Drone Components and Architecture
Unit 2

Drone Technology

Gujarat Technological University

Academic Year 2024–25

Focus of Unit 2

This unit explains how the drone is physically built and how power, control signals, propulsion, energy storage, and payload systems work together as one integrated architecture.

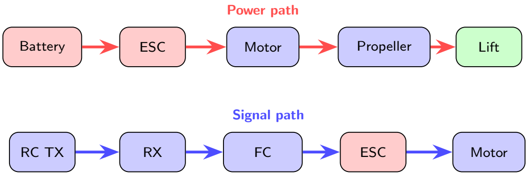
Unit 2 Roadmap: Power Path and Signal Path

Topics Covered

1. Basic block diagram of a drone system
2. Frame types and frame materials
3. Brushless DC motors and their specifications
4. Electronic speed controllers (ESCs)
5. Propellers and their selection
6. Li-Po batteries and power distribution
7. Camera, gimbal, and special payload systems

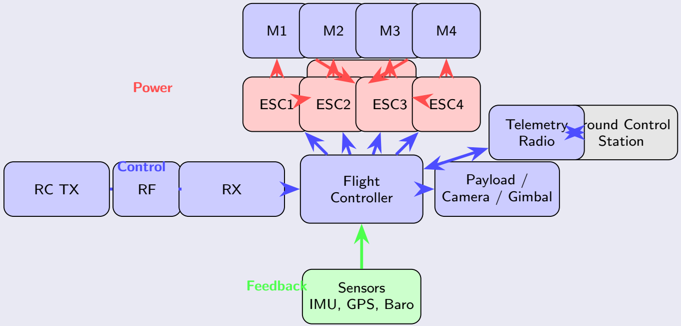
Two Fundamental Flows

Power path moves energy from battery to thrust. **Signal path** moves pilot/autopilot commands to the actuators.



2.1 Basic Block Diagram of Drone System

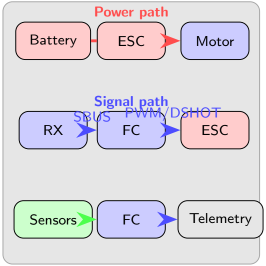
Complete Signal and Energy Architecture



Signal Path vs Power Path

Comparison of the Two Paths

Aspect	Signal path	Power path	Typical level
Purpose	Sends commands and feedback	Delivers electrical energy	Logic vs high-current
Source	RC TX / RX / FC	Li-Po battery	3.3 V, 5 V, battery bus
Form	PWM, OneShot, SBUS, CRSF, DSHOT	DC input and three-phase output	Analog/digital pulses vs current
Current	Very low	High, tens to hundreds of A	mA vs A
Failure effect	Loss of control or unstable flight	Motor stall, brownout, fire risk	Critical in both cases
Protection	Shielding, filtering, failsafe	Fuses, good soldering, proper wire gauge	EMI and heat management
Destination	ESC, FC, telemetry, payload	ESC, motors, BEC, accessories	Distributed network

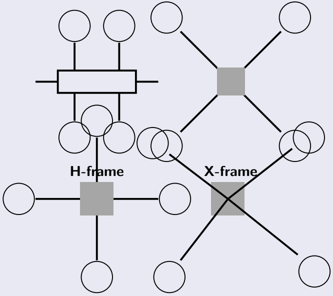


Key Insight

ESC is the bridge: it receives **low-power control signals** and converts them into **high-power timed switching** for the motor.

2.2 Frame Types: H, X, +, and Spider

Top View of Common Multirotor Frames



Use-Case Comparison

Type	Pros	Typical use
H	Large centre plate, easy payload mounting	Aerial imaging, DIY prototyping
X	Symmetric inertia, balanced control response	Racing, freestyle, general quadrotors
+	Simple front-rear orientation	Training, early autopilot experiments
Spider	Wide front view, camera clearance	FPV with unobstructed camera view

Selection Logic

Choose frame geometry based on **stability**, **camera visibility**, **payload space**, and **aerodynamic drag**. X-frame is most common because roll and pitch dynamics remain nearly identical.

Frame Materials Comparison

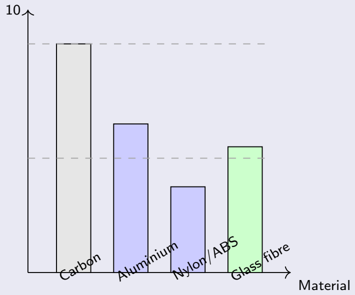
Material Selection Table

Material	Weight	Strength	Cost	Repairability	Typical use-case
Carbon fibre	Very low	Very high	High	Moderate; cracked plates replaced	Racing, professional camera drones
Aluminium	Medium	High	Medium	Good; bent parts can be replaced	Educational and custom fabrication
Nylon / ABS	Low	Low–medium	Low	Easy, but less durable	Toy drones, prop guards, housings
Glass fibre	Medium	Medium	Low–medium	Fair; brittle under impact	Budget hobby frames

Engineering Trade-off

Carbon fibre offers the best **strength-to-weight ratio**, but it is electrically conductive and can transmit vibrations sharply. Plastic parts are cheap and safe, but they flex and reduce control precision.

Strength-to-Weight Ratio (relative)



Practical Rule

For high-performance quadrotors, frame stiffness is valuable because flexing changes motor alignment and increases oscillation.

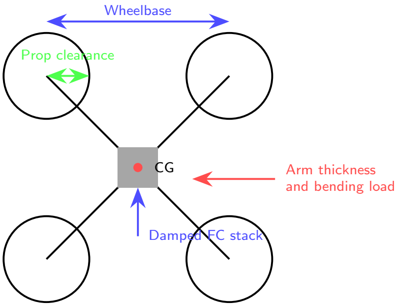
Frame Design Considerations

Key Design Parameters

- **Wheelbase**: motor-to-motor distance affects stability and prop size.
- **Prop clearance**: blades must not overlap or strike the frame.
- **Vibration damping**: FC and camera should be isolated from motor vibration.
- **Centre of gravity (CG)**: battery and payload should sit near the geometric centre.
- **Arm thickness**: must carry bending load during thrust and landing impact.
- **Wire routing**: keep signal lines away from noisy power traces where possible.

Design Insight

A larger wheelbase usually gives smoother flight and larger propellers, while a smaller wheelbase improves agility and reduces mass.



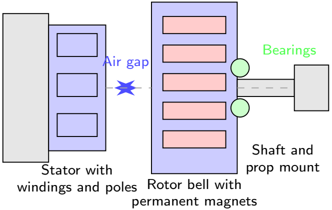
2.3 Brushless DC Motor: Construction

Main Parts of a BLDC Motor

- **Stator**: fixed laminated iron core with copper windings.
- **Rotor bell**: rotating outer shell carrying permanent magnets.
- **Shaft**: transmits torque to the propeller hub.
- **Bearings**: allow low-friction rotation.
- **Base and mount**: connect the motor to the arm.

Why Brushless?

There are no physical brushes or commutator contacts. Electronic commutation by the ESC eliminates sparking, reduces wear, and improves efficiency.



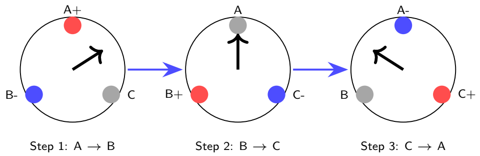
BLDC Motor Working Principle

How Rotation is Produced

- The ESC energises phase windings **A, B, C** in sequence.
- This creates a **rotating magnetic field** in the stator.
- Rotor magnets align with the moving field and continue rotating.
- Commutation repeats rapidly, giving smooth continuous motion.

Why No Brushes Are Needed

In brushed motors, the commutator switches current mechanically. In BLDC motors, the ESC performs the switching electronically using transistor bridges.



BLDC Motor KV Rating

Definition and Formula

KV rating tells how many revolutions per minute (RPM) a motor attempts to produce per volt under no-load conditions.

$$\mathrm{RPM} \approx KV \times V_{\text{battery}}$$

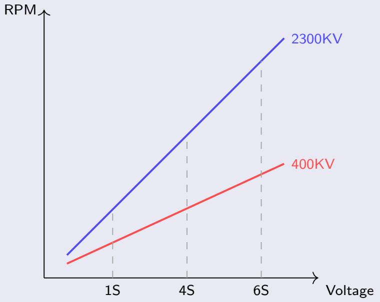
Worked Examples

- **2300KV on 4S**: $V \approx 14.8$ V, so RPM $\approx 2300 \times 14.8 = 34{,}040$ RPM
- **400KV on 6S**: $V \approx 22.2$ V, so RPM $\approx 400 \times 22.2 = 8{,}880$ RPM

High KV vs Low KV

Type	Prop	Torque	Efficiency	Use-case
High KV	Small	Lower	Lower at hover	Racing, freestyle
Low KV	Large	Higher	Better cruise efficiency	Cinema, mapping, lift

RPM vs Battery Voltage



Important Caveat

Real loaded RPM is lower because propeller drag, winding resistance, and battery sag reduce speed from the ideal no-load value.

Motor Specifications and Selection

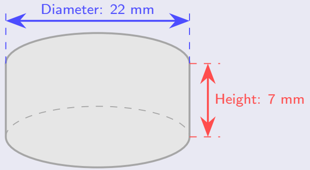
Reading Motor Datasheets

Motor	Stator	KV	Max I	Wt.	Typical use
1104	11 mm × 4 mm	7500	8 A	5 g	Tinywhoop / micro
2207	22 mm × 7 mm	2300	35 A	31 g	5-inch freestyle
2212	22 mm × 12 mm	920	18 A	55 g	450-size trainer
2806.5	28 mm × 6.5 mm	1300	40 A	44 g	7-inch long range
3510	35 mm × 10 mm	700	45 A	82 g	Heavy-lift multirotor

Stator Size Notation

2207 means approximately **22 mm stator diameter** and **7 mm stator height**. Larger stator volume generally means more copper, stronger magnetic interaction, and higher torque capability.

Stator Size (e.g. 2207)



Selection Rule

Select motor, propeller, and battery together. A motor that is efficient with a 10-inch prop may overheat with the same voltage if fitted with a 12-inch prop.

Functions of an ESC

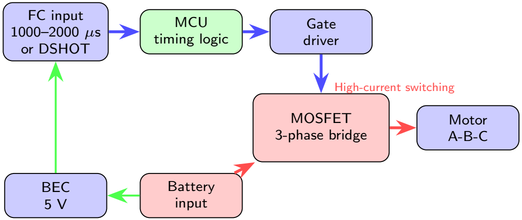
- Receives motor command from FC as PWM, OneShot, or DSHOT.
- Switches MOSFETs to create controlled three-phase power.
- Regulates motor speed, startup, braking, and protection.
- Some ESCs include a **BEC** to provide 5 V for FC or receiver.

Current Rating Selection

ESC current rating should exceed the motor's peak current with safety margin. Example: a motor drawing 32 A should use at least a 35–45 A ESC.

Braking Modes

Passive braking lets the motor coast down. **Active braking** (damped light) quickly slows the propeller and improves control responsiveness.



ESC Calibration and Connection

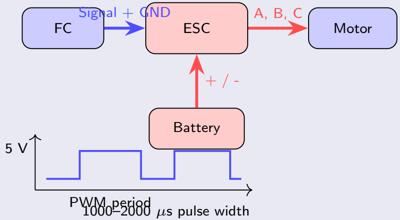
Typical PWM ESC Calibration Procedure

1. Remove propellers for safety.
2. Power transmitter and set throttle to maximum.
3. Connect battery to the ESC.
4. ESC beeps to indicate calibration mode.
5. Move throttle to minimum.
6. ESC stores high and low pulse widths.

Why Calibration Matters

It aligns the FC/transmitter pulse range with the ESC so that all motors start together and reach full throttle consistently.

Wiring and Output



Three-Phase Reversal

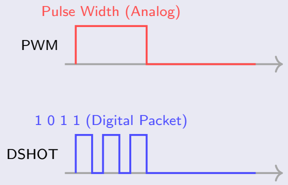
Swap any two of the three motor wires to reverse motor direction if ESC firmware does not provide software reversal.

ESC Protocols Comparison

Command Protocols from FC to ESC

Protocol	Type	Latency	Resolution	Noise immunity
PWM	Analog pulse	Highest	Limited by pulse width	Moderate
OneShot125	Analog pulse	Lower than PWM	Better update rate	Moderate
MultiShot	Analog pulse	Very low	Good	Sensitive to noise
DSHOT300	Digital	Low	Exact digital command	High
DSHOT600	Digital	Very low	Exact digital command	High
DSHOT1200 / 2400	Digital	Lowest on supported hardware	Exact digital command	High

PWM vs DSHOT Waveform

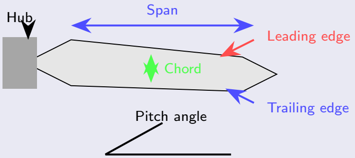


Where Used

Racing and freestyle quads prefer DSHOT600 or faster because rapid throttle changes demand clean low-latency control.

2.5 Propellers: Anatomy and Lift Generation

Annotated Propeller Blade



How Lift Is Produced

- A rotating blade accelerates air downward.
- The aerofoil shape and pitch create pressure difference between upper and lower surfaces.
- By Newton's third law, downward momentum of air produces upward thrust.
- Bernoulli explanation helps visualise pressure difference, but real propeller analysis also includes momentum theory.

Blade Element Theory (concept)

A propeller blade can be imagined as many small airfoil elements. Each radius section experiences different local speed and generates different lift and drag.

Propeller Notation and Performance Trends

Reading Propeller Size

10×4.5 means:

- **Diameter = 10 inch**
- **Pitch = 4.5 inch** theoretical forward advance per revolution
- Optional third number indicates **blade count**, e.g. 5×4.3×3

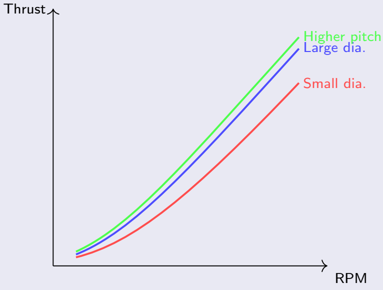
Effect of Parameters

- Larger diameter ⇒ more thrust at low RPM, better efficiency, more inertia
- Higher pitch ⇒ stronger high-speed pull, but more drag and current draw
- 3-blade props ⇒ more grip and response, but lower efficiency than 2-blade in cruise

2-Blade vs 3-Blade

Two-blade props suit endurance and low current draw. Three-blade props are popular for freestyle because they hold authority in turns and rapid throttle changes.

Indicative Thrust vs RPM



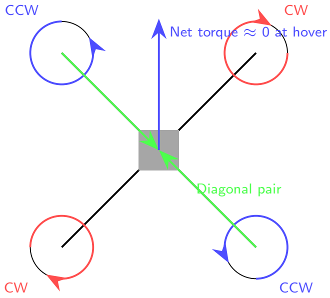
CW and CCW Propeller Pairs

Why Two Clockwise and Two Counter-Clockwise?

- A spinning propeller creates a reaction torque on the frame.
- If all four props rotated the same way, the drone body would spin in the opposite direction.
- Using **2 CW + 2 CCW** cancels net yaw torque during hover.
- Yaw control is achieved by increasing torque on one pair and decreasing torque on the opposite pair.

Identification

Reverse props often carry an **R** suffix or opposite airfoil orientation. Colour rings and embossed arrows also help identify rotation direction.



Propeller Materials and Safety

Material and Failure Modes

Material	Behaviour	Failure mode	Typical application
Carbon fibre	Stiff, sharp response	Delamination, brittle fracture	Racing, cinema, high-speed quads
Plastic	Cheap, flexible	Tip breakage, warp, hub crack	Trainers, toy drones, indoor use
Wood	Smooth damping	Splitting with moisture or impact	Traditional model aircraft

Safety Rules

- Inspect props before every flight for cracks, chips, loose hubs, or imbalance.
- Never arm near people; propellers can cause severe cuts.
- Use **prop guards** for indoor training, education, and close-range inspection work.
- Replace props after hard crashes even if damage seems minor.

Indicative Static Thrust

Prop	Motor class	Thrust
5 inch	2207 / 2300KV	0.9–1.3 kg
10 inch	2212 / 920KV	0.7–1.0 kg
15 inch	3510 / 700KV	1.8–2.8 kg

Interpretation

Bigger props can produce much more thrust, but they also require lower KV motors, stronger arms, and more careful transport and handling.

2.6 Li-Po Battery: Construction and Chemistry

Why Li-Po for Drones?

- High energy density compared with older NiMH packs
- High discharge capability for fast current bursts
- Flat pouch form factor fits multirotor frames well
- Lower weight than equivalent capacity lead-acid or NiMH packs

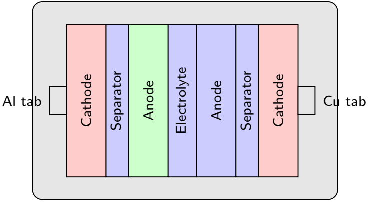
Internal Layers of One Cell

- **Cathode**: lithium metal oxide
- **Anode**: graphite
- **Separator**: porous film preventing short circuit
- **Electrolyte**: lithium-ion conducting medium

Li-Po vs Li-ion

Li-ion cylindrical cells offer very high energy density, but Li-Po packs deliver higher burst current, which is why they dominate high-thrust drones.

Pouch cell stack



Li-Po Battery Specifications and Worked Example

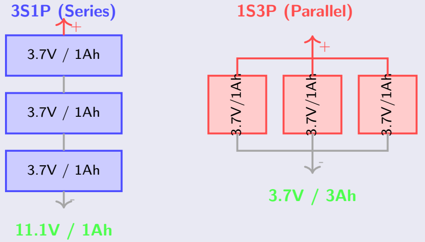
Meaning of Ratings

- **S rating**: number of cells in **series**; raises voltage
- **P rating**: number of cells in **parallel**; raises capacity/current capability
- **Capacity**: charge stored, usually in mAh
- **C rating**: maximum discharge multiple of capacity
- **IR**: internal resistance; lower IR means better voltage stability under load

Worked Example: 4S2P 5000mAh 30C

- Series cells: 4 $\Rightarrow$ nominal voltage $= 4 \times 3.7 = 14.8$ V
- Parallel cells: 2 $\Rightarrow$ pack capacity $= 5000$ mAh $= 5$ Ah
- Maximum discharge current $= 30 \times 5 = 150$ A
- Energy $= 14.8 \times 5 = 74$ Wh

Series vs Parallel Topology



Pack Voltage Reference

3S $\approx$ 11.1 V, 4S $\approx$ 14.8 V, 6S $\approx$ 22.2 V (nominal values).

Li-Po Charging and Balancing

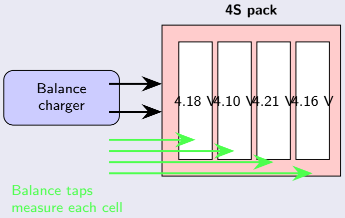
Good Charging Practice

- Use a charger designed for Li-Po chemistry.
- Prefer **balance charge** mode so every cell reaches the same final voltage.
- Follow the **1C rule** unless manufacturer clearly allows higher rate.
- Connect both the **main power lead** and the **balance connector**.

Charger Types

Common smart chargers include iCharger and SkyRC units. They measure per-cell voltage and terminate charge safely at about 4.2 V per cell.

Balance Charging Concept



Li-Po Safety and Storage

Common Failure Causes and Prevention

Issue	Cause	Risk	Prevention
Swelling	Gas from overcharge / aging	Internal damage, fire	Stop using pack immediately
Puncture	Crash, sharp object	Thermal runaway	Protect pack, inspect after crash
Over-discharge	Flying below safe voltage	Cell damage, loss of capacity	Land early, use voltage alarm
Overheating	High current or poor airflow	Fire, fast aging	Match C rating and allow cooling
Storage at full charge	Long-term chemical stress	Capacity loss	Store near 3.8 V per cell

Critical Safety Rules

- Never fly or charge a swollen battery.
- Store packs in a Li-Po bag or metal safety box.
- Never short the main leads.
- Dispose of damaged packs responsibly after safe discharge.

Storage Voltage

Keep the battery near **3.8 V/cell** for long-term storage. This reduces stress compared with full charge (4.2 V/cell) or deep discharge.

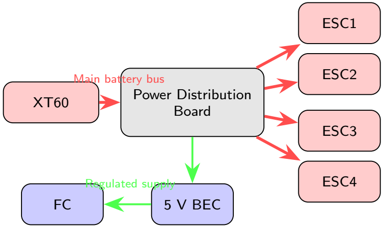
Power Distribution Board (PDB)

Role of the PDB

- Splits battery power to multiple ESCs from one main connector.
- Provides **common positive and common ground** rails.
- May include current sensor, voltage sense, and **BEC output**.
- Simplifies wiring and reduces heavy wire clutter.

Connector and Current Rating

XT60 is common for medium quadrotors. Heavy-lift drones may use XT90 or anti-spark connectors. PDB copper thickness must support expected current safely.



Battery Selection Guide

How to Choose a Battery

1. Estimate all-up weight and required thrust-to-weight ratio.
2. Calculate peak current from all motors together.
3. Choose voltage level: 3S for gentle trainers, 4S for general quads, 6S for high-performance or efficient high-power setups.
4. Check C rating so pack can safely supply peak current.
5. Use endurance formula:

$$T(\text{min}) \approx \frac{C_{\text{mAh}} \times 0.8}{I_{\text{avg}} \times 1000} \times 60$$

Worked Example

Drone uses average current of **22 A**. Choose **4S 3000mAh 50C** pack.

- Max discharge $= 3 \times 50 = 150$ A
- Enough for a quad with peak demand below 150 A
- Estimated flight time:

$$T \approx \frac{3000 \times 0.8}{22 \times 1000} \times 60 \approx 6.5 \text{ min}$$

Design Balance

A very large battery improves endurance but increases total weight, requiring more thrust and often cancelling the expected gain.

2.7 Camera Systems for Drones

Major Camera Types

Type	Example	Weight	Use-case	Approx. cost
Action camera	GoPro Hero	120–160 g	FPV footage, adventure video	Rs. 25,000–40,000
Drone camera	DJI Zenmuse	150 g to >1 kg	Survey, cinema, enterprise	Rs. 80,000 and up
Thermal / IR	FLIR Vue / Boson	90–250 g	Inspection, rescue, firefighting	Rs. 1.5 lakh and up
Multispectral	MicaSense	200–450 g	Agriculture, crop health mapping	Rs. 3 lakh and up
LiDAR	Compact UAV LiDAR	500 g to >1.5 kg	Terrain, corridor mapping	Rs. 5 lakh and up

Selection Criteria

- Resolution and sensor size
- Weight and power draw
- Stabilisation needs
- Required data product: video, thermal map, NDVI, point cloud

Examples

Action cameras prioritise image quality. **Thermal cameras** detect heat leakage. **Multispectral cameras** support precision agriculture.

3-Axis Gimbal Construction

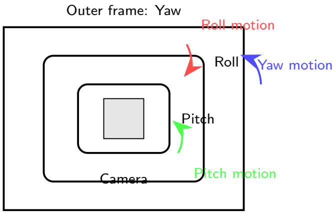
- Separate motors control **roll**, **pitch**, and **yaw** axes.
- Built-in **IMU** senses angular disturbance.
- Controller drives motors to keep the camera stable with respect to the horizon.

2-Axis vs 3-Axis

2-axis gimbals stabilise roll and pitch only. 3-axis gimbals add yaw isolation and produce smoother cinematic footage during turns.

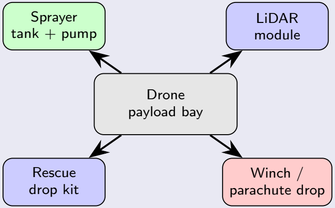
Gimbal Lock Note

Large rotations can align axes and reduce control freedom. Good mechanical layout and control software minimise such singularity issues.



Additional Payload Systems

Modular Payload Bay Concept



Examples of Mission Payloads

- **Agricultural sprayer**: tank, nozzles, pump, controlled flow rate in L/min.
- **LiDAR**: emits laser pulses and builds 3D point cloud for terrain or asset mapping.
- **Rescue payload**: flotation aid, medicine, or radio beacon delivery.
- **Delivery mechanism**: winch or parachute release for contactless drop.

Design Challenge

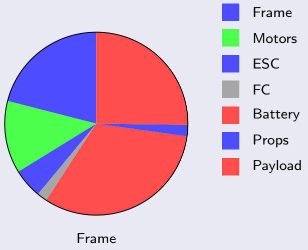
Extra payload changes CG, power demand, flight time, and structural load. Payload integration must therefore be checked at the system level.

Component Weight Budget Example

Example Quadrotor Weight Budget

Component	Weight (g)	Share
Frame	210	21.0%
4× motors	128	12.8%
4× ESC	52	5.2%
Flight controller	18	1.8%
Battery	320	32.0%
Propellers	20	2.0%
Payload	252	25.2%
Total	**1000**	**100%**

Weight Distribution Pie Chart



Interpretation

Battery and payload dominate the mass budget. If payload increases, either thrust must rise or endurance must fall.

Complete Drone Assembly Checklist

Assembly Order

1. Build frame and arms
2. Mount motors
3. Install ESCs or 4-in-1 ESC
4. Connect PDB or main battery leads
5. Mount flight controller and vibration dampers
6. Connect receiver, GPS, telemetry, camera, buzzer
7. Route antennas and secure wires
8. Fit propellers only after configuration checks
9. Install payload and verify CG

Testing Sequence

- Continuity check before connecting battery
- Power up without props
- Verify FC orientation, radio mapping, and failsafe
- Test motor order and spin direction
- Check sensor calibration, GPS lock, and battery voltage reading
- Hover test in open area before mission use

Useful Tools

Hex keys, soldering station, multimeter, thread locker, heat shrink, cable ties, prop wrench, and smoke stopper for first power-up.

Summary and Review Questions

Key Takeaways from Unit 2

- A drone is an integrated system of **frame, propulsion, control, power, and payload**.
- Frame geometry and material affect stiffness, mass, and mission suitability.
- BLDC motors and ESCs form the electromechanical heart of the quadrotor.
- Propeller size, pitch, and rotation direction strongly affect thrust and stability.
- Li-Po batteries demand correct decoding, charging, and safety handling.
- PDB and wiring quality are crucial for reliable high-current power delivery.
- Payloads such as cameras, gimbals, sprayers, or LiDAR change the entire design budget.

Review Questions with Hints

1. Draw the basic block diagram of a quadrotor. *Hint: show both power and signal flow.*
2. Compare X-frame and H-frame designs. *Hint: think about symmetry and payload space.*
3. What does a 2207, 2300KV motor specification mean? *Hint: stator size and speed per volt.*
4. Why is DSHOT preferred over PWM? *Hint: digital command and telemetry.*
5. Explain propeller notation 10×4.5. *Hint: diameter and pitch.*
6. Calculate max current of a 4S 5000mAh 30C pack. *Hint: convert mAh to Ah first.*
7. Why must quadrotors use both CW and CCW propellers? *Hint: reaction torque cancellation.*
8. Estimate flight time using average current and battery capacity. *Hint: use only about 80% usable capacity.*