2C, CAN, and other input/output ports determines how many peripherals can be connected. A good FC should have enough motor outputs for the desired frame type (quad, hex, octa) and extra ports for GPS, telemetry radios, gimbals, rangefinders, or companion computers.

4. Size, Weight, and Form Factor

The physical size and weight of the flight controller are important for integration. Standard sizes include 30.5×30.5 mm, 20×20 mm, and 16×16 mm mounting patterns. Smaller FCs are suitable for racing drones, while larger, more robust boards are used in industrial or heavy-lift drones.

5. Connectivity and Communication Protocols
Modern UAVs often integrate with telemetry radios, companion computers (like Raspberry Pi or NVIDIA Jetson), and ground control stations. Therefore, the FC should support multiple communication protocols:

- UART/I²C/SPI: For sensors and modules.
- CAN Bus: For high-reliability peripherals (GPS, ESCs, LiDAR).
- Telemetry/RC Protocols: SBUS, CRSF (ExpressLRS), DSMX, etc.

Good connectivity ensures scalability and integration with advanced modules.'

6. Power Management
A flight controller must have stable power regulation. Many FCs support wide input voltage ranges (5V–36V) and include onboard power distribution boards (PDBs) or external power modules for voltage/current sensing. Built-in protection against surges and noise is essential to avoid resets mid-flight.

2.4 Other UAV Components and parameters while choosing

1. Electronic Speed Controllers (ESCs)
Overview:
The ESC is the bridge between the flight controller and the motors. It converts low-power control signals into high-power pulses to drive the brushless DC motors.

Working:

- Receives throttle signals (PWM, OneShot, DShot) from the flight controller.
- Converts DC power from the battery into 3-phase AC signals to spin the motor.
- Regulates motor speed, direction, and braking when required.

Parameters to Look For

- Current rating (must exceed motor's max current).
- Voltage rating (should match battery voltage, e.g., 3S–6S).
- Protocol support (PWM vs DShot for response time).

2. Motors
Overview
Motors provide the mechanical thrust needed for lift and maneuvering. Most drones use Brushless DC (BLDC) motors due to their efficiency, durability, and high thrust-to-weight ratio.

Working

- ESC supplies 3-phase AC to the motor.
- Permanent magnets on the rotor interact with electromagnetic coils, causing rotation.
- Propellers attached to the motor convert rotation into thrust.

Parameters to Look For

- KV rating (RPM per volt, higher KV = faster RPM but less torque).
- Thrust capacity (must exceed 2x drone weight when multiplied by number of motors).
- Efficiency (grams of thrust per watt).
- Weight of motor (affects overall drone design).
- Compatibility with propeller size.

3. Propellers

Overview

Propellers are the aerodynamic components that convert motor rotation into lift and thrust. Their design (diameter, pitch, blade count) significantly affects performance.

Working

- Rotating blades accelerate air downward, generating lift (Newton's Third Law).
- The pitch determines how much air is displaced per revolution.
- Larger propellers give more lift but require more torque.

Parameters to Look For

- Diameter (larger = more lift, but slower response).
- Pitch (higher = faster forward flight, lower = stable hover).
- Material (plastic = cheap, carbon fiber = strong and efficient).
- Blade count (2-blade = efficient, 3/4-blade = more thrust but less efficient).
- Rotation direction (CW vs CCW for balance).

4. Battery and Power Management

Overview

The battery is the energy source of the drone. LiPo (Lithium Polymer) batteries are most common due to high energy density and discharge rates. The Battery Management System (BMS) ensures safe charging, discharging, and monitoring.

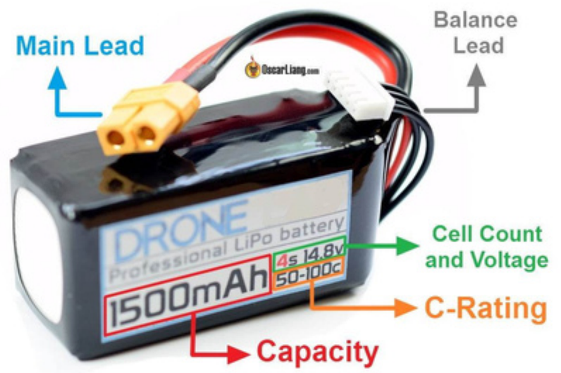
Working

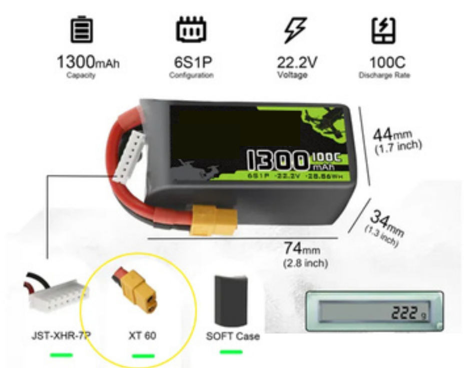
- Supplies DC power to ESCs, flight controller, and peripherals.
- Voltage drops as current draw increases; requires careful monitoring.
- BMS prevents overcharge, deep discharge, and overheating.

Parameters to Look For

- Cell count (S rating) [3S (11.1V), 4S (14.8V), 6S (22.2V)].
- Capacity (mAh)
- C-rating (maximum safe discharge rate).
- Weight-to-capacity ratio (must balance endurance and payload).
- Cycle life and safety features.

2.5 Understanding Drone Battery Ratings:





Capacity: Indicates how much electrical charge a battery can store, measured in milliampere-hours (mAh). For example, a 1500mAh battery can provide 1500 milliamps for one hour or 3000 milliamps for half an hour. Higher capacity means longer flight time but usually adds more weight.

C Rating: Indicates the maximum safe discharge rate of the battery as a multiple of its capacity. For example, a 1500mAh battery with a 50C rating can safely provide 1500mAh × 50 = 75,000mA or 75A continuous current. It shows how fast the battery can release energy safely.

S Rating: Represents the number of cells connected in series in the battery pack. Each cell adds about 3.7V nominal voltage. So a 3S battery has 3 cells (11.1V), a 4S has 4 cells (14.8V), etc. This determines the battery voltage and directly affects motor speed and power.

2.6 Choosing the Right Battery for Drones: LiPo vs Li-ion vs NiMH

🔋LiPo (Lithium Polymer) Batteries

- Structure: Gel-like or solid polymer electrolyte, packaged in lightweight pouches; highly shape-flexible.
- Charge Voltage: Typically 4.20 V per cell (nominal 3.7 V). Must not exceed safe upper voltage, or risk swelling/fire.
- Discharge Voltage: Safe lower limit ~3.0 V per cell (below this = risk of degradation).
- Discharge Rates (C-Rating): Very high — often 25C to 100C, enabling very high current output for short bursts (great for drones/RC).
- Energy Density: 150–200 Wh/kg (lower than Li-ion but lighter form factor).
- Thermal Stability: Sensitive to overcharge, puncture, and heat — can swell or vent fire. Requires careful handling.
- Cycle Life: ~100–300 cycles under stress, up to 500 with gentle storage/use.
- BMS: Rare in hobby packs. Balance achieved using balance leads + balance charger.
- Balancing: Critical due to pouch design and narrow safe voltage range. Achieved externally during charging.
- Risks & Safety: Swelling, fire if overcharged/discharged; prone to abuse.

🔋 Li-ion (Lithium-ion) Batteries

- Structure: Liquid electrolyte in rigid metal or prismatic casing; safer structural integrity than soft pouch cells.
- Charge Voltage: Typically 4.20 V per cell (nominal 3.6–3.7 V). Newer chemistries like $LiFePO_4$ = ~3.65 V max.
- Discharge Voltage: Generally 2.5–3.0 V per cell minimum.
- Discharge Rates (C-Rating): Moderate — usually 1C to 5C continuous; some high-power cells may reach 10–20C briefly.
- Energy Density: 180–250 Wh/kg (higher than LiPo and NiMH).
- Thermal Stability: More robust than LiPo but still flammable if shorted/overcharged.
- Cycle Life: 500–1000 cycles; advanced chemistries ($LiFePO_4$) may last over 2000–3000 cycles.

- BMS: Essential for drone packs. Integrates: over/under-voltage cutoff, temp. monitoring, and active/passive balancing.
- Balancing: Mandatory in multi-cell packs (especially >3S).
- Risks & Safety: Can suffer runaway if abused; safer casing than LiPo.

🔋 NiMH (Nickel-Metal Hydride) Batteries

- Structure: Aqueous electrolyte (potassium hydroxide) in rigid cylindrical/prismatic casing.
- Charge Voltage: Peak detection charging; nominal 1.2 V per cell, charged up to ~1.4–1.6 V.
- Discharge Voltage: Safe minimum ~1.0 V per cell; below 0.9 V risks damage.
- Discharge Rates (C-Rating): Low to moderate — typically 0.5C–5C; less suited for very high bursts compared to LiPo.
- Energy Density: 60–120 Wh/kg (much lower than Li-ion and LiPo).
- Thermal Stability: Very safe (non-flammable), though can overheat during overcharge. Robust to abuse.
- Cycle Life: 300–500+ cycles with proper charging; modern "low self-discharge" types last even longer with storage.
- BMS: Not required; packs typically charged by detecting −ΔV (voltage drop at full charge) or timed cutoff.
- Balancing: Naturally more tolerant of imbalance. High self-discharge levels tend to equalize cells somewhat, but mismatch still reduces performance.
- Risks & Safety: Very safe; main issue is heating when overcharged.

Comparison Table

Parameter	**LiPo**	**Li-ion**	**NiMH**
Nominal Voltage/Cell	3.7V	3.6–3.7V	1.2V
Max Voltage/Cell	4.2V	4.2V	1.4V
Cycle Life	150–300	300–500	500–1000
Energy Density	Medium	High	Low
Discharge Rate (C)	High (20–100C)	Low (2–5C)	Very Low (~1C)
Weight	Light	Medium	Heavy
Cost	Medium	Higher	Lower

Conclusion

- LiPo batteries are ideal for high-performance drones that need fast discharge and lightweight packs, but they require strict safety handling.
- Li-ion batteries are suitable for long-endurance missions where energy density and cycle life are more important than discharge rate.
- NiMH batteries remain useful in low-power applications such as transmitters, backup systems, and cost-sensitive devices.

2.7 Quadcopter Configuration Report:

Component	Model	Info	Datasheet	Weight (g)
Frame	Tarot XS690		http://www.tarotrc.com/Product/Detail.aspx?Lang=en&Id=e0c3cff6-7dd1-4f2f-	675
FC	Pixhawk orange cube+		https://docs.px4.io/main/en/flight_controller/cubepilot_cube_orange	73
Motor (×4)	T-Motor MN5212 340 KV		https://store.tmotor.com/product/mn5212-kv340-motor-navigator-	205 × 4 = 820
ESC (×4)	RD D-Pro ESC 40A		https://reflexdrive.in/product/rd-d-pro-esc-40a/	30 × 4 = 120
Propellers (×4)	T-Motor NS17*5.8 Prop		https://store.tmotor.com/product/ns17x5_8-prop-uav-carbon-fiber.html?	33 × 4 = 132
Battery	Tattu G-Tech 6S 25000mAh 22.8V 10C Lipo		Tattu G-Tech ...	2577
GPS	Here4 GPS Module		https://docs.cubepilot.org/user-guides/here-4/here-4-manual	60
Receiver	RP1 V2 ExpressLRS 2.4ghz Nano Receiver		RP1 V2 Expre...	2.2
Cables and other Miscellanous	-		-	100
Total AUW	—			4557g

Thrust generated by each motor = 3716g
Thrust generated by all 4 motor = 14864g

Drone Component Selection and Calculation

BLDC Motor:

MN5212 340KV

Propeller:

T-Motor P17*5.8 Prop

~~We~~ Based on the data of thrust and current mentioned in the datasheet.

At Full RPM

Thrust by each motor = 3716 g

Thrust by all 4 motors = 14,864 g

Current drawn by each motor = 26.1 A

Current drawn by all 4 motors = 104.4 A

ESC Selection:

ESC should have 10-20% more current rating than the current drawn by each motor

20% of 26.1 = 5.2 A

ESC current rating should be 31.3A

As the obtained current rating of ESC is not standard. We will be choosing 40A one.

Battery Selection:

By motor datasheet we should choose a 24V Battery. Since it is not a standard LiPo Voltage we will be going with 22.8V LiPo

Battery pack: Tattu G-Tech 6S 25000mAh 22.8V 10C High voltage LiPo Battery.

Power and Current Calculation

T-Motor:

$$\left.\begin{array}{ll} \text{Current draw} & = 26.1A \\ \text{Power } R & = 6269W \end{array}\right\} \text{As per datasheet at } 24V$$

Flight Controller

Current = ~~[illegible]~~ 2.5A (at 5.6V)

Voltage Range = 4.1V - 5.7V

Max Power = 14W

→ Power consumed by GPS, Receiver and other modules <1W

→ Current draw of motor at 24V is ~~taken~~ assumed to be same for 22.8V

→ Current drawn by Flight controller, GPS, Receiver

$$= \frac{15W}{22.8V} = 0.65A$$

∴ Total Current drawn from Battery = $(26.1 \times 4) + 0.65$

$$= \underline{\underline{105A}}$$

Thrust to Weight Ratio:

i) Net thrust generated by all 4 motors = 3716×4

= 14,864g

ii) Total All Up Weight (AUW) of Drone = 675 + 73 + 820 + 120 + 132 + 2577 + 60 + 2.2 + 100

= 4559.2g

Thrust to Weight Ratio $= \frac{14864}{4559.2} = 3.26$

Flight time Calculation

Taking overall power efficiency (Including Battery, ESC & other components) as 85%.

Effective capacity of Battery = 0.85 × 25000

= 21,250mAh = 21.25Ah

Flight time (at full throttle) $= \frac{21.25}{105} = 0.20h =$ 12mins

Flight time (at 55% throttle) $= \frac{21.25}{24.65} = 0.86h =$ **51 mins**

Just enough fly

Current at 55% throttle is 24.65A

Thrust produced at 55% throttle = **5280g**

E-calc

Couldn't use E calc, As the components mentioned above couldn't be used without paying for the calculator

3.Propeller Blade Design & Simulation

Objective

- Understand the basics of propellers and their nomenclature
- Learn the need for clockwise and anticlockwise propellers
- Study:
  - Identification of clockwise and anticlockwise propellers
  - Factors affecting propeller efficiency
  - Conversion from 2-blade to 3-blade propellers
- Design a 2-blade clockwise or anticlockwise propeller to generate a minimum of 8N lift, also state the diameter of the designed propeller
- Run a Computational Fluid Dynamics (CFD) simulation ONLY on Autodesk CFD
  (OPTIONAL)
  Write a detailed report on toroidal propeller in the resource article section.

Learning

2.1 Basics of Propellers

A propeller is a rotating blade that converts the rotational power of a motor into thrust by accelerating air backward (Newton's 3rd Law). This thrust lifts or moves the aircraft forward.

- Think of it like a rotating wing: each blade has an airfoil shape, creating lift (but directed along the thrust axis).
- The amount of thrust depends on the propeller's diameter, pitch, RPM, and blade count.

2.2 Propeller Nomenclature

Propellers are usually described by a set of numbers and letters.
The format is typically:
Diameter × Pitch + Rotation Direction

1. Diameter
The tip-to-tip length of the circle the propeller makes while rotating.
Larger diameter → moves more air → more lift, but requires more torque (motor power).

2. Pitch
The theoretical distance (in inches) a propeller would move forward in one revolution in a perfect medium (like a screw through wood).
Example: A 5” pitch propeller would move forward 5 inches per rotation (if there was no slippage).
High pitch → faster forward speed, more motor load.
Low pitch → stable hovering, better efficiency.

3. Rotation Direction
CW (Clockwise, marked “R”) → rotates like a clock hand when viewed from above.
CCW (Counter-Clockwise, “L” or no suffix) → rotates in the opposite direction.
Both types are used together in drones to balance torque.

Examples of Nomenclature
1045R→
10-inch diameter
4.5-inch pitch
Clockwise (since “R” at the end)

2.3 How to match Diameter & Pitch to Your Purpose?

High Diameter + Low Pitch
Moves more air, generates more lift.
Best for hovering, stability, carrying payloads (photography drones, heavy lift).

Low Diameter + High Pitch
Spins fast, designed for speed.
Best for racing drones where forward speed matters more than stability.

Rule of Thumb:
If pitch increases → reduce diameter, and if diameter increases → reduce pitch.
This balances motor load and prevents overheating.

2.4 Motor Compatibility

High KV motors → small diameter, low-pitch props (they spin fast, need less load).
Low KV motors → large diameter, higher-pitch props (they spin slower but handle bigger props).

2.5 Number of Blades in Drone Propellers

Blades	Efficiency	Thrust	Stability	Advantages	Disadvantages	Use Case
1-Blade (Unusable)	Highest (least drag)	Low	Very poor (imbalance & vibration)	Minimal drag	Low thrust, unstable, impractical	Experimental setups, rarely used in drones
2-Blade (Standard)	Very high	Moderate	Good (but less smooth than multi-blade)	Best efficiency → longer flight time, low motor load	Lower thrust than 3-blade at same RPM	Photography drones, endurance drones, general-purpose use
3-Blade	Lower than 2-blade (more drag)	High (more thrust in same diameter)	Very stable, smooth response	More thrust, faster response, less vibration → better FPV	Higher power consumption, reduced flight time	Racing drones, freestyle FPV, smooth video capture

2.6 Need for CW and CCW Propellers

1.Torque Balance
A single rotating propeller generates thrust + torque.
If multiple propellers rotate in the same direction, their torques add up.
This makes the drone spin continuously about its yaw axis.
By using equal numbers of CW and CCW propellers, torques cancel each other out.

2. Stable Flight
With torque balanced, the drone can hover steadily without spinning.
This allows precise control for takeoff, landing, and mid-air maneuvers.

3. Yaw Control (Turning Left/Right)
Yaw movement is controlled by differential torque.
By slightly increasing the speed of CW props while decreasing CCW props (or vice versa), the torque becomes unbalanced, making the drone rotate left or right.

2.7 Identification of CW & CCW Propellers

1. Markings
Clockwise (CW) propellers are sometimes marked as “R” or simply CW, while counter-clockwise (CCW) propellers are usually marked as L or CCW. These markings are a quick way for drone builders to distinguish between the two types when assembling or replacing propellers.

2. Edge Shape
The leading edge of a CW propeller (the thicker side of the blade) points to the right when the propeller is facing forward. On the other hand, the leading edge of a CCW propeller points to the left when facing forward. This difference in blade orientation is what allows them to generate thrust in opposite rotational directions.

3. Airflow:
When installed correctly, both CW and CCW propellers generate downward thrust, but their blade orientation differs. A CW propeller pushes air downward when spinning clockwise, while a CCW propeller does the same when spinning counter-clockwise.

4. By Blowing Air Externally:
If you are unsure, a simple hands-on method is to blow air onto the curved side of the propeller blade. For CW propellers, the air is directed downward when rotated clockwise, and for CCW propellers, the air is directed downward when rotated counter-clockwise. This quick test helps confirm the orientation without mounting it on a motor.

2.8 Propeller conversions (2 Blades <–-> 3 Blades):

when converting from a 2-blade propeller to a 3-blade propeller, the drone gains better stability, smoother control, and improved responsiveness in maneuvers. This comes at the cost of slightly reduced efficiency, as the third blade increases drag and requires more power from the motor and battery. The conversion is often chosen in racing drones or high-performance builds where agility is more important than endurance.

Simply replacing a 2-blade with a 3-blade of the same size can increase the load on the motor significantly, so careful matching is required to avoid overheating or reduced lifespan of components.

Propeller Blade Conversion

2-Blade $\longleftrightarrow$ 3 Blade Propeller

$$D^3 \times P\sqrt{N-1} = (D')^3 \times P'\sqrt{N'-1}$$

D: Diameter of the propeller 1

D': Diameter of the propeller 2

P = Pitch of the propeller 1

P' = Pitch of the propeller 2

N = No. of blades in propeller 1

N' = No. of blades in propeller 2

In our case, pitch is kept constant

Example:

Convert 1758 2 Blade propeller to 3 Blade propeller

Given Propeller $\Rightarrow N = 2$

$D = 17''$

$P = 5.8''$

Replacement Propeller $\Rightarrow N' = 3$

$D' = ?$

$P' = 5.8''$

Pitch is constant, $P = P'$

Wkt, $D^3 \times \cancel{P}\sqrt{N-1} = (D')^3 \times \cancel{P'}\sqrt{N-1}$

$$(17)^3\sqrt{2-1} = (D')^3 \times \sqrt{2}$$

$$D' = \left(\frac{(17)^3}{\sqrt{2}}\right)^{1/3} = 15.15''$$

Replacement 3 Blade propeller should have 15.15" Diameter and 5.8" pitch

2.9 How to design a propeller

Designing a propeller involves balancing aerodynamic efficiency, thrust generation, and structural integrity to suit the intended aircraft or drone application. The process starts with defining requirements such as payload capacity, flight endurance, motor specifications, and desired speed range. Based on these inputs, parameters like diameter, pitch, number of blades, and blade shape are selected. Airfoil profiles are chosen to maximize lift-to-drag ratio while minimizing noise and vibrations. Computational simulations (CFD) and empirical propeller charts are often used to predict performance. Finally, prototypes are tested to validate thrust, efficiency, and stability, with refinements made iteratively to achieve the optimal design.

Key Factors in Propeller Design

Diameter

The diameter directly influences the volume of air displaced per revolution. Larger diameters generally provide higher thrust at lower rotational speeds, enhancing efficiency, but may increase drag and structural stress. The optimal diameter must balance thrust requirements with motor capability and airframe clearance.

Pitch

Pitch defines the theoretical distance a propeller would move forward in one revolution. A higher pitch produces greater forward speed but demands more torque from the motor. Conversely, a lower pitch favors better acceleration and control at the cost of top speed. Correct pitch selection ensures alignment with the aircraft's mission profile.

Number of Blades

Increasing the blade count allows more thrust to be generated at smaller diameters, making it suitable for limited clearance or noise-sensitive applications. However, more blades also increase drag and reduce efficiency compared to a well-optimized two-blade design. A balance must be struck between thrust output, efficiency, and operational constraints.

Blade Shape and Airfoil

The cross-sectional profile and curvature (airfoil) of the blade affect lift, drag, and noise characteristics. Thicker blades with greater camber can produce more lift at low speeds but increase drag, while thinner airfoils are efficient at higher speeds. Proper aerodynamic shaping is crucial for smooth airflow and reduced turbulence.

Blade Angle Distribution (Twist)

A propeller requires varying blade angles along its radius to maintain optimal angles of attack. Near the hub, the blades rotate slower and thus require a higher angle, while near the tips, the angle decreases to prevent stalling. Correct twist ensures uniform thrust generation across the blade span.

Material Selection

Propeller material impacts weight, strength, and vibration characteristics. Common options include wood (lightweight, good damping), plastic (cost-effective, durable), carbon fiber (high strength-to-weight, stiff), and metal (robust but heavier). Material choice must consider performance, cost, and environmental durability.

Balance and Vibration Control

Even minor imbalances in mass distribution can cause significant vibration, leading to reduced efficiency, motor wear, and structural fatigue. Precision manufacturing and balancing are therefore critical for reliable performance.

RPM and Motor Compatibility

The propeller must be matched to the motor’s torque and RPM characteristics. Oversized propellers can overload motors, while undersized ones may underutilize available power. Proper motor-propeller pairing ensures efficiency, longer motor life, and desired flight performance.

Noise Considerations

Blade tip speed and shape significantly affect noise levels. Designs with more gradual pitch changes, optimized airfoil sections, and lower tip velocities generally produce quieter operation—an increasingly important factor for drones in urban and regulatory-sensitive environments.

Operating Environment

Environmental conditions such as altitude, temperature, and application type (fixed-wing aircraft, rotorcraft, or drones) influence propeller performance. For instance, high-altitude applications require designs optimized for thinner air density, while marine propellers must account for cavitation in water.

4. Flight Computers and Drone Stabilization

Objective

- Design and build a basic 2 or 3 axis gimbal using servo or brushless motors along with motion sensors to stabilize a camera on a drone, and also add feedback.
- Review and document various flight controllers focusing on the onboard chipsets and sensors, as well as their purposes.
- Propose a custom, simple flight computer that can be embedded in the flight controller itself to handle automation tasks and Process onboard sensor data.
- Implement optical flow for drone stabilization using an ESP32-CAM module or OpenCV to track relative motion between the drone and ground or stationary objects. Capture low-resolution grayscale images, Compare frames to detect motion, and estimate movement of the drone by how the ground appears to move(drift or shift). Convert this movement into control feedback for stabilization

Learning

Component Elimination

1.Integrated Flight Control and Video Stabilization System

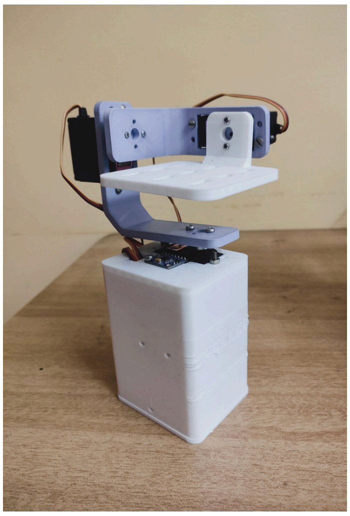
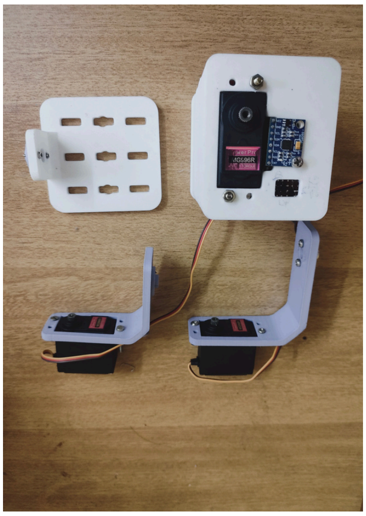
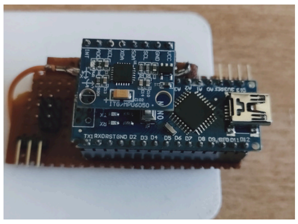
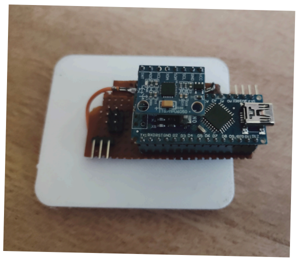
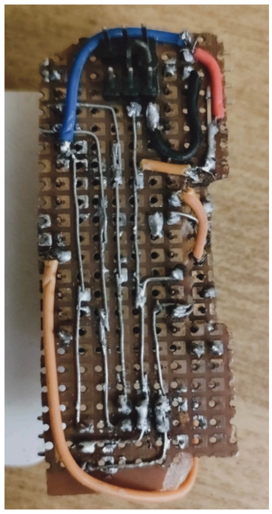
A unified system that combines the drone's flight controller and video transmission module offers significant advantages by sharing the same inertial measurement sensors (gyroscope and accelerometer) for both flight stabilization and camera gimbal control. Instead of using a dedicated IMU for the gimbal, the flight controller's sensor data can directly drive camera stabilization, reducing hardware redundancy, weight, and power consumption. This integration ensures that both the drone's navigation and the camera's orientation respond to the same real-time motion data, leading to tighter synchronization between flight dynamics and video output. Additionally, with onboard processing and video transmission in a single unit, latency is minimized, system complexity is reduced, and overall reliability is improved by making the drone lighter, more efficient, and better suited for aerial imaging applications.

2.Optical Flow Using Onboard Camera

By leveraging the onboard camera for optical flow, a drone can estimate its motion relative to the ground or surrounding environment without relying solely on GPS. The camera continuously captures images, and onboard processing algorithms track the movement of pixel patterns between successive frames to calculate velocity and displacement. This information, combined with inertial sensor data, enables the drone to achieve stable hovering, precise position hold, and smoother navigation even in GPS-denied environments such as indoors or under dense canopy. Using the same camera for both video capture and optical flow analysis reduces the need for additional sensors, saving weight and cost while enhancing situational awareness and autonomous capability.

DIY Camera Gimbal (MG996R + MPU6050 + Arduino Nano)

This model describes the design, build, calibration, and testing of a 3-axis (pitch + roll+yaw) camera gimbal built using MG996R hobby servos, an MPU6050 IMU, and an Arduino Nano.

Working Video: https://youtu.be/jZe7llJGDcU?si=WuBhFGhBRrrKzizY

System overview

Sensors: MPU6050 (3-axis gyro + 3-axis accel).
Actuators: MG996R analog hobby servos for pitch and roll.
Controller: Arduino Nano (ATmega328P).
Power: 5V supply (With reverse voltage protection)
Algorithm: Read gyro + accel -> complementary filter for attitude (pitch/roll) -> PID controllers for each axis -> output servo PWM angles.

Working Principle and Algorithm of the 3-Axis Gimbal

The self-stabilizing gimbal operates on the principle of inertial sensing and feedback correction. The MPU6050 sensor, which contains a 3-axis gyroscope and a 3-axis accelerometer, continuously measures angular velocity and linear acceleration along the yaw, pitch, and roll axes of the camera platform. These raw measurements are processed by the Digital Motion Processor (DMP) inside the MPU6050, which fuses gyro and accelerometer data to generate accurate orientation estimates in the form of quaternions and yaw-pitch-roll (YPR) angles.
The Arduino Nano retrieves this processed orientation data from the MPU6050's FIFO buffer via the I²C bus. To ensure correct reference alignment, the system performs an initial calibration step in which the yaw offset is averaged during the first ~300 sensor readings. This ensures that the gimbal starts with a zeroed reference frame, eliminating random initial yaw drift.
Once the orientation angles are available, the algorithm performs the following steps in real time:

1. Sensor Fusion & Orientation Calculation
   - The DMP computes yaw, pitch, and roll values.
   - The Arduino converts these from radians to degrees for easier interpretation.

2. Offset Compensation
   - An initial yaw correction is applied to make the gimbal's zero-point stable.

3. Mapping to Servo Angles
   - Each orientation angle (yaw, pitch, roll) is mapped from the sensor's natural range (-90° to +90°) to servo motor command values (0–180°).
   - For example, when the pitch changes by +20°, the mapped servo command moves in the opposite direction to counteract that tilt.

4. Feedback Correction
   - The Arduino sends PWM signals to the three MG996R servo motors through the Servo library.
   - Each servo rotates its corresponding axis of the camera platform (yaw, pitch, roll) in real time to counteract drone motion.
5. Closed-Loop Stabilization
   - As the drone tilts or rotates, the MPU6050 instantly detects the change.
   - The control loop calculates corrective servo positions, driving the gimbal in the opposite direction of disturbance.
   - This continuous feedback loop keeps the camera stabilized, ensuring smoother video output.

The algorithm essentially implements a proportional correction system where the sensor data directly drives servo angles. While this approach is simple and efficient for low-cost builds, more advanced gimbals often add PID control loops to fine-tune response and eliminate oscillations.

In summary, the working principle of this 3-axis Arduino gimbal is:

- Sense orientation via MPU6050 → Process data with DMP and Arduino → Correct orientation by driving servos → Stabilize the camera through continuous feedback.

Flight Controllers:

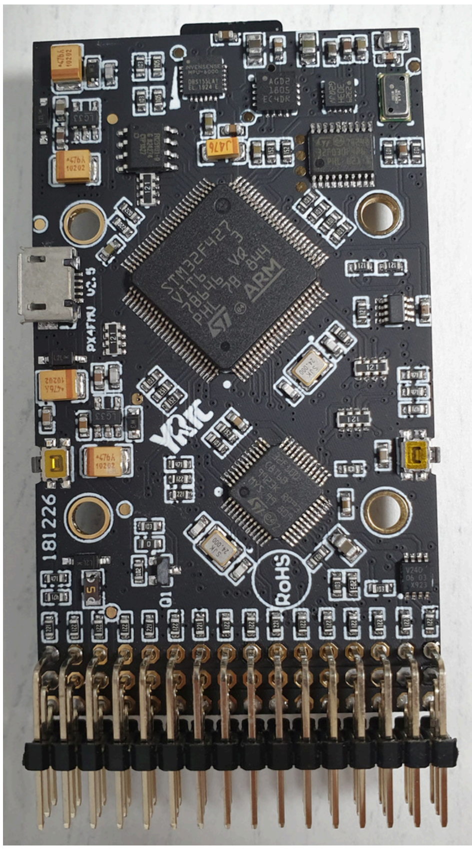
What a Flight Controller Actually Does

A flight controller reads motion and environment sensors (IMU, barometer, magnetometer, GNSS, airspeed, rangefinders), fuses them into a state estimate (attitude, altitude, position, velocity), and closes control loops (rate/attitude/position) to command motors/servos via PWM/OneShot/DShot. It also manages radio control inputs, failsafes, logging, and peripheral buses (I2C/SPI/UART/CAN). Firmware commonly used: ArduPilot, PX4, Betaflight, INAV.

Core building blocks inside an FC:

- Main MCU (FMU/Processor): Typically STM32 (F4/F7/H7 families). Runs RTOS and flight firmware.
- IMUs (Gyro + Accelerometer): Single or redundant (e.g., ICM-series, BMI-series, legacy MPU6000). Provide angular rates and linear acceleration.
- Barometer: MS5611/BMP/DPS families. Measures static pressure for altitude.
- Magnetometer: Often offboard (in the GPS puck) to reduce magnetic interference; common parts include LIS3MDL/IST8310.
- Power & Regulation: 5V/3.3V regulators, power monitors (voltage/current), TVS/LC filtering.
- I/O & Buses: PWM/DSHOT outputs (motors/servos), UARTs (RC/GPS/telemetry), I2C/SPI (sensors), CAN (UAVCAN/DroneCAN), microSD for logging.

Pixhawk 2.4.8 — Circuitry & Component Overview



1. Core Processing & Redundancy

- Main MCU: STM32F427 (Cortex-M4, 168 MHz, FPU, 2 MB flash, 256 KB RAM) — executes flight stack, sensor fusion, control loops
- Failsafe MCU: STM32F103 — monitors main MCU health and handles emergency shutdown or fallback control if needed

2. Inertial & Environmental Sensors

- MPU6000: 3-axis gyro + accelerometer — main IMU for angular rate and acceleration measurements
- L3GD20: 16-bit gyroscope (redundant gyro data)
- LSM303D: 14-bit accelerometer + magnetometer — provides redundancy and compass capability
- MS5611: High-resolution barometer for altitude measurement

3. Power & Safety Hardware

- Ideal Diode Power Switch: Manages dual redundant power inputs and automatic failover
- Servo Power Rail: 7 V high-current power output for driving servos/ESCs, with over-current protection on each peripheral port

4. Interfaces & Connectivity

- Serial Ports (UART): 5 × hardware UARTs (one high-power, two with flow control) for telemetry, RC receivers, or telemetry radios
- CAN: 2 × CAN bus ports for connecting CAN-based peripherals like advanced GPS or controllers
- I²C & SPI: For extra sensors and communication modules (e.g., magnetometers, optical flow units)
- Receiver Inputs: Supports PPM-SUM, S.Bus, Spektrum satellites
- RSSI Input: Accepts PWM or voltage-based signal for link quality

- ADC Inputs: Dual analog voltage inputs — 3.3 V and 6.6 V for battery/misc sensors
- micro-USB: Primary interface for firmware upload and configuration

5. Indicators & Safety Features

- Safety Switch: External push-button for arming and disarming, improving safety before motor spin-up.
- Buzzer & LED: Multi-tone buzzer and RGB LED provide visual/audible feedback on status, errors, or warnings.
- microSD Slot: Onboard data logger for telemetry and flight history.

Functional Circuit Design Highlights

The Pixhawk 2.4.8 PCB integrates the above components in a carefully designed layout to maintain signal fidelity, component isolation, and robustness:

- Sensor placement: MPU6000 and LSM303D are located near the board center to minimize vibration and EMI.
- Power separation: Ideal diode and high-current servo rail keep noise and voltage fluctuations isolated from the MCU power rail.
- Redundancy: Backup MCU and sensors ensure safe operation even under component failure.

Additional ICs: AGDS1805, 2329 303H, V240 0603

While these parts are not well-documented in public schematics, they likely correspond to:

- AGDS1805: Dual analog switch; possibly used for selecting redundant IMUs or dual power rails.
- 2329 / 303H: SMT voltage regulators or buck converters, powering 3.3 V / 5 V rails from battery.
- G2QJW / V240 06 03: MOSFETs or FET drivers in the ideal diode circuit or servo power rail.

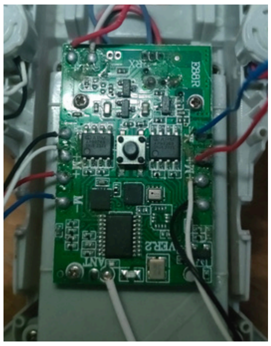
Proposed Embedded Flight Computer Module

To ixhawk 2.4.8, flight computer may not be necessary but we can embed a lightweight automation co-processor—such as an STM32F411 or RP2040—to handle higher-level tasks, freeing the main MCU to focus on flight control loops.

Features:

- High-level automation: Waypoints, grid mapping, geofencing, conditional logic.
- Sensor fusion preprocessing: e.g., optical flow filtering, rangefinder filtering.
- Peripheral control: Gimbal, payload actuation, scripting (Lua/MicroPython).
- Telemetry formatting / MAVLink bridge: Offload communication formatting.
- Failsafe isolation: Acts only via setpoints; never controls motors directly.

E88 Toy Drone Flight Controller — Circuit & Components Documentation



What interests me about this toy drone is that it has optical flow and relies solely on it for stabilization. Remarkably, it is sold in the Chinese market for just $10.

1. Main Controller IC
   - APM AP99288 (center-bottom of the PCB, QFN package):
     - This is the main flight control SoC (System on Chip).
     - Integrates:
       - A microcontroller (likely ARM Cortex-M0/M3 class).
       - Interfaces for motor control (PWM/ESC driving).
       - Communication protocols (SPI/I2C/UART).
       - Built-in stabilization logic for optical flow.
     - Role: Processes signals from the optical flow sensor, user commands (from RF receiver), and stabilizes the quadcopter by adjusting motor outputs.
2. Motor Driver ICs
   - Two identical chips visible, labeled SMJ5 2326 (H-Bridge MOSFET driver ICs):
     - Each IC drives two brushed DC motors.
     - They act as dual H-bridge motor drivers, converting the low-power control signals from the APM AP99288 into high-current outputs for the motors.
     - Role: Controls motor speed and direction for stable flight.
3. Optical Flow Sensor
   - Small black square sensor on the underside (not visible in this angle but mounted on the bottom of the PCB in E88 drones).
   - Likely a low-res CMOS sensor similar to ADNS3080 but custom-integrated.
   - Role: Captures continuous ground images → compares pixel shifts between frames → calculates drone displacement (X-Y motion).
   - This replaces a full IMU (gyro + accelerometer), so stabilization depends almost entirely on optical flow.
4. RF Receiver Section
   - The white wire labeled ANT is the antenna.
   - Next to it is an RF transceiver chip (possibly integrated into the APM99288 or a dedicated IC).
   - Role: Receives pilot commands from the remote controller (throttle, pitch, roll, yaw).
5. Supporting Components
   - Voltage regulators (small SOT-23 packages):
     - Step-down from LiPo battery (~3.7V) to required logic levels (3.3V, 1.8V).
   - Crystal oscillator:
     - Provides a stable clock for the flight controller.

Working Principle

- Pilot sends stick commands via RF transmitter.
- RF receiver (antenna + RF IC) feeds commands into APM99288.
- Optical flow sensor continuously tracks motion relative to the ground.
- APM99288 fuses pilot input + optical flow feedback → generates motor speed corrections.
- SMJ5 2326 drivers power the motors accordingly.
- LEDs provide user feedback (power on, binding, low battery).

Input and Output Summary

- Inputs:
  - Pilot commands (RF remote).
  - Optical flow sensor data.
  - Battery power (3.7V LiPo).
- Outputs:
  - Motor PWM signals → SMJ5 2326 → Motors.
  - LED control signals.
  - Stabilized flight response.

Proposed Custom Flight Computer for E88 Upgrade

Since E88 relies only on optical flow, it is unstable indoors or in low-light conditions. A better flight computer could be designed as:

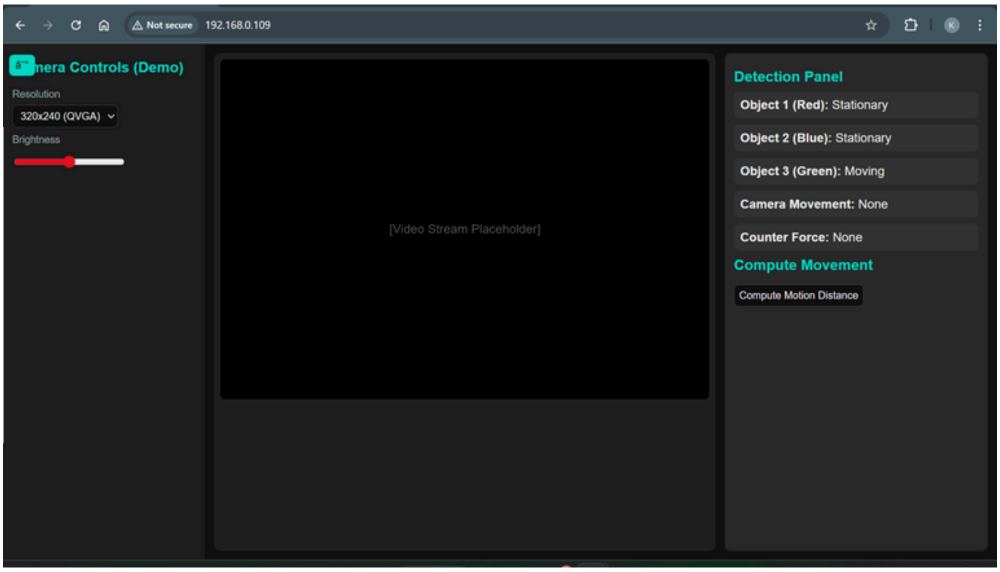
- MCU: STM32F405 or ESP32 (higher computational power, WiFi/Bluetooth).
- GPS

- Integration:
  - Fuse IMU + Optical Flow + Barometer with Kalman Filter for robust stabilization.
  - Maintain brushed motor drivers for compatibility.
- Extra features:
  - Onboard SD card logging.
  - Trajectory mapping

Optical Flow Implementation for Drone Stabilization

Optical flow is a computer vision technique that estimates motion by analyzing changes in pixel patterns between consecutive image frames. In drones, it is widely used to stabilize hovering, measure displacement, and achieve autonomous navigation, especially in GPS-denied environments. Three experimental approaches were made to implement and demonstrate optical flow: (1) ESP32-CAM, (2) ADNS3080 optical flow sensor, and (3) OpenCV with a webcam. Each attempt highlights the design, limitations, and final outcome.

First Attempt: ESP32-CAM



In the first attempt, an ESP32-CAM module was used to capture frames and perform onboard optical flow processing. However, the ESP32-CAM lacked sufficient computational power to handle real-time frame analysis. Camera initialization was also unstable, frequently failing to start streaming. Due to these limitations, this approach could not achieve stable and consistent optical flow results, leading to the attempt being considered unsuccessful.

Components Used
- ESP32-CAM module
- FTDI programmer (for uploading code)

Process
- The ESP32-CAM was programmed to initialize the onboard OV2640 camera and capture video frames.
- Image processing libraries were used to attempt motion estimation.
- Frame differencing and block-matching techniques were explored.

Issues & Failure
- Camera initialization failure occurred frequently due to unstable drivers and RAM limitations.
- The ESP32-CAM had insufficient computational power to perform real-time optical flow algorithms (e.g., Lucas-Kanade or Horn-Schunck).
- Frame rate dropped significantly, making stabilization impossible.

Conclusion
The ESP32-CAM was not suitable for standalone optical flow due to low processing capability and unreliable camera handling.

Second Attempt: ESP32-CAM with External OpenCV Processing

The third attempt combined the ESP32-CAM with OpenCV running on an external computer. The ESP32-CAM streamed video over Wi-Fi to a PC, where OpenCV performed the optical flow analysis. While this avoided the computational limitations of the ESP32, the system suffered from severe network streaming issues.

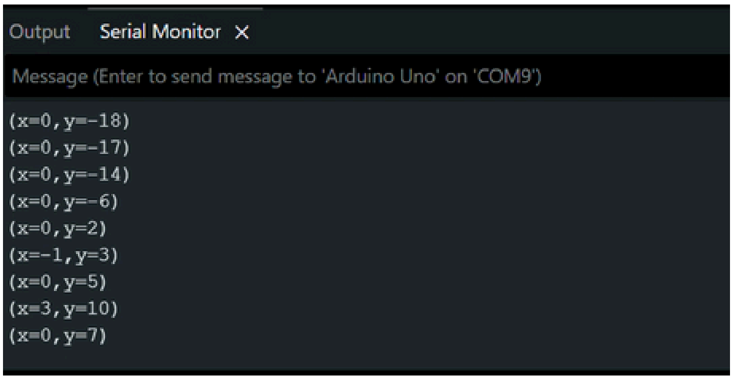
Components Used

- ESP32-CAM module
- FTDI programmer (for uploading code)

Conclusion

This hybrid setup also failed to provide practical results.

Third Attempt: ADNS3080 Sensor



Working Video: https://youtu.be/dH2UQ6pKxlM?si=SO-ub89CTPqyizNA

Objective

To use the ADNS3080 optical flow sensor (commonly used in optical mice) for lightweight motion tracking.

Components Used

- ADNS3080 Optical Flow Sensor Module
- Arduino NanoUno

Process

- The ADNS3080 was interfaced with Arduino Nano via SPI.
- The sensor outputs displacement values (ΔX, ΔY) directly, which were read and logged.
- The values were scaled and used to estimate drone displacement.

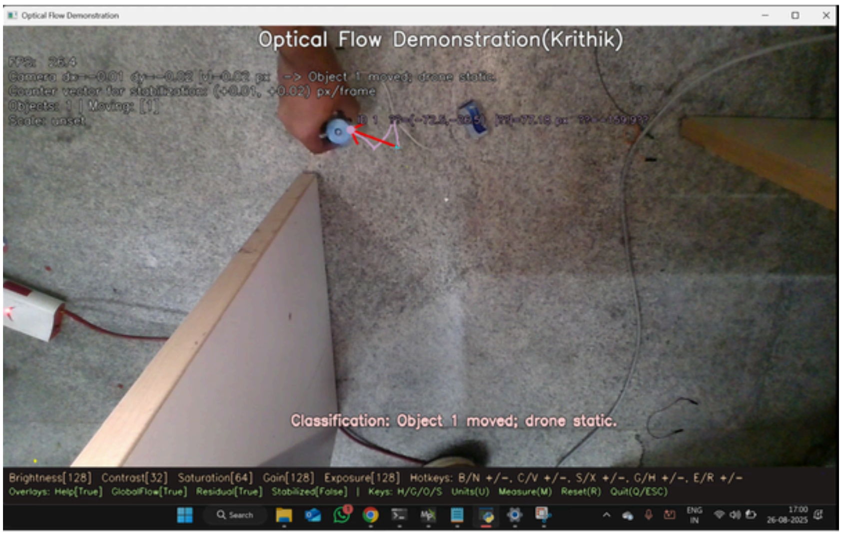
Issues & Failure

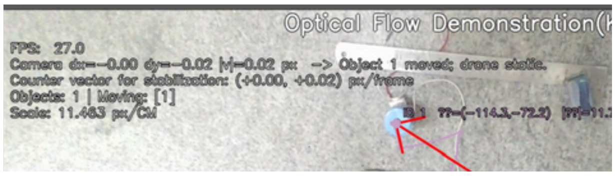
- The accuracy was poor when the drone moved over complex or low-texture surfaces.
- The sensor's low-resolution imaging (30x30 pixels) limited its effectiveness in varying lighting conditions.
- Data was too noisy to be used for stable drone control.
- The field of view was narrow, reducing robustness.

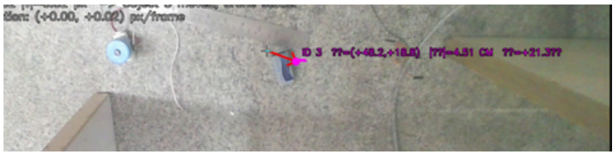
Conclusion

Although lightweight, the ADNS3080 was too inaccurate and environment-dependent, making it unreliable for drone stabilization.

Fourth Attempt — OpenCV with Webcam







Working Video: https://youtu.be/mLC3GNMDdjI?si=PFgYEV3H2usgiO5R

Objective

To implement optical flow using a webcam connected to a computer running OpenCV for real-time image processing.

Components Used

- Laptop/PC with Python & OpenCV installed
- Python libraries: cv2, numpy

Process

- The webcam captured video frames at 30 fps.
- OpenCV's built-in Lucas-Kanade Optical Flow and Farnebäck Dense Optical Flow algorithms were tested.
- Pixel displacement between frames was calculated to estimate motion vectors.
- Visualization was added by drawing flow vectors on frames.
- Results were logged and displayed with minimal lag.

Results

- Stable and accurate optical flow detection was achieved.
- Worked reliably under different lighting and textured surfaces.
- Could successfully track drone-like motions when the camera was moved.

Conclusion

The OpenCV + webcam approach was the most successful implementation, demonstrating smooth optical flow calculation and real-time visualization. While not directly embedded on a drone due to weight and power constraints, it proved the concept effectively and can be ported to more powerful onboard processors (e.g., Raspberry Pi or NVIDIA Jetson).