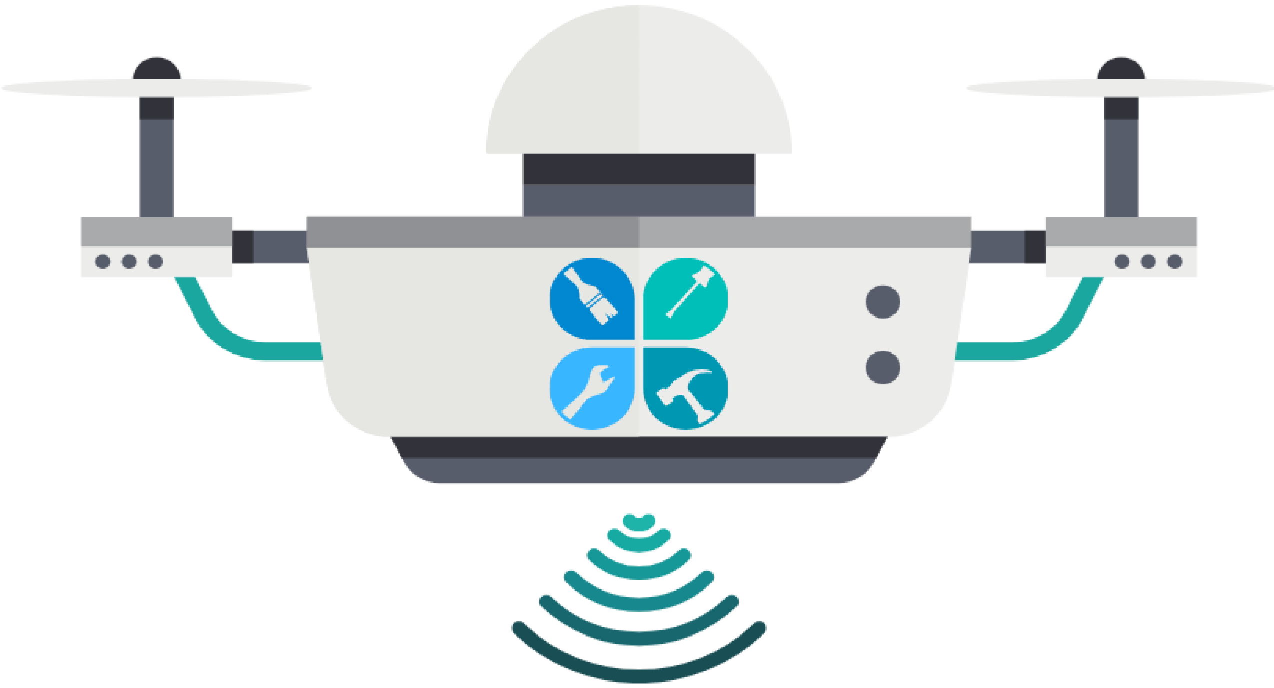
UAVET



HANDBOOK

FOR UAV REPAIR AND MAINTENANCE TECHNICIANS

DEVELOPING VOCATIONAL SKILLS OF ELECTRO-MECHANICAL TECHNICIANS FOR UAV MAINTENANCE AND REPAIR

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Developing Vocational Skills of Electro-Mechanical Technicians for UAV Maintenance and Repair

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2.1.2. Visual Resources

Other than the visuals taken by the partnership consortium members, we acknowledge the use of visuals from Canva (Pro version), Pixabay and Pexels under their respective licences and extend our thanks to those platforms for their valuable efforts to provide us with quality visual materials. Some of the drone component illustrations in this book were generated using OpenAI's GPT 4.0. Their use complies with OpenAI's content and usage policies.

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INTRODUCTION

The purpose of the handbook

Welcome to the UAVET Digital Handbook on drone repair and maintenance! This handbook is one of the key outcomes of the UAVET project, alongside the Occupational Standards E-Book, the UAVET Training Programme, and the Video Tutorials. It is a user-friendly and easy-to-digest resource, carefully developed to serve as a practical and comprehensive guide for vocational education and training (VET) students and graduates who aspire to build a career as drone repair and maintenance technicians.

The digital handbook is designed not only to teach theory, but it also integrates practical applications to improve the learning experience, enabling users to engage with the material precisely. This practice-oriented approach makes it not only a source of information but also an effective teaching and learning resource that bridges the gap between theory and practice.

Our goal is to empower young people by equipping them with the technical know-how and hands-on experience required to confidently enter the drone maintenance sector. Additionally, we want to support vocational schools and training providers in delivering high-quality education tailored to the needs of the drone industry.

The handbook is structured into five core chapters:

1. **UAV System Components,**
2. **Troubleshooting,**
3. **Maintenance Procedures,**
4. **Repair and Component Replacement Procedures**
5. **Documentation and Communication.**

CHAPTER 1

UAV System Components

In this chapter, you will find the introductory and general descriptions of the UAV system components before the detailed explanations about their smaller parts in the following chapters.

1.1. Airframe

Figure 1.1 *UAV airframe*

The airframe serves as the structural backbone of any UAV, supporting and integrating all major subsystems, such as propulsion, avionics, power, and payload. Its design directly impacts the aircraft's aerodynamic performance, flight efficiency, and overall durability.

Depending on the mission profile, airframes can vary significantly in shape and configuration, ranging from multirotor setups (such as quadcopters or hexacopters) to fixed wing or hybrid VTOL designs. Materials like carbon fiber, reinforced composites, and lightweight aluminium alloys are typically used to strike a balance between strength, weight, and resilience.

A well-engineered airframe is critical to ensuring stable flight characteristics, system reliability, and the successful integration of advanced UAV technologies.

1.2. Propulsion system (motors, ESCs, propellers)

Figure 1.2 *UAV propellers (Resource owner: DRONINT)*

The propulsion system is responsible for generating the thrust that enables a UAV to take off, manoeuvre, and maintain a stable flight. At the heart of this system are brushless DC motors, known for their efficiency, reliability, and high power-to-weight ratio, making them ideal for aerial platforms.

These motors drive the propellers, which are specifically engineered to manipulate airflow and produce lift. The number and orientation of propellers vary depending on the UAV's configuration, ranging from single-rotor platforms to quadcopters, hexacopters, or even octocopters for heavy-lift applications.

The Electronic Speed Controllers (ESCs) serve as the link between the flight controller and the motors. They regulate the rotational speed and direction of each motor based on real-time input, allowing the UAV to execute precise throttle adjustments and coordinated flight manoeuvres.

Together, motors, ESCs, and propellers form a tightly integrated system that determines the UAV's responsiveness, stability, and flight performance.

1.3. Power system (batteries, charging, power distribution)

The power system is the UAV's electrical core, responsible for delivering energy to every critical component, from motors and flight controllers to cameras and communication links. At the heart of this system are lithium polymer (LiPo) batteries, which represent one of the most important innovations in modern drone technology.

They offer an ideal balance of high energy output and low weight, making it possible for UAVs to stay airborne longer without compromising performance. Simply put, these batteries have redefined what's possible in terms of flight time and payload capacity.

Figure 1.3 *UAV batteries (Resource owner: DRONINT)*

A well-designed power system goes beyond just plugging in a battery. Safe charging is essential. LiPo batteries require balance charging to ensure all cells maintain equal voltage, which helps extend battery life and reduces the risk of overheating or failure. Onboard, power distribution boards (PDBs) or integrated power modules route electricity where it's needed, often using voltage regulators to supply clean, stable power to sensitive systems like the autopilot and telemetry.

Professional-grade drones also include real-time power monitoring, so pilots and onboard systems can track voltage, current, and remaining capacity during flight. This allows for smart decisions, like triggering a return-to-home before the battery is too low, and is critical for avoiding crashes and ensuring mission success.

1.4. Flight control system (autopilot, sensors, GPS)

The flight control system is the brain of the UAV. It is responsible for interpreting sensor data, executing flight commands, and keeping the aircraft stable and responsive in all conditions. At the centre of this system is the Flight Controller, often referred to as the drone's motherboard. It's where all the data from sensors, GPS, and user inputs converge, and from where all critical decisions are made during flight.

Figure 1.4 *UAV Flight Controller (Resource owner: DRONINT)*

The autopilot software, typically integrated into the flight controller, manages both manual and autonomous operations. It stabilizes the drone, manages orientation (pitch, roll, and yaw), and executes pre-programmed flight paths or waypoint missions. Whether the drone is flying manually or autonomously, the autopilot ensures smooth and coordinated control, even in dynamic environments.

To support precise flight behaviour, the controller relies on a suite of embedded sensors:

- Gyroscopes and accelerometers that monitor angular movement and linear acceleration for balance and stability.
- Magnetometers that act as digital compasses, keeping the drone correctly oriented relative to Earth's magnetic field.
- Barometers and altimeters that provide accurate altitude data.
- GPS modules, which are often coupled with IMU (Inertial Measurement Unit) fusion, and deliver real-time positional data, enabling functions like autonomous navigation, return-to-home, and geo-fencing.

Together, these components form a tightly integrated system that gives the drone its ability to fly precisely, respond quickly, and carry out complex missions with minimal human input. Without a robust flight control system, safe and reliable drone operation simply wouldn't be possible.

1.5. Communication system (RC, telemetry)

A UAV's communication system is what connects the drone to the pilot or ground control station (GCS), making real-time control and monitoring possible. It operates through a combination of radio control (RC) links and telemetry data links, both of which are essential for safe and effective operation.

The RC link allows the operator to manually control the drone's movements, typically using frequencies like 2.4 GHz or 5.8 GHz. More advanced systems may use long-range RF or even satellite communication for beyond-visual-line-of-sight (BVLOS) missions. These links are secured and optimized for low latency, ensuring immediate responsiveness to pilot commands.

Figure 1.5 *UAV Telemetry*

Telemetry, on the other hand, is the drone's feedback channel. It continuously transmits critical flight data back to the GCS, including GPS position, altitude, speed, heading, battery voltage, motor status, and sensor readings. This stream of information typically originates from the autopilot and onboard sensors, such as gyroscopes, accelerometers, magnetometers, and the power system. It enables the pilot or mission operator to monitor the UAV's status in real time and respond proactively to anomalies, such as low battery, signal loss, or geofence violations.

Communication is usually handled via antennas mounted on both the UAV and the ground station, with some systems incorporating directional or diversity antennas to maintain signal integrity over longer distances.

In professional applications, reliable communication is non-negotiable. Whether the drone is flying manually or executing a fully autonomous mission, robust data links are what ensure full situational awareness, compliance with safety protocols, and mission success.

1.6. Remote Controller / Ground Control Station (GCS)

The Remote Controller or Ground Control Station (GCS) is the human-machine interface of the UAV system. It is where UAV operators monitor telemetry, plan missions, and issue real-time flight commands. Whether it's a handheld controller with integrated display or a full-scale laptop-based GCS, this component is essential for both manual and autonomous operations.

Figure 1.6 *UAV Remote Controller (Resource owner: DRONINT)*

Modern GCS setups typically include:

- Live telemetry visualization (e.g., altitude, speed, heading, battery status)
- Real-time video feed from onboard cameras
- Mission planning interfaces, allowing users to predefine waypoints and geofences
- Manual override controls for emergency interventions or precision tasks

The remote controller, often used in field operations, is typically equipped with dual joysticks, customizable buttons, and a high-brightness screen for viewing telemetry and video. It may also connect to tablets or smartphones running specialized flight apps. More advanced GCS configurations are used in control rooms or mobile command vehicles, featuring multiple screens, long-range antennas, and redundant communication links.

These systems also support critical Command and Control (C2) functions such as:

- Return-to-home (RTH) in case of signal loss
- Failsafe settings (e.g., auto-landing, hover, hold position)
- Integration with airspace management platforms, allowing safe operation in complex environments

Ultimately, the GCS acts as the central nervous system of any UAV mission, combining situational awareness, manual control, and autonomous flight management in one integrated hub.

1.7. Payloads (cameras, sensors, etc.)

Payloads are the mission-specific tools carried by a UAV. They define what the drone is actually used for, whether it's mapping farmland, inspecting infrastructure, or conducting search and rescue. The most common payloads are cameras and sensors, but these vary widely in type and complexity depending on the application

Figure 1.7 *UAV Camera (Resource owner: DRONINT)*

Cameras are often the primary payload and can be either fixed or detachable. Many drones are designed with modular payload bays, allowing operators to quickly swap out cameras or sensors depending on the task. The camera itself can range from a standard RGB sensor for photography and videography, to highly specialized systems such as:

- Multispectral cameras for agricultural and vegetation analysis.
- Thermal or infrared imagers for heat mapping, search & rescue, or inspection of electrical components.
- LiDAR systems for high-precision 3D mapping and terrain modeling.

Beyond imaging, drones can also carry air-quality sensors, radiation detectors, or environmental monitors for scientific and industrial missions. The modularity and flexibility of modern UAV payload systems allow a single platform to support a wide variety of missions simply by changing out the sensor package. Ultimately, the payload is what gives the drone its purpose, and choosing the right one is critical to the success of any aerial operation.

CHAPTER 2

Troubleshooting

2.1. Introduction: Scope and Rationale

Effective troubleshooting is fundamental to maintaining operational readiness and flight safety in unmanned aerial vehicle (UAV) operations. This chapter provides a comprehensive framework for identifying, diagnosing, and resolving the most frequently encountered UAV malfunctions that can compromise mission success and aircraft integrity. The systematic approach outlined here encompasses the recognition of malfunction symptoms, application of diagnostic procedures, and utilization of specialized tools to ensure rapid problem resolution.

The chapter's scope covers essential troubleshooting methodologies, from basic symptom identification to advanced diagnostic techniques using flight logs and error code interpretation. Structured flowcharts guide technicians through logical problem-solving sequences, while sensor calibration procedures ensure optimal system performance. This systematic methodology enables drone technicians to minimize aircraft downtime and maintain the highest standards of operational safety and reliability. Figure 2.1 serves as a symbolic representation illustrating the process of identifying and resolving issues within drone systems.

Figure 2.1 *Troubleshooting in drones*

Troubleshooting in drones involves a structured process before, during, and after flight. Table 2.1 outlines troubleshooting procedures tailored to different phases of drone operations. Pre-flight inspection includes visual checks for physical damage or looseness, system diagnostics via software, sensor calibration (IMU, compass, GPS), firmware and software status verification, and environmental evaluations like weather and GPS signal quality.

Table 2.1 *Troubleshooting procedures according to drone operations phases*

Pre-flight Inspection	In-flight Monitoring	Post-flight Analysis
Visual checks	Real-time telemetry analysis	Log reviews
System diagnostics	Onboard alerts	Performance comparisons
Sensor calibration	Flight behavior observation	Component inspection
Firmware/software status		Data backup & reporting
Environmental check		Issue classification

In-flight monitoring focuses on real-time telemetry analysis of key parameters such as voltage, temperature, and altitude, tracking onboard alerts, and observing any abnormal flight behavior. Post-flight analysis involves reviewing flight logs, comparing expected and actual performance, rechecking components, backing up data and generating reports, and classifying identified issues into software, hardware, or user-related categories.

2.2. Issues Frequently Encountered in UAV

2.2.1. Common Malfunctions in UAV Propulsion System

The UAV's propulsion system consists of the motor, ESC, and propellers. Brushless motors are responsible for turning the propellers to lift the UAV into the air, and their speed is directly related to the kV value. Propellers are thrust generating components and their size and pitch are important parameters. They can rotate clockwise or counterclockwise. Electronic Speed Controllers (ESCs) are electronic circuits that adjust the rotational speed of the motors according to signals from the flight controller.

Motor malfunctions can arise from various causes, each affecting performance and reliability. Overheating is the most frequently encountered issue, often resulting from intensive use, insufficient cooling, or overloading the motor. Debris ingress is another common problem, especially in drones operating outdoors, where particles like sand, dust, or grass clippings can enter the motor. Damaged bearings may occur due to prolonged use, vibration, or physical impacts, leading to increased friction and reduced efficiency. Bent or misaligned shafts often result from crashes, hard landings, or imbalanced propellers, which can disrupt smooth motor operation. Burnt windings, caused by excessive current, short circuits, or continuous overloading, can lead to complete motor failure. Lastly, although magnet deterioration is the least common, it may occur due to prolonged exposure to high temperatures or natural aging, reducing the motor’s magnetic strength and performance. Table 2.2 shows a detailed overview of the common malfunctions observed in the propulsion system of UAVs.

ESC malfunctions can arise from various causes. Overheating is a common issue, often due to insufficient cooling or excessive current draw, which can damage internal components. Failures in MOSFETs or capacitors, essential power-handling parts, may result in complete burnout. Poor solder joints are another risk, especially when exposed to constant vibration and heat, leading to intermittent or total disconnection. Signal issues, such as corruption or loss of the PWM signal from the flight controller, can disrupt proper ESC function.

Table 2.2 *The most common malfunctions in the propulsion system of UAVs*

PROPULSION SYSTEM OF UAVS

		
Motor	**ESC**	**Propeller**
Overheating	Overheating	Cracks & cuts
Debris ingress	Poor solder joints	Wear
Damaged bearings	Signal loss	Propeller strike damage
Bent or misaligned shaft	Calibration issues	Deformation
Burnt winding	Power supply problems	Incorrect mounting
Magnet deterioration	Motor synchronization issues	Imbalance
	Moisture damage	Looseness

Firmware bugs or improper calibration may introduce software-related errors that affect performance. Power supply problems, including voltage fluctuations or a failing BEC (Battery Eliminator Circuit), can destabilize the ESC. Motor synchronization issues, typically related to timing mismatches, can cause erratic motor behavior. Finally, water or moisture intrusion may lead to short circuits and corrosion, further compromising ESC reliability.

Propeller malfunctions in UAVs can arise from a variety of issues that compromise flight safety and performance. Cracks and cuts on the blades often result from impacts with foreign objects or prolonged use, leading to structural weaknesses. General wear can degrade material integrity over time, increasing the risk of failure during operation. Propeller strike damage, typically caused by collisions with hard surfaces, can lead to visible or hidden fractures. Deformation of the propeller, whether from heat or impact, affects aerodynamic efficiency and stability. Incorrect mounting may cause misalignment, while imbalance in the propeller can result in vibrations that stress the motor and frame. Additionally, looseness in the propeller attachment can lead to detachment or erratic rotation, posing a serious safety hazard.

2.2.2. Common Malfunctions in UAV Power System

The power system of an UAV relies on two critical components: the battery and the Power Distribution Board (PDB). The battery, typically a Lithium Polymer (LiPo) type, acts as the drone's main power source, with key electrical parameters like nominal voltage (S-count), capacity (mAh), and maximum continuous discharge rate (C-rating) being crucial for selection. The PDB, or integrated power circuit, functions as the central electrical hub, distributing power from the battery to essential components such as the ESCs flight controller, and other electronics. This board can sometimes be integrated into the flight controller or a 4-in-1 ESC unit.

Battery malfunctions can arise from a range of issues, both due to natural aging and improper usage. Capacity loss is the most common and expected problem occurring as the battery ages. Cell imbalance, where individual cells in a multi-cell pack have different voltage levels, often leads to voltage inconsistency, further affecting performance. As batteries age, they also develop increased internal resistance, reducing efficiency. Connector wear is another frequent issue caused by repeated use, which can degrade performance over time. More severe problems include puffing or swelling, especially in lithium-ion and LiPo batteries, which indicate internal damage and poses a serious safety risk. Overheating may result from high current draw or damage, while deep discharge damage occurs when a battery is drained below safe voltage levels, often causing irreversible harm. Older battery types like NiMH may suffer from the memory effect, where incomplete discharge cycles reduce capacity. Short circuits, typically due to physical damage, can lead to electrolyte leakage or, in extreme cases, thermal runaway, a dangerous condition where internal shorts cause uncontrollable heat buildup, potentially resulting in fire or explosion. Table 2.3 shows a detailed overview of the common malfunctions observed in the power system of UAVs.

Table 2.3 *The most common malfunctions in the power system of UAVs*

POWER SYSTEM OF UAVS	
	
Battery	**Power Distribution Board (PDB)**
Capacity loss	Cold solder joints
Cell imbalance	Connection failures
Voltage inconsistency	Short circuits
Increased internal resistance	Damaged voltage regulators
Connector wear	Burn marks
Swelling	Capacitor failures
Overheating	Overheating
Deep discharge damage	PCB trace breaks
Memory effect	Connector pin damage
Short circuit	EMI/RFI interference problems
Electrolyte leakage	Grounding problems
Thermal runaway	

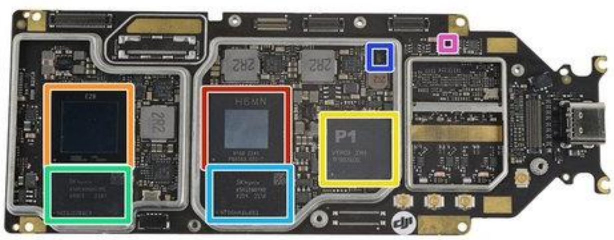
A malfunction in the Power Distribution Board (PDB) of a drone can result from various issues that compromise power delivery to essential components. Common problems include cold solder joints and connection failures, which can cause intermittent power loss or complete disconnection. Short circuits and damaged voltage regulators may lead to system instability or component failure, often evidenced by burn marks or signs of overheating. Capacitor failures and broken PCB traces further disrupt voltage regulation and power flow. Connector pin damage can create unreliable connections, while electromagnetic interference (EMI or RFI) and grounding problems may introduce signal noise, affecting both control and sensor accuracy.

2.2.3. Common Malfunctions in UAV Flight Controller Board and Flight Sensor

In a drone's intricate control system, often likened to its "brain" and "nervous system," the Flight Controller (FC) acts as the central processing unit, interpreting data from various sensors to ensure stable flight and navigation. Key to this system is the Inertial Measurement Unit (IMU), which integrates an Accelerometer for linear acceleration and a Gyroscope for angular rotation. Additional sensors like the Magnetometer (Compass) determine heading, while the Barometer measures altitude based on air pressure. For precise global positioning, altitude, and ground speed, a GPS/GNSS Module is essential. Furthermore, a Failsafe Module is crucial for initiating automatic emergency procedures such as Return-to-Home in the event of signal loss or critical system failure. More advanced drones may also include Onboard Processing Units to manage complex functions like obstacle avoidance or AI-driven tasks. Table 2.4-2.5 provides a detailed overview of the common malfunctions observed in flight controller board and flight sensors respectively.

Table 2.4 *The most common malfunctions on the flight controller board of UAVs*

FLIGHT CONTROLLER BOARD



Connection Issues	**Firmware Issues**	**System Response Issues**	**Hardware Issues**	**External Interference**
Radio connection loss to remote controller Telemetry link failure Communication timeout between FC and ground station Receiver binding problems	Software update problems Firmware conflicts between components Boot loop failures Parameter corruption Flash memory corruption	Unresponsiveness Incorrect response to commands Erratic behavior and unexpected maneuvers Control loop instability PID tuning issues Fail-safe activation problems	Overheating due to intensive use or poor ventilation Power supply instability Internal component failure Memory errors Processor lockup	Electromagnetic interference (EMI) from external devices Radio frequency interference (RFI)

***Table 2.5** The most common malfunctions in the flight sensors of UAVs*

FLIGHT SENSORS			
			
IMU (Inertial Measurement Unit)	**Magnetometer (Compass)**	**Barometer**	**GPS/GNSS Module**
Gyroscope drift/failure Accelerometer calibration problems IMU temperature drift Vibration-induced noise in IMU readings IMU mounting orientation errors Multi-IMU inconsistency (when multiple IMUs are used) IMU health monitoring failures	Compass calibration problems Magnetic declination errors Compass drift over time Metal interference affecting compass readings Hard/soft iron calibration issues Compass-GPS heading mismatch Multiple compass inconsistency	Barometric pressure sensor drift Altitude hold instability Temperature compensation errors Barometer calibration issues Pressure sensor clogging (dust/moisture) Rapid altitude changes causing sensor lag	GPS signal dropout Incorrect location data reporting GPS accuracy degradation Satellite constellation issues GPS spoofing/jamming RTK/differential GPS errors GPS-compass fusion problems Multi-constellation switching issues GPS cold start delays HDOP (Horizontal Dilution of Precision) warnings

2.2.4. Common Malfunctions in UAV Communication System

Drone communication systems face various issues such as signal loss, interference from nearby RF (Radio Frequency) sources, and range limitations due to distance or obstacles. Power anomalies, environmental conditions, and frequency congestion in 2.4GHz/5.8GHz bands can disrupt control. Antenna damage, binding failures, and faulty channel outputs impair transmission. Firmware bugs may cause erratic behavior. Telemetry and video links suffer from weak signals, interference, latency, packet loss, and power-related disruptions. Adverse weather and ground station faults also affect performance. Overall, maintaining reliable Radio Transmitter (Tx) & Receiver (Rx) systems is essential for stable and safe UAV operation. Table 2.6 shows a detailed overview of the common malfunctions observed in the communication system of UAVs.

***Table 2.6** The most common malfunctions in the communication system of UAVs*

COMMUNICATION SYSTEM OF UAVS	
	
Radio Transmitter (Tx) & Receiver (Rx)	**Data Transmission (Telemetry, Video Transmitter)**
Signal loss and interference	Weak signal
Range limitations	Interference
Battery and power anomalies	High latency
Environmental impact	Packet loss/corruption
Frequency band conflicts	Power issues
Antenna damage	Environmental factors
Binding and pairing failures	Frequency band congestion
Faulty channel outputs	Ground station issues
Firmware and software glitches	Damaged/misaligned antennas
	Firmware bugs

Communication system typically comprises a radio transmitter, the pilot's handheld device for sending commands, which are then picked up by the drone's radio receiver and relayed to the flight controller. A Telemetry Radio provides a vital bi-directional link, allowing the drone to send essential data like battery status, position, and overall status back to the pilot, while also receiving settings or commands.

For real-time situational awareness, a Video Transmitter (VTx) beams a live video feed from the drone's camera to the pilot. Crucially, Antennas are attached to all these components

Tx, Rx, VTx, and the video receiver (VRx) to ensure efficient and reliable transmission and reception of radio signals.

2.2.5. Common Malfunctions in UAV Payload

Drones are highly versatile thanks to their payload, which integrates mission-specific equipment beyond basic flight components. At its core, this system often includes a Camera, crucial for various applications from high-quality photography and videography to advanced vision-based navigation, with options ranging from gimbal-stabilized units for smooth footage to FPV (First Person View) and specialized multispectral cameras.

Complementing the camera, a Gimbal is frequently employed to actively stabilize the camera, ensuring clear and steady imagery regardless of drone movement. Beyond visual capture, the payload can also house a diverse array of Specialized Sensors such as LiDAR for precise mapping, thermal cameras for heat detection, gas sensors for environmental monitoring, or multispectral sensors for agricultural analysis, truly enabling drones to perform a wide range of tasks. Table 2.7 shows a detailed overview of the common malfunctions observed in the payload of UAVs.

Gimbal and camera systems are prone to various issues that can affect performance and image quality. Common gimbal errors include gimbal motor failure, often caused by continuous operation, physical impacts, or excessive load. Flex cable breakage is another frequent issue due to the repeated movements of the gimbal, while loose connections may occur over time from vibrations or general wear. Image vibrations can result from imbalanced or damaged propellers, disrupting footage stability.

Additionally, gimbal calibration failure may stem from sudden temperature shifts or impacts, and the gimbal suspension system, which includes damping mechanisms and flexible connectors is also susceptible to wear and damage. If the gimbal tilt or pan exceeds its mechanical limits, the internal limiters may strain or break.

Table 2.7 shows a detailed overview of the common malfunctions observed in the payload of UAVs.

Table 2.7 The most common malfunctions in the payload of UAVs

PAYLOAD OF UAVs

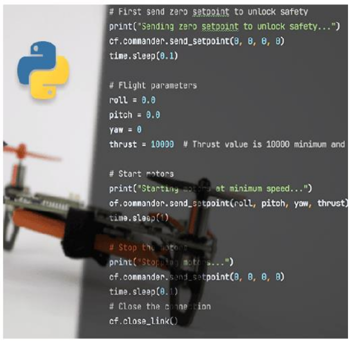
Gimbal	**Camera**
Gimbal motor failure	Camera sensor problems
Flex cable breakage	Sd card issues
Loose connections	Lens fogging
Image vibrations	Firmware incompatibilities
Gimbal calibration failure	
Gimbal suspension system damage	
Gimbal tilt/pan exceeds limits	

On the camera side, problems include camera sensor damage, typically resulting from prolonged use or impact. SD card issues such as corrupted cards, recording errors, and data loss are also common. Environmental factors like temperature changes can lead to lens fogging from moisture buildup inside the lens. Lastly, firmware incompatibilities may occur due to update errors or software conflicts, affecting the proper functioning of both the gimbal and camera systems.

2.2.6. Common Malfunctions in UAV Frame and Software

The foundational structure of any UAV is its frame & chassis, providing the essential backbone upon which all other components are integrated. This core framework typically includes main frame, serving as the primary top and bottom surfaces for mounting electronics and other parts. Extending from these plates are the arms, crucial elements where the motors are securely attached, with designs varying from fixed to conveniently foldable for portability. Holding this entire structure together are various mounting hardware pieces, such as screws, nuts, and support spacers, ensuring rigidity and stability. Finally, landing gear provides the necessary feet or skids, enabling the drone to make safe and stable landings. Table 2.8 shows a detailed overview of the common malfunctions observed in the frame and software of UAVs.

Table 2.8 *The most common malfunctions in the UAV frame and the software*



Body/Frame	**Software/Firmware**
Cracks and breaks	Power optimization issues
Loose screws and connections	Data reading errors
Vibration	Communication interruptions
Bent or misaligned parts	Data loss
Material fatigue	Stabilization problems
Wear and tear	Compatibility issues
Corrosion	Firmware update errors
Bearing and pivot point failures	GSC connection issues
Deformation	Log file corruption
	Fail-safe mechanism errors

Drone frame malfunctions commonly include cracks and breaks in structural components, which typically result from hard landings, collisions, or material fatigue. These issues directly compromise structural integrity and pose significant safety risks. Loose screws and connections often arise due to sustained vibration, thermal expansion and contraction cycles, or insufficient tightening during assembly, potentially causing part detachment, system imbalance, and performance degradation.

Vibration damage itself, induced by engine imbalance, propeller damage, or excessive RPM, accelerates material fatigue and loosens critical connections. Bent or misaligned parts, usually caused by impacts, improper assembly, or excessive loads, disrupt aerodynamics and introduce imbalance. Material fatigue, driven by repetitive stress, aging, or environmental factors, gradually weakens components and increases the risk of sudden breakage. General wear and tear from friction, environmental exposure, and normal use leads to performance decline and loss of effective seals.

Corrosion from moisture, salt, or chemicals degrades materials and weakens structural elements. Failures in bearings and pivot points, often due to inadequate lubrication, contamination, or overload, impair mechanisms such as landing gear. Lastly, deformation caused by excessive temperatures, improper storage, or impacts creates assembly difficulties and ongoing imbalance problems.

2.3. Identifying Malfunctions in UAV Sstems

2.3.1. Symptoms of Malfunctions in UAV Propulsion Systems

UAV propulsion issues manifest as unusual motor noise/vibration, overheating, or jerky movement, often indicating motor problems. ESC failures present as sudden motor stops, irregular behavior, or no throttle response, with burn marks or swollen components common. Propeller damage leads to increased vibration and reduced lift.

Combined, these can cause overall flight instability, unexpected altitude loss, or an inability to maintain hover. Table 2.9 provides a detailed overview of the common symptoms of malfunctions observed in UAV propulsion systems.

2.3.2. Symptoms of Malfunctions in UAV Power Systems

UAV power issues often stem from the battery or Power Distribution Board (PDB). Battery problems include reduced flight time, rapid voltage drops, swelling, overheating, and cell imbalance. PDB issues typically manifest as inconsistent power, overheating, component power loss, or discolored solder joints.

Recognizing these symptoms is crucial for prompt diagnosis and safe operation. Table 2.10 shows a detailed overview of the common symptoms of malfunctions observed in UAV power systems.

Table 2.9 *The most common symptoms of malfunctions in the propulsion system of UAVs*

		
Motor	**ESC**	**Propeller**
Unusual noise/vibration	Sudden motor stop	Increased vibration
Difficulty turning by hand	Irregular motor behavior	Reduced lift/thrust
Inconsistent power	SC won't engage	Visible damage
Overheating	Unusual noises	
Visible damage/discoloration	Burn marks	
Jerky movement of motor	Swollen components	
Excessive current draw	Overheating	
Bearing grinding or rough rotation	No response to throttle input	
	Intermittent connection	
	LED status indicators showing error codes	
	Voltage drops under load	

Table 2.10 *The most common symptoms of malfunctions in the power system of UAVs*

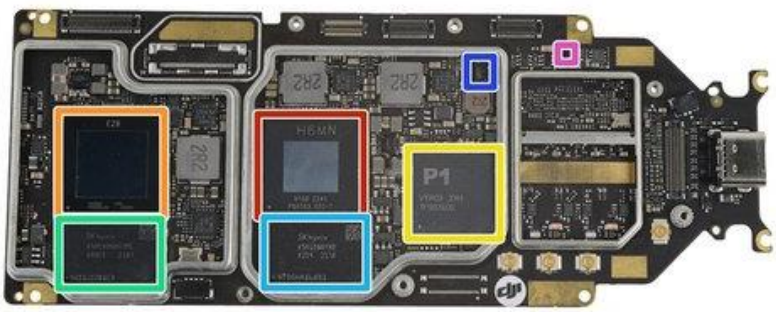
	
Battery	Power Distribution Board (PDB)
Reduced flight time	Inconsistent power distribution
Rapid voltage drops under load	Overheating
Physical swelling	Visible burn signs
Overheating during charging	Overheating
Overheating	Power loss to certain components
Battery not holding charge	Intermittent power to motors/camera
Charging time longer than normal	Discolored or melted solder joints
Battery voltage imbalance between cells	
Unusual sounds during charging	

Corrosion or leakage around battery terminals	

2.3.3. Symptoms of Malfunctions in UAV Flight Controller Board and Flight Sensor

Common flight controller (FC) issues include power failure, boot loops, USB connection problems, and inability to arm. Erratic sensor readings, uncommanded movements, delayed stick response, or flyaways may occur. Even with proper setup, FCs can cause motor desync, GPS function failures, or inconsistent flight due to deeper system or firmware faults. Table 2.11-12 shows a detailed overview of the common symptoms of malfunctions observed in the flight controller board and the flight sensors respectively.

Table 2.11 *The most common symptoms of malfunctions in the flight controller board of UAVs*



Arming & Pre-Flight Issues	**Behavioral Symptoms**
No power/no lights	Uncommanded movements
Failure to boot	Erratic flight behavior
Computer/configurator not detecting	Failure to respond/stick lag
Failure to arm	Flyaways / loss of control
Incorrect arming flags	Intermittent power cuts
Inconsistent sensor readings	Inconsistent autonomy
	Motor desync/stuttering

Sensor errors in UAVs especially in the IMU, magnetometer, barometer, and GPS/GNSS can lead to serious flight anomalies. IMU failures may cause wobbling or unstable hover. Magnetometer errors can result in drifting, yaw issues, or GPS mode failures. Barometer problems often lead to altitude instability. GPS/GNSS errors may cause poor satellite lock, inaccurate positioning, or map jumps. These issues can prevent stable flight or Return to

Home (RTH) functions. Combined sensor failures may even cause flyaway, posing major safety risks.

Table 2.12 *The most common symptoms of malfunctions in the flight sensors of UAVs*

			
IMU (Inertial Measurement Unit) Errors	**Magnetometer (Compass) Errors**	**Barometer Errors**	**GPS/GNSS Module Errors**
Erratic flight behavior Drifting Failure to stabilize Uncommanded movements Failure to arm/initiate	Toilet bowling Erratic yaw behavior Incorrect heading display Failure to engage GPS-assisted modes Poor RTH performance Calibration failures	Altitude instability Incorrect altitude readout Failure to maintain altitude Poor terrain following RTH altitude issues	Failure to acquire fix Slow fix acquisition Low satellite count Poor HDOP/VDOP Inaccurate position Position drift/jumping Failure to engage GPS modes Erratic rth behavior Flyawayrisk

2.3.4. Symptoms of Malfunctions in UAV Communication System

Uncommanded movements like drifting or twitching often indicate issues within a UAV's communication system, impacting radio transmitter (Tx) and receiver (Rx) functions. Symptoms include binding failures, weak/intermittent signals, or complete signal loss, leading to ground station "disconnected" warnings or "no signal" on FPV goggles.

Additionally, slow/freezing telemetry, video latency, pixelation, and reduced range are common signs of data transmission problems, all of which compromise flight safety and control. Table 2.13 provides a detailed overview of the common symptoms of malfunctions observed in UAV's communication system.

2.3.5. Symptoms of Malfunctions in UAV Payload

Gimbal and camera malfunctions in UAVs often manifest as clear symptoms. Gimbal issues include unusual noises, tilting, initialization failures, visible sag, and erratic movements. Camera problems can lead to blurry or distorted footage, color shifts, improper exposure, and video stuttering. These symptoms are critical for diagnosing and addressing problems within the drone's imaging and stabilization components. Table 2.14 provides a detailed overview of the common symptoms of malfunctions observed in UAV’s payload.

***Table 2.13** The most common symptoms of malfunctions in the communication system of UAVs*

	
Radio Transmitter (Tx)	**Data Transmission (Telemetry, Video Transmitter)**
Radio Receiver (Rx)	Ground station shows "Disconnected" warning
No power/unresponsive	FPV goggles display "No Signal" or snow static
Binding failure	Slow telemetry updates or freezing
faulty channel outputs	Video feed latency
Weak signal	Values flickering or jumping erratically
Intermittent signal	Missing or corrupted data display
Signal loss	Pixelation, tearing, snow effect in image
	OSD elements flickering or disappearing
	Reduced range
	Sudden static bursts
	Patterned lines or waves in video

Table 2.14 The most common symptoms of malfunctions in the payload of UAVs

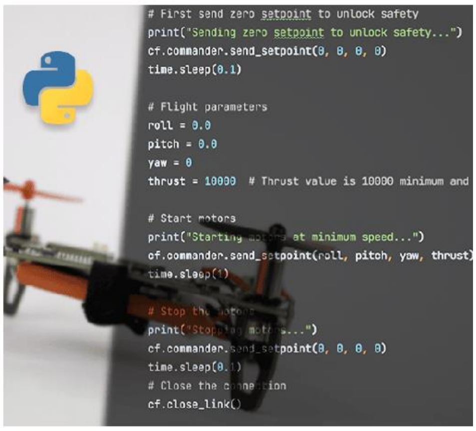
Gimbal	**Camera**
Unusual noises from gimbal motors	Blurry or out-of-focus footage
Gimbal tilts to one side when powered on	Jello effect or rolling shutter in video
Gimbal doesn't initialize properly at startup	Image distortion or warping
Visible gimbal sag or drooping	Color shifts or incorrect white balance
Gimbal moves but doesn't hold position	Overexposed or underexposed footage
Gimbal drifts or tilts unexpectedly	Video stuttering or frame drops
Jerky or stuttering movement during operation	
Gimbal vibrates or shakes excessively	
Slow or unresponsive gimbal control	
Gimbal locks up or becomes completely unresponsive	
Erratic or random gimbal movements	

2.3.6. Symptoms of Malfunctions in UAV Frame and Software

UAV frame malfunctions are often visually evident or detectable during flight. Watch for visible cracks, loose screws, or bent arms, as these directly impact structural integrity. In-flight symptoms include excessive vibration, unusual instability, or difficulty maintaining level flight, indicating underlying frame issues.

Other signs like deformed sections, worn screw holes, rattling sounds, or problems with folding mechanisms also point to critical frame damage that requires immediate attention for safe operation**.** Table 2.15 shows a detailed overview of the common symptoms of malfunctions observed in UAV's frame and software.

__Table 2.15__ The most common symptoms of malfunctions in the frame and software of UAVs



Body/Frame	**Software/Firmware**
Visible cracks or fractures in carbon fiber/plastic	Erratic or unstable flight behavior
Loose or missing screws and fasteners	Unexpected altitude changes
Bent or twisted frame arms	Unresponsive to control inputs
Excessive vibration during flight	Return-to-home function failure
Unusual flight instability or wobbling	Position hold instability
Difficulty maintaining level flight	Loss of telemetry data transmission
Deformed or warped frame sections	Control signal dropouts
Worn or enlarged screw holes	Video feed interruptions or lag
Surface corrosion or discoloration	Ground station disconnection warnings
Rattling sounds during operation	Continuous error beeping or LED warnings
Difficulty folding/unfolding (for foldable drones)	System health check failures
	Low battery warnings despite full charge
	Memory or storage errors

When a drone exhibits erratic flight, altitude shifts, or ignores commands, software or firmware issues are likely culprits. Failures in return-to-home, unstable position holding, lost telemetry, dropped control signals, and video interruptions also point to these problems. Persistent error beeps, LED warnings, health check failures, false low battery alerts, and memory errors further indicate underlying software or firmware malfunctions demanding attention and potential updates.

2.4. Diagnostic Tools and Methos for UAV Malfunctions

Content within this section addresses drone troubleshooting, specifically under the categories of 'Tools' and 'Fault Diagnosis Method'. For a visual representation of commonly used diagnostic tools for UAV failures, refer to Figure 2.2.

Figure 2.2 Commonly Used Diagnostic Tools for UAV Failures

2.4.1. Diagnostic Tools and Methos for UAV Propulsion Systems

For motors, diagnostics include visual inspection, resistance/temperature monitoring, and vibration analysis using an oscilloscope or motor test bench. ESCs are assessed via visual inspection for burnt components, temperature monitoring, and current/voltage testing with a multimeter and thermal camera. Propellers are diagnosed through visual/tactile inspection, balance tests, and mounting checks using a magnifying glass and propeller balancer, ensuring efficient and safe drone operation. Table 2.16 outlines key measurement tools and fault diagnosis methods for UAV propulsion systems.

2.4.2. Diagnostic Tools and Methos for UAV Power Systems

UAV power system diagnostics rely on specific tools and methods. For the battery, a digital multimeter, battery analyzer, and infrared thermometer are crucial for voltage testing, capacity checks, and temperature monitoring. The PDB requires a digital multimeter, thermal imaging camera, and magnifying glass for visual inspection, voltage measurement, and thermal imaging to pinpoint issues. These combined approaches ensure comprehensive fault diagnosis, from cell balance to current draw analysis, maintaining UAV reliability. Table 2.17 proves key measurement tools and fault diagnosis methods for UAV power systems.

Table 2.16 *Tools and fault diagnosis methods in the propulsion system of UAVs*

	Motor	ESC	Propeller
Tools	Oscilloscope Motor test bench Gaussmeter Thermal imaging camera or infrared thermometer	Multimeter Oscilloscope Thermal imaging camera ESC programming card/software Flight controller configurator software Props off tester Magnifying glass	Magnifying glass Bright LED flashlight Propeller balancer Torque wrench Vibration analyzer
Fault Diagnosis Method	Visual Inspection Manual shaft rotation test Multimeter resistance testing across motor windings Motor temperature monitoring Vibration analysis RPM measurement Power consumption	Visual inspection for burnt components Temperature monitoring via telemetry Measure current draw vs rated capacity Voltage testing under load Check for voltage sags/spikes Continuity testing with multimeter Check signal wire continuity Verify power distribution board connections Test with known good flight controller Thermal imaging during operation	Visual & tactile inspection Magnified inspection Balance test Flex test Spin test Sound inspection Mounting check

Table 2.17 *Tools and fault diagnosis methods in the power system of UAVs*

	Battery	Power Distribution Board (PDB)
Tools	Digital multimeter Battery analyzer	Digital multimeter Thermal imaging camera

	Internal resistance meter	Digital thermometer with probe
	Infrared thermometer	Magnifying glass with LED illumination
	Battery charger	Soldering station with temperature control
Fault Diagnosis	Voltage Testing	Visual Inspection
Method	Cell Balance Check	Voltage Measurement
	Capacity Testing	Current Draw Analysis
	Internal Resistance	Continuity Testing
	Measurement	Thermal Imaging
	Temperature Monitoring	
	Visual Inspection	
	Discharge Rate Testing	
	Charge Time Analysis	
	Cyclic Load Testing	

2.4.3. Diagnostic Tools and Methos for UAV Flight Controller Board and Flight Sensor

Diagnosing UAV malfunctions, especially those involving uncommanded movements like drifting or twitching, relies heavily on a systematic approach to the flight controller board and flight sensors. As detailed in Table 2.18, a range of specialized measurement tools, including oscilloscopes and logic analyzers, are crucial for pinpointing issues within these intricate systems. Effective fault diagnosis methods span from visual inspections and power supply analysis for the flight controller to data logging analysis and environmental testing for flight sensors, ensuring comprehensive troubleshooting for optimal drone performance.

Table 2.18 *Tools and fault diagnosis methods in the flight controller board and flight sensor of UAVs*

	Flight Controller Board	Flight Sensor
Tools	Digital multimeter	Digital multimeter
	Oscilloscope	Oscilloscope
	Spectrum analyzer	Logic analyzer
	Logic analyzer	GPS/GNSS testing device
	Current probe/clamp meter	Compass calibration tool
	Hot air rework station	Imu test platform
	USB	Spectrum analyzer

Fault Diagnosis Method	Visual inspection Power supply analysis Communication port testing Sensor calibration check Signal tracing Firmware flashing/recovery Component substitution Thermal analysis Flight log analysis	Data logging analysis Static calibration testing Cross reference Environmental testing Signal path tracing Communication protocol testing

2.4.4. Diagnostic Tools and Methos for UAV Communication System

Diagnosing communication faults in UAVs is crucial for reliable operation. As detailed in Table 2.19, effective troubleshooting involves specific measurement tools and methods for key components. For the Radio Transmitter (Tx) and Radio Receiver (Rx), engineers utilize tools like RF Spectrum Analyzers and SWR Meters to perform Signal Strength Testing and Range Testing, ensuring robust control links. Similarly, issues with data transmission covering telemetry and video—are addressed using packet loss analysis and frequency sweep analysis, often with RSSI meters and antenna analyzers. These systematic approaches, guided by the right instruments, are vital for maintaining UAV communication integrity.

Table 2.19 *Fault diagnosis methods and tools and in the communication systems of UAVs*

	Radio Transmitter (Tx) Radio Receiver (Rx)	Data Transmission (Telemetry, Video Transmitter)
Fault Diagnosis Method	Signal strength testing Range testing Frequency scanning Bind/link testing Failsafe testing Channel mapping Latency measurement	Packet loss analysis Frequency sweep analysis Signal strength testing Antenna pattern testing Link budget calculation Latency measurement
Tools	Rf spectrum analyzer SWR meter Multimeter Oscilloscope Rf power meter Antenna analyzer Signal generator	

	RSSI meter

2.4.5. Diagnostic Tools and Methos for UAV Payload

Troubleshooting UAV payload issues effectively hinges on using the right measurement tools and fault diagnosis methods, as detailed in Table 2.20. For gimbals, tools like inclinometers and vibration analyzers, paired with visual inspection and load testing, pinpoint stability and movement problems.

Table 2.20 *Tools and fault diagnosis methods in the payload of UAVs*

	Gimbal	Camera
Tools	Inclinometer Vibration analyzer Current clamp meter Encoder/position sensor tester Precision calipers Multimeter Oscilloscope	HDMI/video signal tester USB protocol analyzer Digital multimeter Oscilloscope Spectrum analyzer
Fault Diagnosis Method	Visual inspection Functional testing Load testing Signal tracing Data log analysis	Visual inspection Power supply testing Signal path tracing Component substitution Firmware version verification Vibration analysis Communication protocol testing

Meanwhile, cameras benefit from HDMI/video signal testers and spectrum analyzers, combined with power supply testing and communication protocol verification to address imaging and data flow issues. Adhering to these systematic approaches is crucial for maintaining the operational integrity of a drone's critical payload.

2.4.6. Diagnostic Tools and Methos for UAV Frame and the Software

Maintaining UAV structural integrity is crucial for flight safety and performance. As outlined in Table 2.21, "Measurement tools and fault diagnosis methods in the frame and the software of UAVs," a thorough pre-flight inspection of the drone's body/frame is essential. Tools like magnifying glass and LED illumination aid in detailed visual inspection and fastener checks. A bubble level helps ensure symmetry and alignment, while a vibration analyzer can detect subtle issues.

Regular checks of cable routing, insulation, and battery holder security prevent common malfunctions, ensuring the drone performs reliably and safely.

***Table 2.21** Tools and fault diagnosis methods in the frame and the software of UAVs*

	Body/Frame	Software
Tools	Magnifying Glass	Log analyzers (mission planner, qgroundcontrol)
	LED illumination	Real-time telemetry dashboards
	Digital Calipers	Simulation tools (gazebo, SITL)
	Screwdriver	Health monitoring metrics
	Bubble Level	Ping/heartbeat monitors
	Vibration Analyzer	Debug consoles / ground control logs
	Weight Scale	Data recorders (ROS bag, MAVlink logger)
	Thread Pitch Gauge	
Fault Diagnosis Method	Detailed visual inspection	Error code analysis
	Symmetry check	Sensor redundancy check
	Fasteners check	Watchdog timers
	Cable routing and insulation check	State estimation consistency checks
		Parameter sanity validation
	Battery holder and fixing check	Log signature matching
	Body flexibility and torsion test	Failsafe trigger analysis

2.5. Troubleshooting flowcharts

This section presents a structured approach to diagnosing common operational issues encountered in unmanned aerial vehicles (UAVs). The flowcharts are designed to help identify and resolve problems such as control latency, hover drift, reduced flight time, unexpected altitude changes, asymmetric flight behavior, unstable hover, excessive vibrations, unexpected mode changes, and high temperature. Each malfunction is supported by dedicated diagrams and visual references provided in this chapter, guiding users through step-by-step decision paths. The goal is to enhance maintenance efficiency, minimize downtime, and support both novice and experienced operators in achieving safe and stable drone performance.

In addition to flight performance anomalies, UAV systems are also prone to various operational and electronic issues that can compromise mission success. Video and photo quality degradation is one of the most common problems, often resulting from gimbal miscalibration, lens contamination, or faulty SD cards. Signal loss is frequently reported in dense urban environments, areas with high electromagnetic interference, or under adverse weather conditions. Automatic landing triggers are also widespread, typically caused by low battery levels, signal interruption, or the activation of built-in safety protocols. Another prevalent issue is controller connection drops, which may stem from excessive range, physical obstructions, or frequency conflicts. Return-to-home failures, usually tied to GPS logging faults or obstacle detection inaccuracies. Other issues in this category are inadequate wind resistance, particularly affecting lightweight drones, and gimbal or camera stabilization freezing due to mechanical fatigue or firmware inconsistencies.

Comprehensive flowcharts are provided in **Figure 2.3 to Figure 2.12** to aid in troubleshooting various issues, including control latency, excessive vibrations, hover drift, reduced flight time, unexpected altitude changes, asymmetric flight behavior, unstable hover, high temperature, and unexpected mode changes. These diagrams guide users through systematic diagnostic steps, ensuring efficient identification of root causes and appropriate corrective actions. Each flowchart is designed to address specific symptoms, minimizing downtime and enhancing operational safety. By following these structured procedures, users can better understand the underlying systems and make informed maintenance decisions, ultimately improving UAV performance and reliability in both field and lab settings.

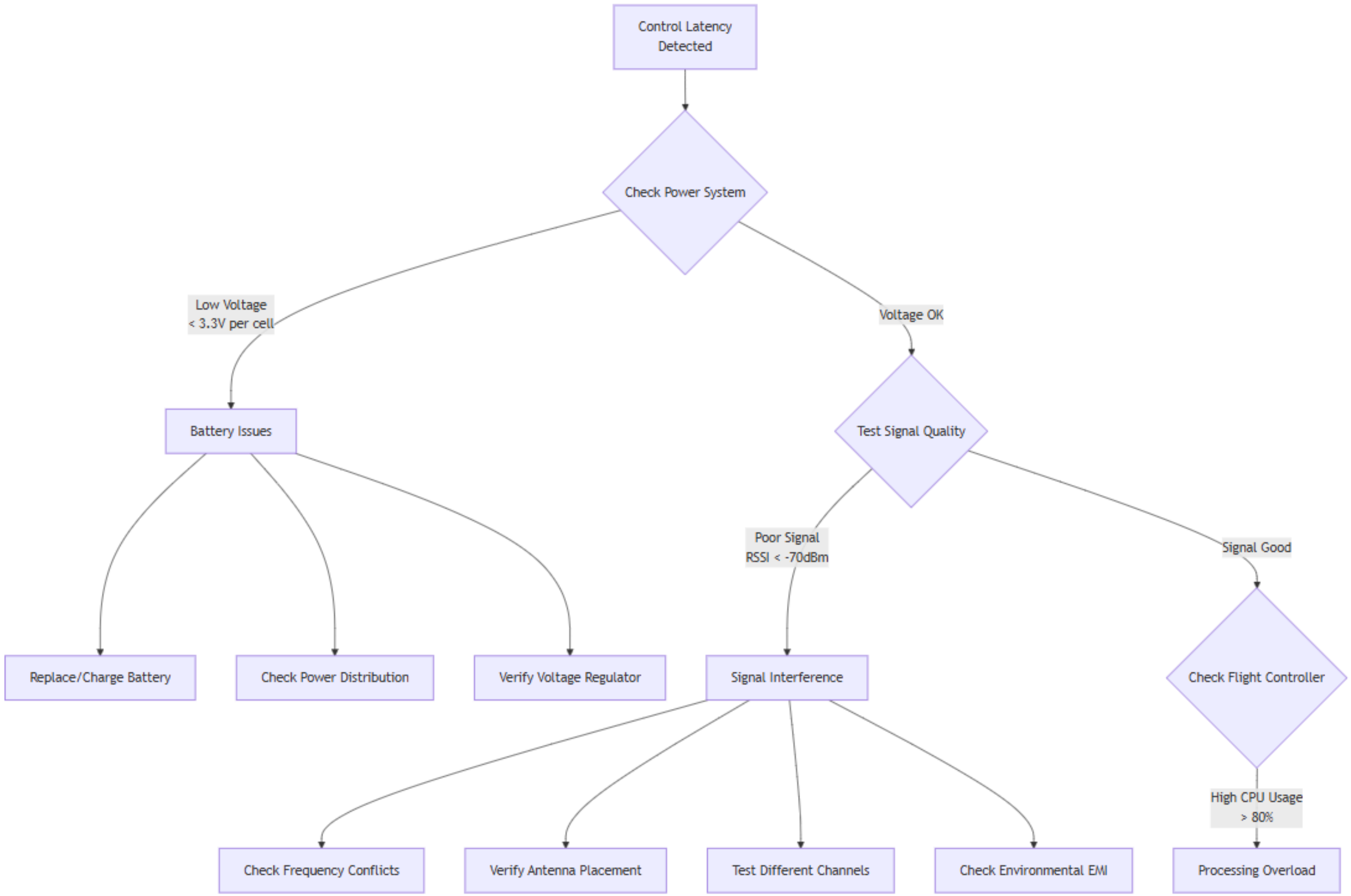


Figure 2.3. Flowcharts for Troubleshooting Control Latency (Part 1)

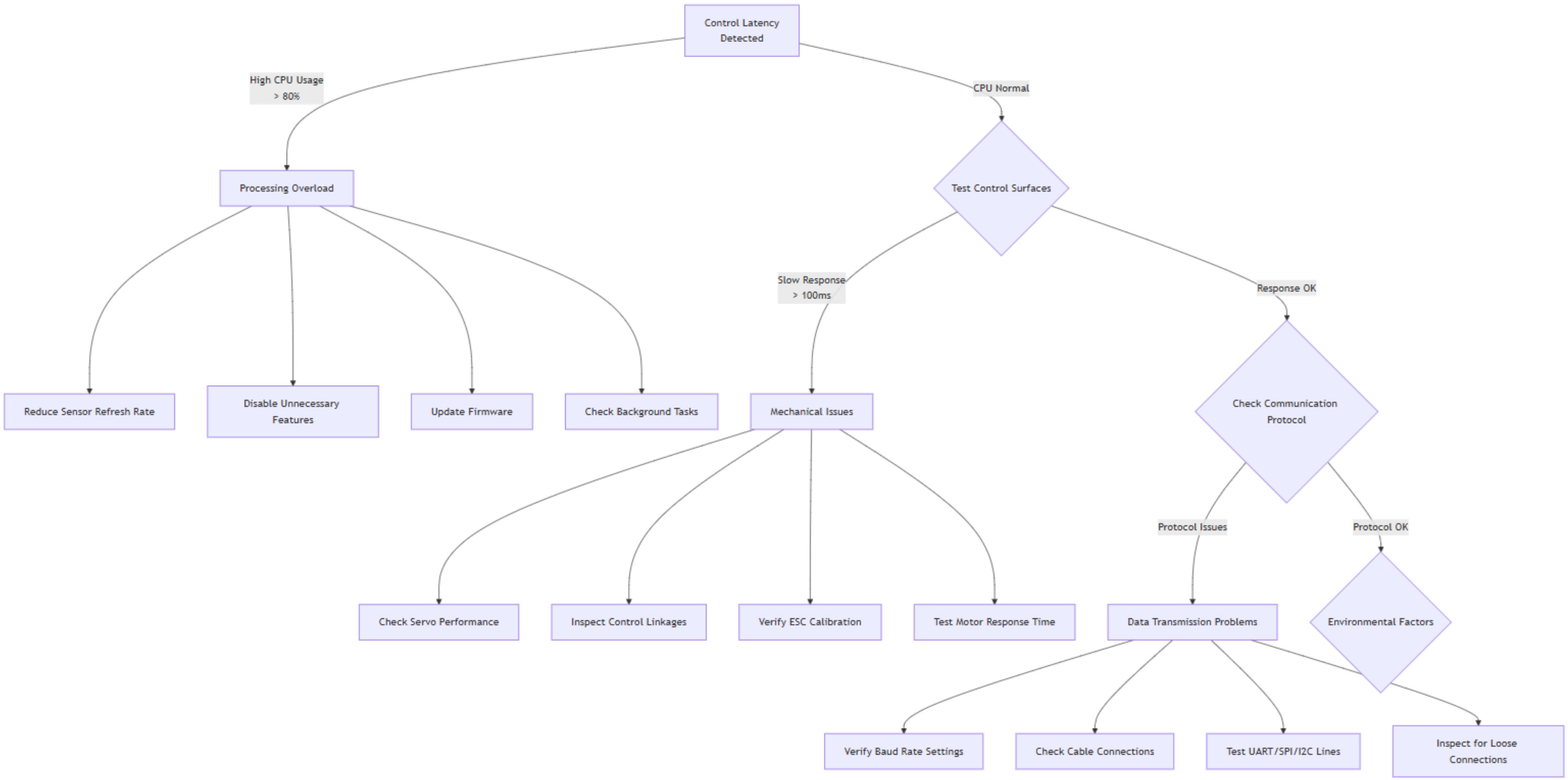


Figure 2.4. Flowcharts for Troubleshooting Control Latency (Part 2)

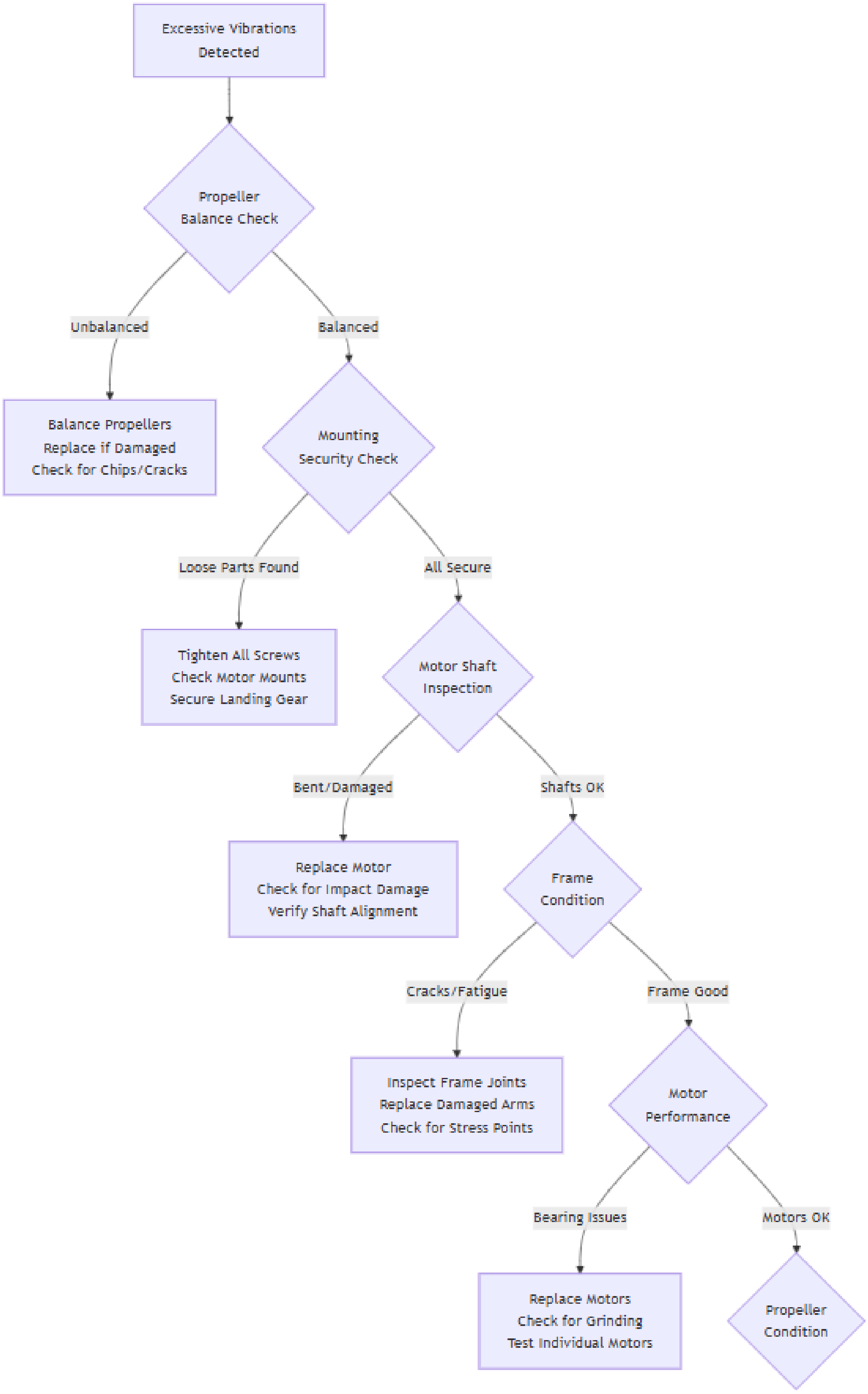


Figure 2.5 Flowcharts for Troubleshooting Excessive Vibrations

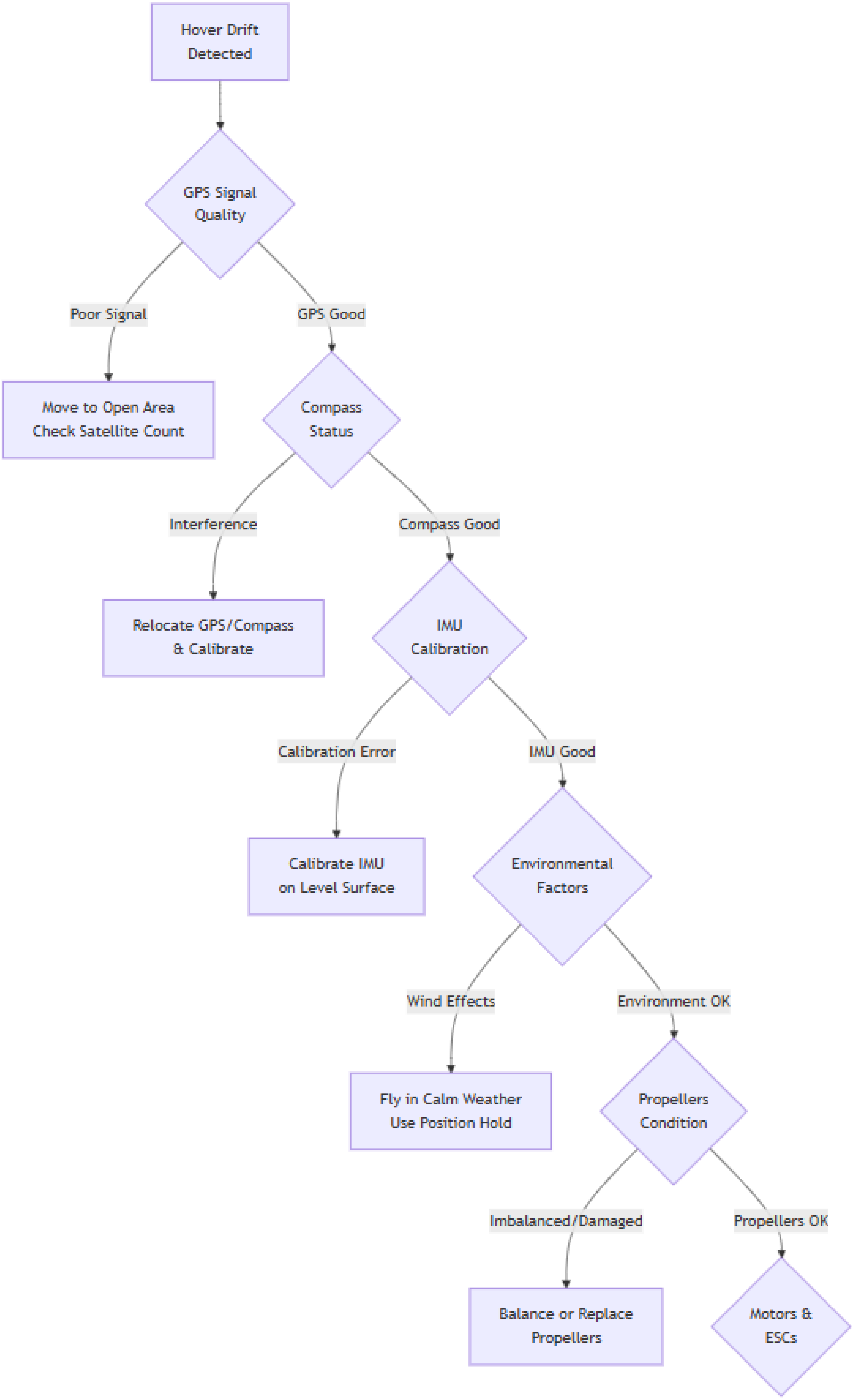


Figure 2.6 Flowcharts for Troubleshooting Hover Drift

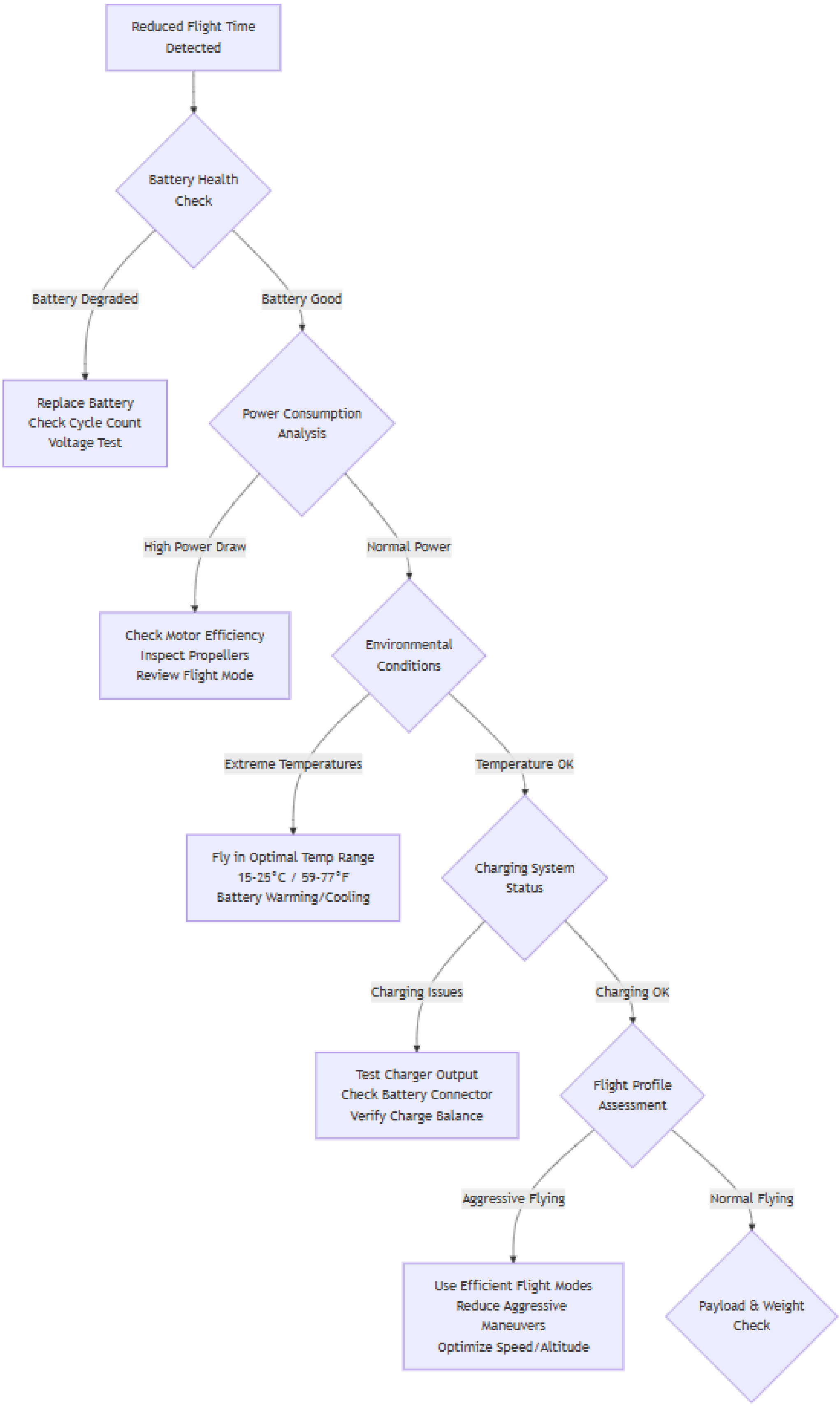


Figure 2.7 Flowcharts for Troubleshooting Reduced Flight Time

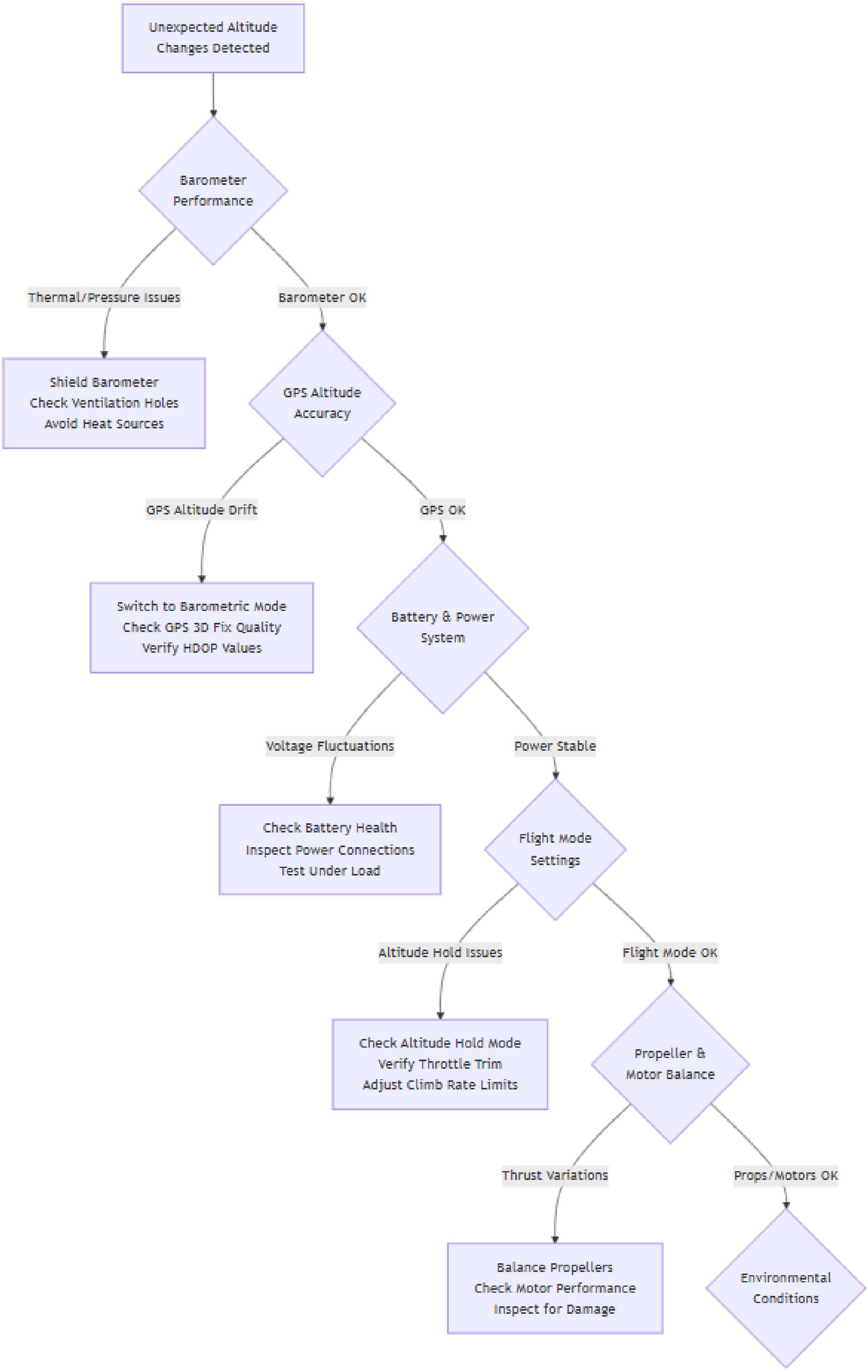


Figure 2.8 Flowcharts for Troubleshooting Unexpected Altitude Changes

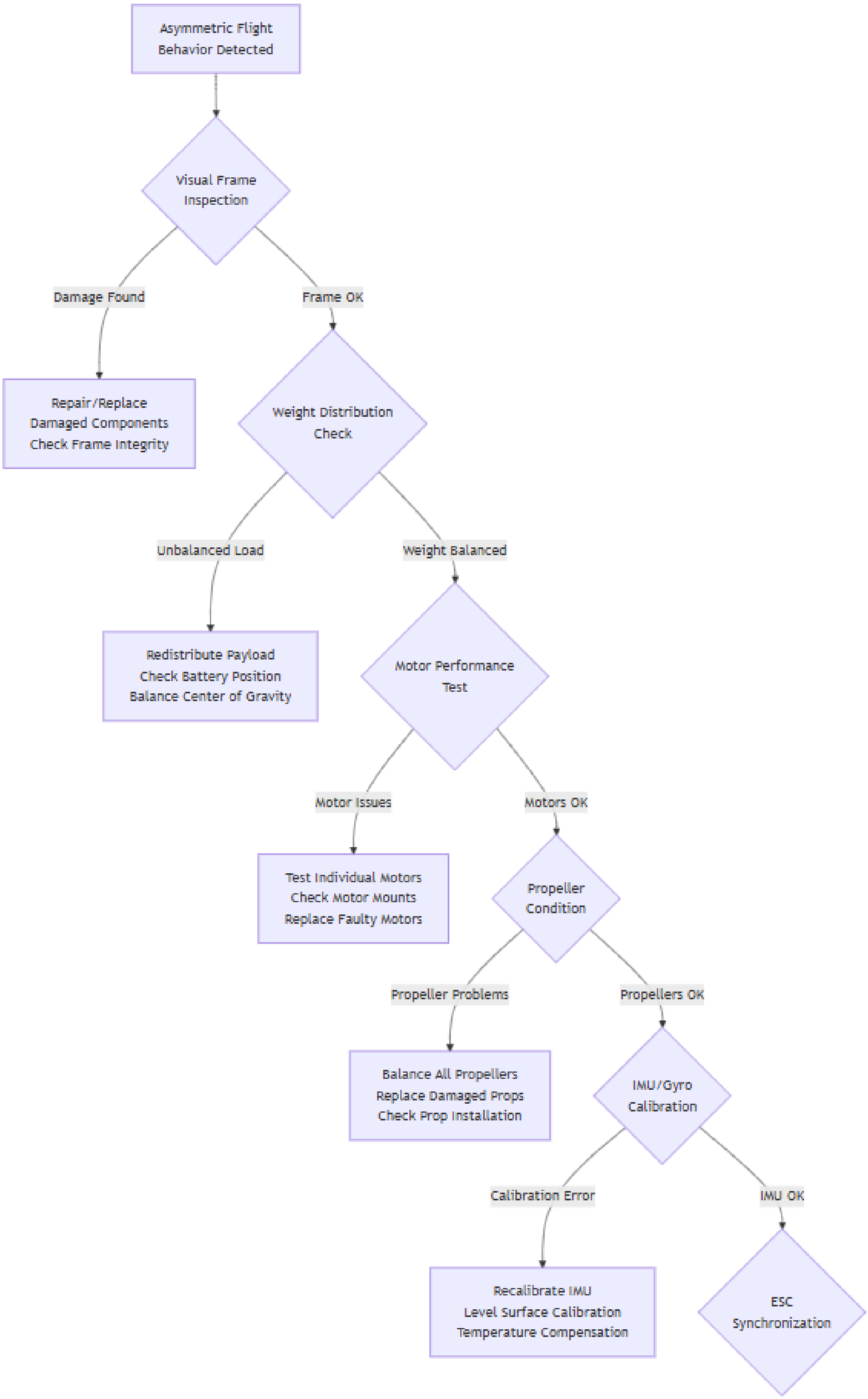


Figure 2.9 Flowcharts for Troubleshooting Asymmetric Flight Behavior

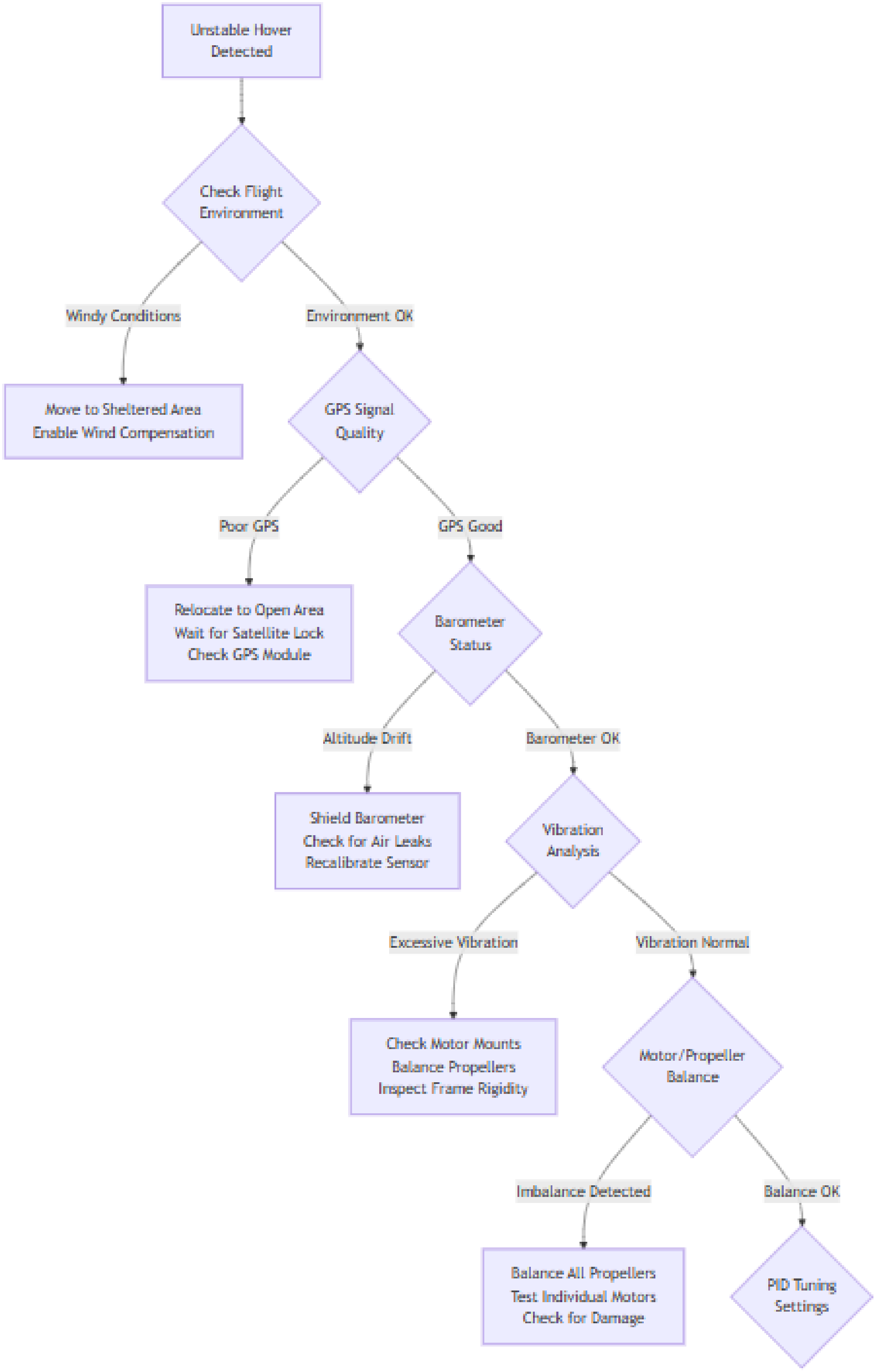


Figure 2.10 Flowcharts for Troubleshooting Unstable Hover

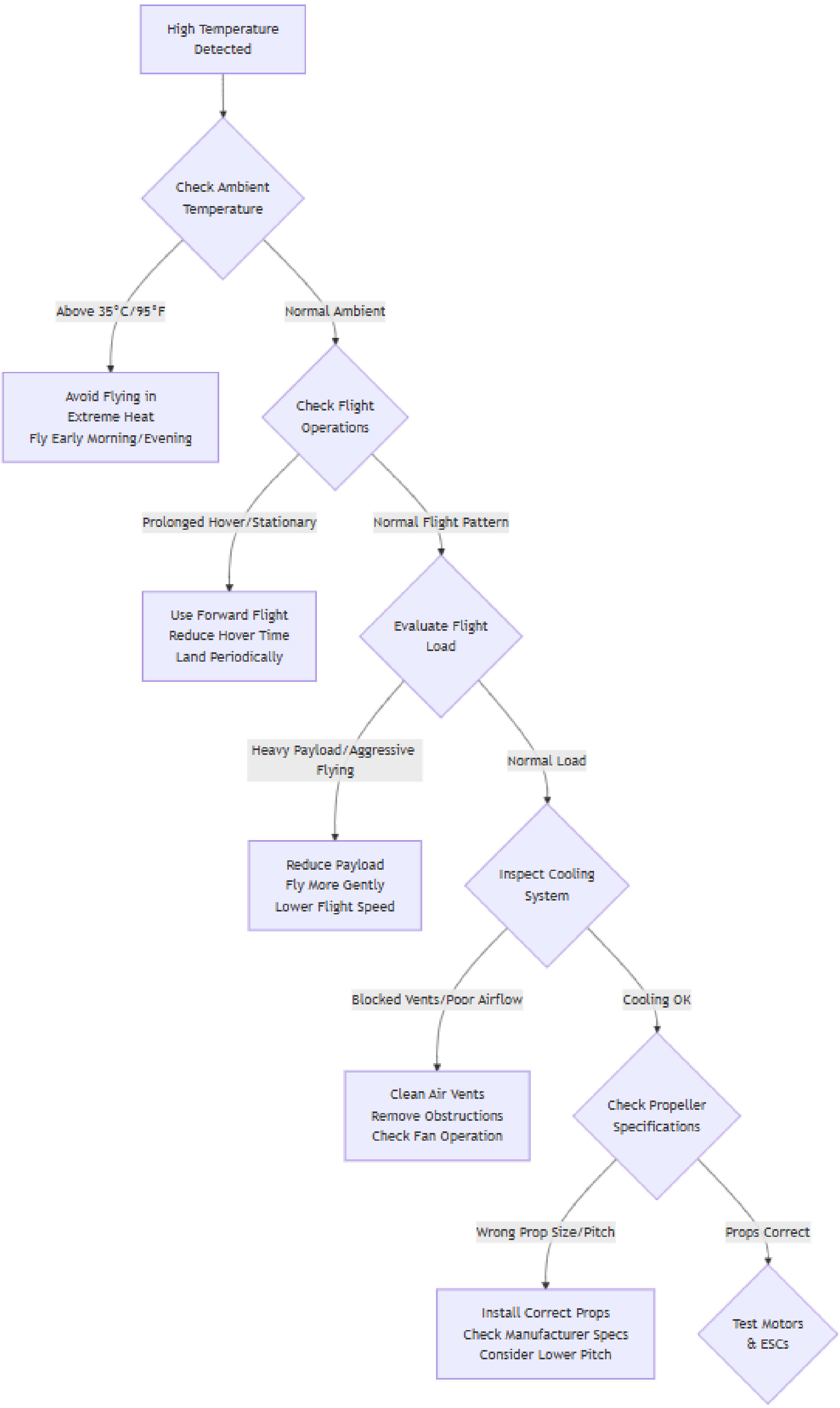


Figure 2.11 Flowcharts for Troubleshooting High Temperature

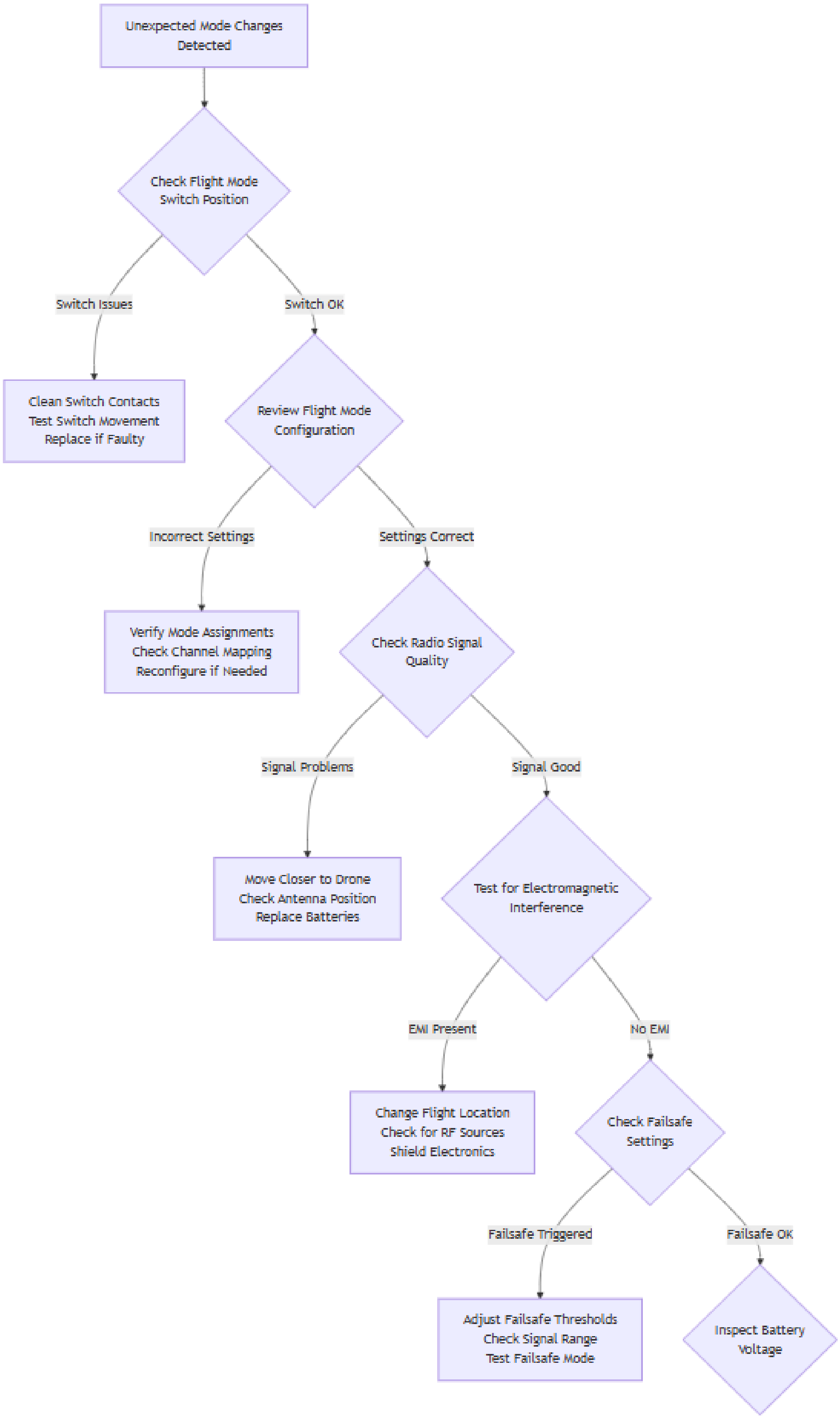


Figure 2.12 Flowcharts for Troubleshooting Unexpected Mode Change

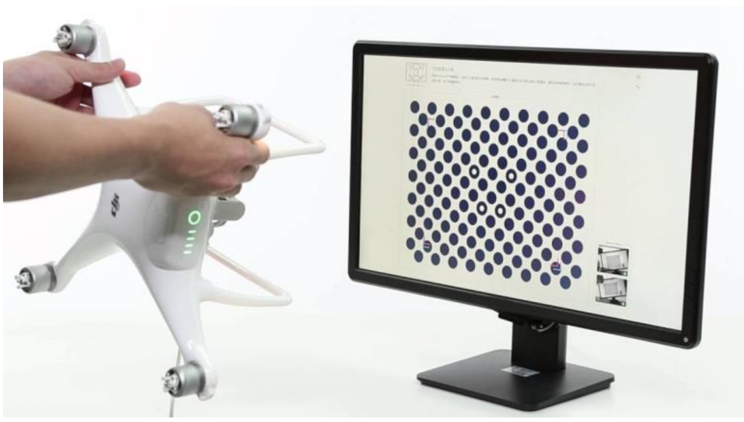
2.6. Sensor calibrations

Sensor calibration is essential to ensure drone systems perform accurately and safely. Different components require calibration at varying frequencies based on usage and environmental changes. For example, the compass needs the most frequent calibration, especially after large location or altitude shifts. The IMU must be recalibrated after crashes or temperature changes. Gimbal, transmitter, optical flow sensor, GPS, and ESC calibrations are typically triggered by performance issues or hardware changes.

2.6.1. Calibration Procedures

Each sensor has unique calibration conditions and requirements—such as surface stability, lighting, or magnetic interference—making routine checks critical for maintaining optimal drone functionality. The procedures for compass and vision sensor calibration are depicted in Figure 2.13. Table 2.22 details the calibration procedures for the Compass, IMU, Gimbal, Remote Controller, Vision Sensor, and ESC.

Compass Calibration



Vision Sensor Calibration

Figure 2.13 Compass and Vision Sensor Calibration

Table 2.22 *Compass, IMU, Gimbal, Remote Controller, Vision Sensor, and ESC Calibration Procedures*

Component	Procedure
Compass Calibration	Hold drone horizontally, rotate 360°. Hold vertically (nose down), rotate 360°.
IMU Calibration	Place drone on a flat surface. Access calibration via app. Keep steady and follow on-screen instructions
Gimbal Calibration	Place drone on a level surface. Ensure gimbal movement is unobstructed. Access gimbal calibration via app. Gimbal will move through full range.
Remote Controller Calibration	Access calibration via app Follow on-screen stick movement instructions.
Vision Sensor Calibration	Choose a well-lit, textured area. Hold drone ~0.5m high. Slowly move drone as per app instructions. Maintain consistent altitude.
ESC Calibration	Remove the propellers (for safety). Connect the drone battery and transmitter (TX). Turn on the transmitter, set the throttle to max. Power on the drone After the beeps, lower the throttle to minimum; ESCs will beep again. Turn off the drone's power and then back on

Sensor calibration is a vital part of drone setup, ensuring stable flight and accurate data collection. Each sensor requires a specific procedure: for compass calibration, the drone is rotated horizontally and vertically; IMU calibration involves placing the drone on a flat surface and following app instructions. Gimbal calibration requires an unobstructed, level setup, allowing the gimbal to complete its full motion range. The procedures for controller and gimbal calibration are depicted in Figure 2.14.

Controller Calibration

Gimbal Calibration

Figure 2.14 Remote Controller and Gimbal Calibration

Transmitter calibration is done through the app by moving sticks as instructed. For optical flow sensors, the drone is held 0.5 meters above a well-lit, textured surface and moved slowly. ESC calibration, which requires propeller removal for safety, involves setting throttle levels and following beep signals to synchronize the ESCs. Each step enhances flight accuracy and safety. Table 2.23 presents the calibration frequency, trigger conditions, and basic properties of the components that frequently need calibration in the UAV.

2.6.2. Calibration Frequency, Trigger Conditions and Key Features in UAVs

***Table 2.23** Calibration frequency, trigger conditions and basic properties of the components that frequently need calibration in the UAV*

Component	Calibration Frequency	Trigger Conditions	Key Features
COMPASS	**Most frequent** Before each flight or when needed	Location change (>50 mi / 80 km) Altitude change (>1,000 ft / 300 m) Magnetic field variations Travel to new regions	Magnetic field-sensitivity Requires open area No metal interference
IMU	**Very frequent** Every 30 mi (48 km) or when alerted	Temperature changes After crashes Long storage System alerts	Includes gyro, accelerometer, magnetometer Needs stable surface
GIMBAL	**Frequent** When performance issues arise	Horizon tilt (>20°) Vibration/jitter Camera imbalance Stabilization errors	Requires level surface Full range of motion test
REMOTE CONTROLLER	**Medium frequent** When binding or input issues occur	New controller binding If stick movements don't match drone response Input delays Range drops	Stick movement calibration Signal strength check
OPTICAL FLOW SENSOR	**Medium frequent** **When obstacle detection worsens**	When the sensor lens is dirty Flight over different surface types (concrete, grass, sand) Position hold issues (without GPS) When height change sensitivity decreases	Requires surfaces with pattern/texture. Optimal working height: 0.3-8 meters. Lighting conditions are critical.
GPS	**Medium frequent** After major location changes	Cross-country travel Weak GPS signal RTH failures Position drift	Often auto-calibrates Firmware-dependent

ESC	**Medium frequent** After motor/esc replacement	New ESC/motor installed Throttle inconsistencies Motor sync issues	Modern drones handle this via software Throttle range adjustment Motor response check

Calibration frequency varies by component and is often triggered by environmental or performance-related conditions. Magnetic sensors need calibration before each flight, especially after traveling long distances or experiencing magnetic field changes. The IMU requires very frequent checks due to temperature shifts, crashes, or alerts, needing a stable surface. Gimbal calibration is needed when camera stabilization issues occur. Remote controllers and optical flow sensors require medium-frequency calibration, especially after binding changes or when flight accuracy drops. GPS and ESCs also need recalibration after significant location changes or hardware replacement, though modern systems often support partial auto-calibration.

2.7. Flight logs

Flight logs are a critical component of drone investigations, offering a comprehensive digital footprint of each mission. They provide essential insights into the drone's behavior, pilot actions, environmental conditions, and system performance. Analyzing these logs involves a structured forensic process starting from securing original data and verifying its integrity, to acquiring logs from multiple sources such as drones, apps, or mobile devices. Figure 2.15 illustrates the most common flight log review tools. Through specialized tools like Mission Planner, PX4 Flight Review, and forensic software, investigators examine flight paths, GPS data, power systems, sensor accuracy, and more. This multifaceted analysis helps reconstruct incident timelines, assess compliance with aviation regulations, and identify root causes with precision.

Figure 2.15 Flight log review tools

The 26-step process is grouped under five main categories: pre-investigation and data collection, initial review and data validation, human and operational factors, incident reconstruction and causality, and final reporting and risk review (See Table 2.24-2.28).

Table 2.24 *Pre-Investigation and data collection steps for flight logs*

Pre-Investigation and Data Collection		
Step	**Procedure and Parameters**	**Tools/Software**
Pre-Investigation Setup	Secure chain of custody Document original files Create forensic copies Verify file integrity	MD5/SHA hash tools Write blockers Forensic imaging software
Log Acquisition	Download logs from drone/app/SD card Extract from mobile devices if needed	DJI Assistant 2 Autel Explorer Yuneec DataPilot Mission Planner PX4 Flight Review
Legal & Compliance Check	Airspace restrictions Flight permissions Insurance validity	Local Authority database LAANC system Operator certificate database

Table 2.25 *Initial review and data validation steps for flight logs*

Initial Review and Data Validation		
Step	Procedure and Parameters	Tools/Software
Initial Log Review	Flight duration Basic parameters Error messages System warnings	Open-source tools (MAVExplorer) Native manufacturer software
Environmental Data Analysis	Wind speed/direction Visibility Temperature	Weather APIs METAR data Historical weather databases
Flight Route & GPS Analysis	Plot GPS coordinates Analyze flight path Check for deviations GPS signal quality	Mission Planner FlytNow DroneDeploy Google Earth Pro
Altitude & Airspeed Analysis	Altitude changes Speed variations Climb/descent rates Airspeed anomalies	PX4 Flight Review Tower, Custom analysis scripts
Attitude & Stability Analysis	Analyze pitch, roll, yaw angles Check for oscillations, unusual movements	MAVExplorer Mission Planner MATLAB/Python scripts
Power System Analysis	Battery voltage Current draw Power consumption Thermal conditions	DJI Assistant 2 Battery analysis tools Custom dashboards
Motor & Propulsion Analysis	Motor RPM ESC data Thrust output Propeller efficiency	PX4 Flight Review Mission Planner Motor test software
Communication & Control Analysis	Radio signal strength Control inputs Telemetry data Link quality	MAVLink tools Radio analysis software Signal strength meters
Sensor Data Validation	Verify IMU, compass, barometer, GPS data consistency and accuracy	Mission Planner Sensor calibration tools Data validation scripts
Flight Mode & Automation Analysis	Review autonomous modes, waypoint execution, return-to-home performance	Mission planning software Autopilot analysis tools

Vibration & Mechanical Analysis	Use FFT analysis on accelerometer data Check for resonance, mechanical issues	MATLAB/Python FFT tools Vibration analysis software Spectrum analyzers
Payload & Camera Analysis	Check gimbal performance, camera stability, payload weight effects	Gimbal analysis tools, Image stabilization software Weight/balance calculators

Table 2.26 *Human and operational factors steps for flight logs*

Human and Operational Factors		
Step	Procedure and Parameters	Tools/Software
Human Factors Analysis	Evaluate pilot inputs, decision-making, response times, training records	Flight data recorders Pilot logbooks Training databases
Geofencing & No-Fly Zone Analysis	Verify compliance with airspace restrictions, geofencing effectiveness	Geofencing databases Airspace maps NFZ verification tools
Electromagnetic Interference Analysis	Check for RF interference, GPS jamming, communication disruption	Spectrum analyzers RF interference detectors EMI analysis tools

Table 2.27 *Incident reconstruction and causality steps for flight logs*

Incident Reconstruction and Causality		
Step	Procedure and Parameters	Tools/Software
Incident Timeline Reconstruction	Create detailed timeline of events leading to incident	Timeline analysis software Event correlation tools Forensic timeline tools
Comparative Analysis	Compare with baseline flights, similar incidents, manufacturer data	Statistical analysis tools Comparative databases Trend analysis
Root Cause Analysis	Apply systematic investigation methods (5-Why, Fishbone, FMEA)	Root cause analysis software Investigation frameworks

Table 2.28 *Final Reporting and Risk Review steps for flight logs*

Final Reporting and Risk Review		
Step	Procedure and Parameters	Tools/Software
Digital Forensics	Extract data from mobile devices Analyze app data Recover deleted files	Cellebrite Oxygen Forensic EnCase Mobile forensic tools
Compliance & Regulatory Analysis	Check adherence to regulations, operator responsibilities, maintenance records	Regulatory databases Compliance checklists Audit trails
Weather Impact Assessment	Analyze weather effects on flight performance, pilot decision-making	Weather analysis tools Meteorological data Impact models
Risk Assessment	Evaluate risk factors, safety margins, hazard identification	Risk assessment tools Safety analysis software Hazard databases
Evidence Documentation	Document all findings, create visual presentations, prepare legal reports	Report generation tools Evidence management systems, Legal documentation

2.8. Error code interpretation

When issues arise in UAVs, internal systems generate error codes to indicate the nature of the problem. Understanding and interpreting these error codes is crucial for effective troubleshooting, maintenance, and safe operation. This section delves into the various aspects of UAV error code interpretation, covering general categories, brand-specific codes, and other diagnostic indicators. These aspects include the general categories of drone error codes, which provide a foundational understanding of common issues across different UAV platforms. Additionally, DJI drone error codes are examined in detail due to the brand's widespread use and unique diagnostic system. For open-source platforms, the section explores ArduPilot error codes, offering insights into how these systems communicate faults. Beyond textual codes, LED patterns serve as visual indicators of drone status and errors, while remote controller beeping codes provide auditory cues that assist operators in quickly identifying and responding to issues during flight.As depicted in Figure 2.16, a range of error codes are used by DJI systems.

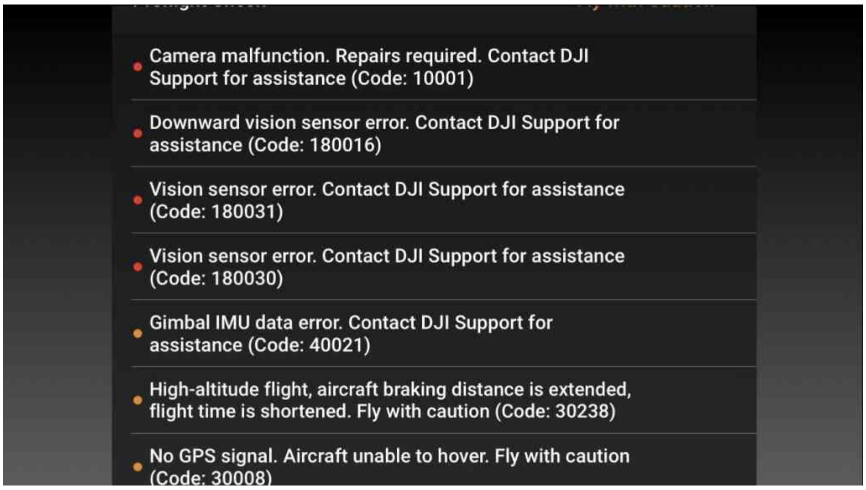


Figure 2.16 DJI Error Codes

2.8.1. Error Classification and Prioritization

Systematically collect all available error information from multiple sources. This includes recording exact error codes displayed on the controller or ground control station, noting LED pattern sequences and their timing, listening for specific beeping patterns, checking mobile app notifications, and reviewing flight logs if accessible. Document the sequence of events leading to errors and any environmental factors (weather, location, interference sources). A comprehensive overview of error types is presented in Table 2.29. Categorize the error by system type (flight control, propulsion, navigation, communication, payload) and severity level. Flight-critical errors affecting basic stability or control take absolute priority, followed by navigation and communication errors that impact mission success, then payload and convenience feature errors. This classification helps determine whether to abort the mission, implement workarounds, or continue with modified procedures.

Table 2.29 *General Error Categorization*

Category	Description
Motor/ESC Errors	Motor not spinning, ESC overheats, or desync.
Battery/PDB Errors	Voltage sag, overcurrent, under-voltage, battery not detected.
Communication Errors	Telemetry loss, RC link loss, MAVLink timeout.
Gimbal & Camera Errors	Gimbal not stabilizing, horizon tilt, camera feed loss, image distortion.
Compass Errors	Magnetic interference, calibration failure, or mismatch between compasses.
GPS Errors	Weak/no signal, poor satellite geometry, or antenna failure.
IMU/Accelerometer Errors	Calibration failure, sensor drift, temperature issues.
Barometer Errors	Altitude sensor problems, clogged vent, temperature drift.

Vision Sensor Errors	Obstacle detection failure, poor surface tracking, dirty or blocked lens.
Software Errors	Firmware crashes, parameter corruption, incompatible configuration, or system boot failure.

2.8.2. DJI Drone Error Codes

DJI error codes are organized in a numerical sequence, with each code representing a specific category or type of issue. This structured approach allows users to quickly identify and troubleshoot problems based on the code number. Table 2.30-37 lists the error codes of DJI drones by class.

Table 2.30 *Camera & SD Card Errors for DJI Drones*

Error Code	Description	Possible Solution
10001	Camera malfunction	Calibrate camera
10016	Camera not calibrated	Insert SD card
10022	No SD card	Try reinserting card or replace SD card
10023	SD card malfunction	Unable to hover, fly with caution

Table 2.31 *GPS & Barometer Errors for DJI Drones*

Error Code	Description	Possible Solution
30004	Aircraft in attitude mode	Repair or replace GPS module
30007	No GPS signal	Check environment, may need GPS repair
30008	No GPS signal/weak signal	Check RC connection
30047	Barometer initialization failed	Restart aircraft or replace GPS module
30049	GPS Module Error	Calibrate IMU, may need GPS module repair

Table 2.32 *Motor ESC and Propeller Errors for DJI Drones*

Error Code	Description	Possible Solution
30045	Motor is idling	Ensure propellers are unobstructed.
30046	Motor overloaded	Remove excess payload.
30047	Not Enough Force/ESC Error	Check motor and ESC connections.
30165	Motor stuck	Check for physical obstructions.
30168	Max power load reached	Avoid aggressive maneuvers.
30210	Power system hardware	Restart aircraft. If not resolved, update firmware

Table 2.33 *IMU & Compass Errors for DJI Drones*

Error Code	Description	Possible Solution
30050	IMU calibration required	Calibrate IMU in settings
30055	IMU not calibrated	Calibrate IMU
30060	Compass error	Remove metal objects, calibrate compass
30082	IMU attitude restricted	Ensure aircraft is level

Table 2.34 *Battery Errors for DJI Drones*

Error Code	Description	Possible Solution
30068	Battery installed incorrectly	Detach and reinstall battery
30078	Battery power low	Check/charge/warm battery
110002	Battery overheating	Check/replace GPS module
110024	Battery error - auto RTH	Stop flying, let battery cool

Table 2.35 Remote Controller & Other Errors for DJI Drones

Error Code	**Description**	**Possible Solution**
30029	Remote controller disconnected	Restart aircraft
30064	Unable to takeoff	Check flight area restrictions, restart if needed
30226	Takeoff failed	Check takeoff conditions

Table 2.36 *Gimbal Errors for DJI Drones*

Error Code	Description	Possible Solution
40002	Gimbal stuck	Check gimbal cover is removed, ensure free rotation
40003	Gimbal motor overloaded	Check gimbal can rotate freely
40011	Gimbal calibration error	Restart aircraft
40012	Gimbal unable to connect	Replace the gimbal
40021	Gimbal IMU data error	Repair or replace GPS module

Table 2.37 *Vision Sensor Errors for DJI Drones*

Error Code	Description	Possible Solution
180016	Downward vision sensor error	Restart drone. If not resolved, sensors need replacement
180018	Forward vision sensor error	Check/clean sensors
180030/31	Vision sensor error	Restart drone. If not resolved, sensors need replacement. Contact DJI Support

2.8.3. ArduPilot Error Codes

During pre-flight checks, UAV systems display specific warning codes to alert users about potential safety or configuration issues. Understanding these codes helps ensure stable flight performance and prevents in-air failures. The table below lists common error messages, their meanings, and recommended actions. Table 2.38 provides a list of frequently encountered errors

Table 2.38 *Common ArduPilot Error Mesages*

Error Messages	Meaning	Action
PreArm: Compass not calibrated	Compass not ready	Calibrate compass
EKF variance	Sensor fusion failure	Check IMU/GPS/compass
GPS Glitch	Sudden GPS signal deviation	Check antenna, move it to open area
Bad AHRS	Attitude estimation failure	Recalibrate IMU
No RC Receiver	No signal from controller	Check connection/bind controller

2.8.4. Error Communication Methods

LED Pattern Interpretation method involves using blinking lights. For example, a fast red blink may signal a critical error such as a motor failure or ESC error, while a steady green light typically indicates normal operation. A slow yellow blink often means the GPS is not locked or that calibration is needed. Buzzers or speakers can emit beeping patterns to alert the user to specific system conditions or problems. For instance, one beep may indicate the battery is connected, three quick beeps might suggest an ESC or motor error, and continuous beeping can warn of a low battery or activated failsafe. These audio signals are valuable during pre-flight checks or when the drone is out of sight but still within hearing range. Mobile applications like DJI Fly display error messages through pop-ups or notifications. These messages provide direct, user-friendly feedback such as “Compass Calibration Required,” “No GPS Signal,” or “Battery Critically Low – Landing.” Ground Control Station (GCS) software, such as Mission Planner on a desktop or tablet, offers real-time telemetry-based alerts. These can include HUD (Heads-Up Display) warnings like “EKF Variance” or “Failsafe: RTL triggered,” status bar messages, or color-coded overlays on a live map indicating the location and nature of a problem. The different methods for error indication are outlined in Table 2.39.

Table 2.39 Error Indication Methods

Category	Description
LED Pattern Interpretation	Using blinking lights (usually RGB LEDs) in specific patterns or colors
Audio/Beeping Codes	Buzzers or speakers produce sound patterns
Mobile App Error Messages	The companion mobile application (e.g., DJI Fly) shows text or pop-up messages
Ground Control Station Alerts	GCS software (e.g., Mission Planner) gives live telemetry-based alerts.

CHAPTER 3

Maintenance Procedures

3.1. Pre-flight checklists

To maintain the safety and optimal performance of the drone, regular inspections are essential (Figure 1). These checks help identify potential issues before flight and prevent risks.

The drone's arms should be inspected for cracks, bends, or weaknesses at the joints. It is also important to check that the arms are properly secured and that the folding or unfolding mechanism works correctly, to avoid structural problems during flight.

The propellers must be checked for scratches, chips, or deformations that could affect the drone's stability. Their proper installation (CW/CCW) must be verified to prevent excessive play and to ensure smooth flight.

The drone's body should be examined for cracks, impacts, or the presence of foreign objects. It is essential to ensure that covers are properly closed and that ventilation openings are clean, to prevent the accumulation of dust and debris.

For a functional and safe power source, **the battery** should be checked before each flight. It is recommended that the battery charge level be at least 70% for a medium-length flight and 100% for a long-duration flight. Overheated or swollen batteries must not be used to avoid risks. The battery's secure attachment, locking mechanism, and the cleanliness of the connectors are important aspects that should be verified. **The stability and accuracy** of navigation depend on the proper functioning of the sensors and GPS system. Optical and ultrasonic sensors should be

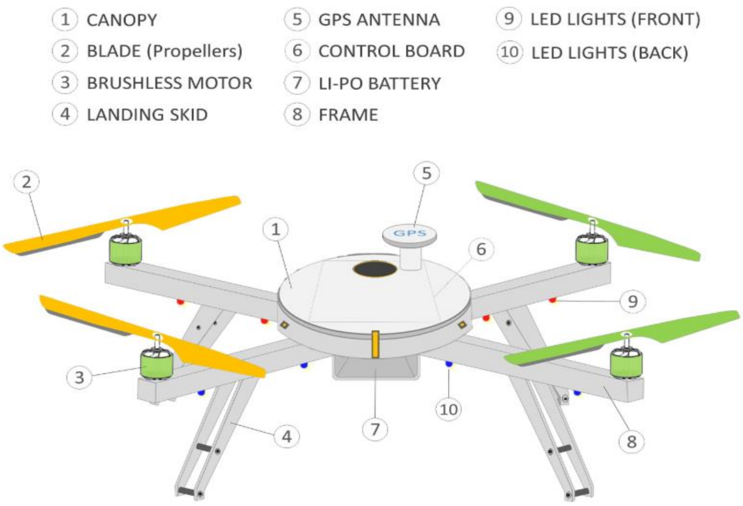


Figure 3.1 *The components of the drone*

cleaned of dust or dirt, and it is recommended to test them for obstacle detection.

The GPS system should establish a connection in an open area with at least **6–8 satellites available**. If the GPS does not connect properly, recalibrating the compass may be necessary.

Before use, the remote controller must be **checked to ensure stable** signal transmission and a proper connection. The drone should be tested at a height of 1–2 meters for tilting, rotation, lateral movement, and acceleration, confirming a prompt and accurate response. Automatic functions, such as "Return to Home" and hover mode, should be tested in safe conditions to ensure efficient operation.

3.2. Post flight checklists

To ensure the proper functioning and durability of the drone, it is important to perform regular checks and careful maintenance. This process involves physical inspection of the device, recording incidents, proper cleaning, and evaluating flight data.

A detailed visual inspection is essential to identify any potential damage. It is recommended to check the arms, propellers, and body for signs of wear or damage (Figure 2). The battery should also be inspected to prevent issues caused by overheating or swelling. Sensors and the camera should be periodically checked and cleaned to remove any dirt deposits that could affect the drone's performance.

Figure 3.2 *Visual inspection of component elements.*

For efficient and safe operation, it is necessary to monitor issues that occur during flights. Collisions, signal loss, or other anomalies should be recorded in a flight log, either physical or digital. This information helps identify recurring problems and prevents future incidents.

Regular maintenance of the drone involves removing dust using a soft cloth or a gentle brush. The camera lens should be cleaned with a microfiber cloth and a special cleaning solution to maintain image clarity. Hard-to-reach areas can be cleaned with a small, soft brush to remove impurities.

Analyzing the drone's route, altitude, and speed provides valuable information about its performance. Identifying anomalies and saving flight data help optimize device usage and prevent errors.

To keep the drone in optimal condition, inspections should be performed in a safe environment. It is recommended to consult the device's manual for specific requirements and to avoid using the drone if any problems are detected.

3.3. Firmware update

Firmware updates are an essential step in maintaining the drone's performance, safety, and operational stability (Figure 3). Firmware refers to the internal software that controls the operation of all components, from motors and sensors to the GPS system and remote-control connections. To avoid operational errors or security vulnerabilities, it is recommended that the drone's firmware be updated regularly using official methods provided by the manufacturer.

The first step in the update process is to check the current version of the installed firmware. For this, the drone must be connected to the manufacturer's application, such as DJI Fly, Autel Explorer, or dedicated software like DJI Assistant 2. Firmware version information for the drone, remote controller, and batteries is usually found in the "Settings" or "About" sections of the application. The identified version should be compared with the latest available version on the manufacturer's official website to determine whether an update is necessary.

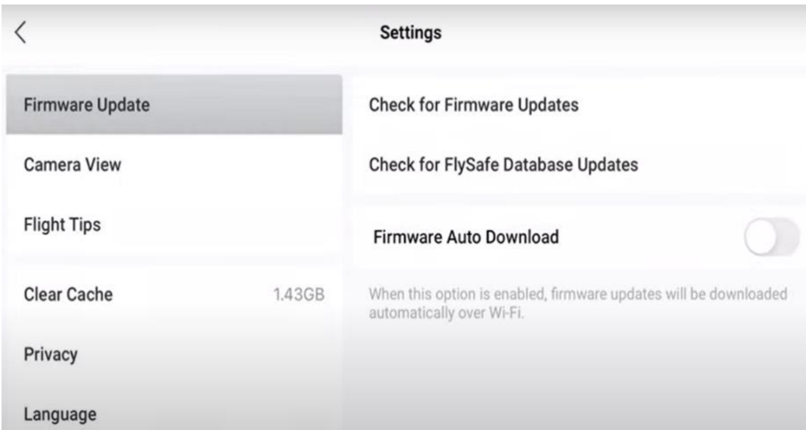


Figure 3.3 Firmware Update

Once the need for an update is established, the next step is to download the corresponding firmware file for the drone model. Downloads should only be performed from the official website of the manufacturer or from the associated mobile app. It is important to verify the compatibility of the downloaded file (e.g., file extensions like .bin or .zip) to avoid installation problems or incompatibilities.

There are several available methods for updating the drone's firmware, depending on the model and manufacturer.

Using the mobile application, the update is carried out easily by connecting the drone via Wi-Fi, Bluetooth, or USB cable. The application will notify the user about the availability of a new version and will automatically guide the download and installation process. During the update, it is crucial not to disconnect any of the involved devices.

Firmware updates via computer are done by connecting the drone to a PC or laptop via USB and using the manufacturer's official software. The procedure involves downloading the firmware file and initiating the update according to the software's instructions. For certain models, there is also the option of updating by placing the firmware file on a microSD card, a method frequently used for industrial or specialized drones such as the Flyability Elios 2. For drones compatible with the DroneCAN protocol, users can employ tools like DroneCAN GUI or Mission Planner to perform firmware updates.

At the end of the process, the drone will restart automatically, and the user must verify the correct installation by accessing the application or software again. It is recommended that after each update, a test flight be conducted in a safe area to confirm the proper functioning of the equipment.

Firmware updates can be carried out using mobile applications such as DJI Fly, Autel Explorer, or Parrot FreeFlight, available for both iOS and Android platforms. The advantage of using mobile applications lies in their user-friendly interface and quick access to updates, but they require a stable internet connection, a battery level of at least 50%, and sufficient storage space on the device.
Alternatively, desktop software such as DJI Assistant 2 or Mission Planner provides greater stability for complex updates, allowing efficient firmware file management. This method requires a USB connection, internet access, and the prior installation of the application on the computer. For certain models, the microSD card may serve as an additional solution for updates.

To prevent process interruption or errors, it is necessary to ensure that the batteries of the drone, the remote controller, and the device used for updating are charged to at least 50%, preferably 100%. If battery firmware requires separate updates, these should be completed before the drone is used.

It is recommended to back up the drone's settings (custom flight modes, calibrations) to a microSD card, a computer, or cloud storage. During the update, it is preferable to avoid Wi-Fi interference, and the USB connections used should be compatible and in good condition. Additionally, removing the drone's propellers and temporarily disabling antivirus software on the computer can help minimize the risk of errors.

After the update, all essential functions of the drone (flight, camera, sensors) must be tested. If necessary, recalibration of the compass, inertial measurement unit (IMU), or camera gimbal should be performed before resuming normal operation.

For frequent or professional drone use, it is recommended to check for firmware updates on a monthly basis. For occasional users, quarterly checks are usually sufficient. Critical updates, especially those that fix safety issues, should be installed as soon as they become available. Before any important mission or specialized flight, a complete test of the equipment is recommended. For added safety, it is advisable to keep previous firmware versions, where the manufacturer allows it.

3.4. Battery care

This section provides essential recommendations for the correct charging, discharging, and storage of LiPo batteries, aimed at extending their lifespan and preventing risks of damage or fire.

- **To maximize the performance and lifespan of LiPo batteries**, it is crucial to follow proper practices during the charging and discharging process (Figure 4).

  It is recommended to use only manufacturer-approved chargers, such as those from DJI or Autel, to avoid battery damage. Charging should be carried out at a current of 1C (e.g., 5A for a 5000 mAh battery), avoiding frequent fast charging, which can reduce cell longevity.

- **The charging process should be performed** in a well-ventilated environment at a temperature between 15–25°C, and the battery should be disconnected once it reaches 100%.

***Figure 3.4** LiPo battery*

- **To prevent cell damage**, the battery should not be discharged below 20–25%. If the battery reaches a critical level (10–15%), immediate landing is recommended. Battery levels should be checked after each flight, either via the dedicated app or through LED indicators on the battery.
- **Partial discharge cycles, such as 30–40%**, are preferable to optimize battery lifespan. If the battery is not going to be used for an extended period, a controlled cycle should be performed every few weeks.
- **To prevent failures and fire hazards**, batteries should always be charged on non-flammable surfaces, such as LiPo fireproof bags. If the battery temperature exceeds 45°C during charging, the process must be stopped immediately. During flight, operating the drone in extreme temperatures (<0°C or >40°C) should be avoided, and between demanding flights, a 10–15 minute cooling period is recommended.
- **For long-term battery health,** batteries should be stored at a charge level of 50–60% (3.8–3.85V per cell) (Figure 5). Storing them fully charged or fully discharged should be avoided. The storage environment should be dry, with a temperature of 15–25°C, away from moisture and dust. Battery levels should be checked every 2–3 months, and a full charge-discharge cycle is recommended every 6 months.
- **A LiPo battery can typically handle between 200 and 300 full charge cycles**, with partial cycles potentially extending lifespan to 400–500 uses. Battery capacity usually decreases by 20–30% after approximately two years. Signs of wear include reduced flight time, swelling, leakage, and overheating. Battery health can be monitored using the manufacturer's application, such as the "Battery Health" feature in DJI Fly. In cases of severe wear, batteries must be replaced with original models, avoiding third-party alternatives.

3.5. Maintenance types

To ensure the optimal operation of the drone, it is essential to adopt an appropriate maintenance strategy. This can be corrective, preventive, or predictive, each with its specific role in maintaining and protecting the device.

- **Corrective maintenance** involves repairing the drone after a malfunction has been identified and is a reactive approach to issues such as broken propellers, faulty motors, or software errors. Common examples include replacing damaged propellers, repairing motors that produce abnormal noises, recalibrating or replacing defective sensors, repairing the frame after hard landings, and reinstalling firmware to fix errors.

Procedures typically involve using the manufacturer's application to identify error codes, consulting the drone's manual, contacting an authorized service center for complex repairs, and exclusively using original parts. The main advantages of this approach are quick resolution of problems; however, it comes with higher costs and does not prevent new failures from occurring.

- **Preventive maintenance** focuses on preventing failures before they occur through regular inspections. This type of scheduled verification is essential for frequent or professional users. Examples include inspecting propellers for wear, cleaning sensors and cameras, checking cables for corrosion, calibrating the compass, IMU, and gimbal, and monitoring battery health. A preventive maintenance schedule may consist of daily visual inspections (propellers, frame, sensors), weekly detailed cleaning and connection checks, monthly sensor calibrations and battery monitoring, and quarterly motor inspections and firmware updates. Advantages of this approach include reduced risk of failures and extended drone lifespan, although it requires time and discipline to implement effectively.
- **Predictive maintenance** is an advanced method that anticipates failures by analyzing data collected by the drone. It relies on flight logs and sensors to detect wear and is ideal for professional fleets or critical missions. Application examples include monitoring battery cycles and temperatures, analyzing motor vibrations, detecting abnormal patterns in flight logs, and using artificial intelligence for specific recommendations. Technologies involved include specialized software such as AirData UAV, DJI FlightHub, and DroneLogbook, integrated sensors for real-time monitoring, and cloud computing for fleet management. This method is primarily applied in professional environments and less in individual use. Its advantages include cost optimization and reduced downtime, but implementation can be expensive and requires advanced technical knowledge.

3.6. Maintenance schedules

To keep the drone in optimal working condition, it is important to adopt a regular maintenance program. This maintenance can be corrective, preventive, or predictive, and the frequency of each type of inspection depends on the usage and specific characteristics of the device.

Table 3.1 *Drone Maintenance Frequency*

Frequency	Corrective Maintenance	Preventive Maintenance	Predictive Maintenance
Daily	Checking for error codes after each flight using dedicated apps. Fixing minor defects such as damaged propellers or loose screws.	Visual inspection of propellers, frame, and sensors. Checking battery level and quickly cleaning optical components.	Monitoring flight logs for immediate errors. Evaluating battery health using specialized applications.
Weekly	Repairing or replacing damaged components, including motors and sensors. Reinstalling firmware in case of recurring errors.	Thorough cleaning of the drone, checking connections for wear, testing basic functions such as flight and camera operation.	Analyzing flight logs to detect abnormal patterns, such as motor vibrations. Monitoring battery charge cycles.
Monthly	Repairing major components, such as the mainboard, at an authorized service center. Restoring settings from backup if firmware issues occur.	Calibrating the compass, IMU, and gimbal. Checking battery health and eliminating potential defects. Updating firmware.	Analyzing flight data to identify component wear. Generating predictive reports for optimal maintenance planning.
Annually	Replacing critical components such as motors or batteries. Performing a complete overhaul at an authorized service center.	Detailed inspection of internal components. Preventive replacement of worn propellers and verification of compliance with current regulations.	Evaluating long-term performance by analyzing historical data. Planning component replacements, such as batteries after 200–300 usage cycles.

Important Considerations

- ***Corrective maintenance*** is performed only when failures occur, and its frequency depends on the incidents encountered.
- ***Preventive maintenance*** is essential for all drones and must be carried out according to a regular schedule.
- ***Predictive maintenance*** is ideal for professional fleets and is implemented using advanced software tools.
- **The frequency** should be adapted according to the manufacturer's specifications and the drone's usage—whether for recreational or industrial purposes.

3.7. Cleaning and protection procedures

3.7.1. Proper Cleaning and Protection of the Drone

To keep the drone in optimal condition, proper cleaning is essential, using suitable materials and following precautions for sensitive components.

For external surfaces, lenses, and sensors, it is recommended to use microfiber cloths that are lint-free and non-abrasive. Examples of effective products include Amazon Basics and 3M Microfiber. Non-abrasive solutions, such as isopropyl alcohol (70–90%) or dedicated lens cleaning products (e.g., Zeiss), should be applied to the cloth—not directly on the drone—to prevent damage. Compressed air, used from a distance of 10–15 cm, helps remove dust from ventilation slots and motors. Soft brushes, such as antistatic LensPen brushes, are ideal for cleaning sensors and motors. Protective sprays, like H_2O Nano Coating, can be applied to external surfaces, avoiding contact with sensors and lenses.

Figure 3.5 *Cleaning the sensors*

Cleaning optical, ultrasonic, and LiDAR sensors must be done with a dry microfiber cloth or isopropyl alcohol, avoiding excessive pressure and liquids that might penetrate internal components. Motors should be cleaned with compressed air and soft brushes, without rotating them manually to prevent mechanical wear. Camera and gimbal lenses require special attention, being cleaned with microfiber cloths and lens cleaning solutions, avoiding manual movement of the gimbal. Ports and connections must be dusted using compressed air or fine brushes, with liquids strictly avoided.

To prevent drone damage, it is essential to avoid contact with water, which can cause corrosion and short circuits, except for water-resistant models such as the DJI Matrice 30. Corrosive substances like detergents, acetone, ammonia, and chlorine must not be used. Pressurized water jets and vacuum cleaners can dislodge fragile components, and excessive use of liquids may impair the functionality of sensors and electronic boards. Drone cleaning must always be performed with the device powered off and the battery removed before any intervention.

3.7.2. Drone cleaning can be adapted depending on the usage context:

- **In the field**: Designed for quick post-flight cleaning using portable tools such as microfiber cloths, soft brushes, compressed air, and isopropyl alcohol. Procedures include turning off the drone, removing the battery, detaching the propellers, using compressed air for motors and sensors, cleaning lenses and sensors with microfiber, and conducting a general inspection of the frame. Precautions include avoiding exposure to wind and dust, minimizing the use of liquids, and storing the drone in a protective carrying case.
- **In the workshop**: Detailed cleaning ensures long-term protection. Tools include microfiber cloths, 90% isopropyl alcohol, higher-power compressed air, antistatic brushes, and protective sprays. Procedures involve disconnecting the battery, removing the propellers, disassembling the frame (if allowed by the manufacturer), cleaning motors, vents, and ports, applying protective spray to external surfaces, reassembling the drone, and testing functionality. Precautions include using a clean working environment, avoiding unauthorized disassembly, and using antistatic tools.

3.8. Component lifespan expectations

3.8.1. Component Lifespan and Replacement Criteria

To ensure long-term drone functionality, it is essential to plan maintenance and identify the optimal time for replacing worn components. The lifespan of these parts depends on usage, flight conditions, and regular maintenance.

Table 3.2 *Estimated Lifespan*

Component	Estimated Lifespan	Replacement Criteria
Propellers	100–200 flight hours / 6–12 months	Presence of cracks, chips, abnormal vibrations, or loss of flight stability.
Batteries (LiPo)	200–300 cycles / 1–3 years	Capacity below 70%, swelling, leakage, or errors reported by the app.
Motors	500–1000 flight hours / 2–5 years	Abnormal noises, vibrations, overheating, or worn bearings.
ESCs (Electronic Speed Controllers)	1000–2000 flight hours / 3–7 years	Motor failures, overheating, or persistent software errors.
Controllers	3–5 years / Physical wear	Weak battery, unresponsive buttons or joysticks, frequent disconnections.

3.8.2. Factors Influencing Component Lifespan:

- **Propellers**: Material (plastic vs. carbon fiber), exposure to dust, impacts, or harsh conditions affect longevity.
- **Batteries**: Frequent full charge cycles and improper storage can significantly reduce battery life.
- **Motors**: Brushless motors are more durable, but operating in extreme environments increases wear.
- **ESCs**: Voltage surges and high temperatures accelerate deterioration, with failures potentially affecting multiple motors simultaneously.
- **Controllers**: Physical wear and incompatibility with firmware updates can impact performance.

To prevent failures and maintain optimal drone performance, the following criteria must be observed:

- **Visual and Functional Inspection**: Propellers should be checked for cracks before each flight, and batteries for swelling or leaks. Motors and ESCs must be monitored for unusual noises and overheating, and controllers tested for joystick responsiveness and stable connectivity.
- **Performance Decrease**: If flight time drops below 70%, stability is compromised, or drone control becomes imprecise, component replacement is recommended.
- **Software Reports**: Specialized applications (e.g., AirData UAV) can indicate battery wear, motor degradation, or other critical errors.
- **Physical Wear**: Any visible damage, such as chipped propellers or swollen batteries, requires immediate replacement.
- **Manufacturer's Recommendations**: Follow the intervals specified in the manual, such as replacing propellers every 200 flight hours, and always use original parts.
- **Special Conditions**: Drones used intensively or in harsh environments (dust, humidity) require more frequent inspections and adjustments to the maintenance schedule.

3.9. Environmental considerations (operating in dust, moisture, etc.)

3.9.1. Operating Drones in Challenging Environments

To ensure the performance and durability of a drone, specific measures must be taken when operating in dusty, humid, or extreme temperature environments.

To protect components from dust accumulation, it is recommended to use air intake filters, such as those available for the DJI Mavic 3 Enterprise. These filters should be cleaned or replaced after each mission to prevent airflow blockage. Additionally, installing protective covers for propellers and sensors—such as PGYTECH Propeller Guards—can help reduce exposure to dust. However, these should be removed during regular operations to optimize flight performance. After each flight, motors, sensors, and air vents should be cleaned with compressed air or a soft brush, while propellers and sensors must be inspected for dust deposits. Flying during sandstorms should be strictly avoided, and the drone's IP rating (e.g., IP54 for DJI Matrice 30) should be checked to determine its level of protection against dust particles.

To prevent corrosion and short circuits, drones should be properly sealed. Checking seals and ports, such as those with an IP43 rating on the DJI Mavic 3 Enterprise, contributes to internal protection. Applying a hydrophobic spray, such as H_2O Nano Coating, can offer additional protection, but it must be kept away from sensors and lenses. Drones without an IP rating should be kept away from rain and fog. After flying, the device should be thoroughly dried: remove the battery, wipe the drone with a microfiber cloth, and leave it to air dry in a ventilated area for 2–4 hours. To absorb internal moisture, silica gel or rice can be used for 12–24 hours. Heat sources such as hairdryers must not be used for drying drones. Starting a wet drone should be avoided, and flights over deep water should only be undertaken with waterproof models such as the SwellPro SplashDrone. Storing the drone in a waterproof carrying case helps protect it from moisture during transport and storage.

Drones should be protected from both extremely low and high temperatures to maintain optimal performance. In cold conditions (below 0°C), batteries should be kept warm before use. Pre-heating functions (if available) and insulated cases are recommended. In hot environments (above 40°C), prolonged exposure to direct sunlight must be avoided. Cooling breaks of 10–15 minutes are required between intense flights, and reflective covers can help maintain optimal operating temperatures. Regardless of the ambient temperature, the drone should be acclimatized for 10–15 minutes before starting, and batteries should be stored at temperatures between 15–25°C. Consulting the manufacturer's manual is essential to respect the drone’s specified temperature operating limits.

3.9.2. Storage & Transportation

To prevent damage during transport and storage, it is essential to use appropriate protective equipment and follow safety regulations.

Hard cases, such as the DJI Mavic 3 Carrying Case or IP67-rated Pelican models, offer protection against impact, dust, and water. These cases should be fitted with custom foam inserts to securely hold the components, and batteries must be stored separately in fireproof compartments. For short trips, soft bags like the DJI Shoulder Bag or Lowepro DroneGuard provide a lightweight and portable option. These bags should be properly padded for extra protection, and overloading must be avoided. For safe transport, propellers should be stored separately, components should be firmly secured, and airline regulations for LiPo batteries must be checked before traveling.

Maintaining the health of drone components requires proper storage conditions. The optimal temperature should be between 15–25°C, avoiding extremes of <0°C or >40°C.

Humidity should be kept below 60%, and using silica gel or dehumidifiers helps prevent moisture buildup. Drones should be kept in a clean, well-ventilated space, away from direct sunlight to avoid UVB radiation exposure. Batteries should be stored at 50–60% charge and checked every 2–3 months. For maximum safety, the use of fireproof battery cases is recommended, and storage cabinets should be kept dry. Avoid storing the drone in damp areas, such as basements, and do not place heavy objects on top of it.

To protect foldable arms, they must be properly secured with clamps, and foam supports in cases should be used to prevent uncontrolled movement. It's important not to force folding mechanisms. The gimbal should be locked using dedicated devices such as the DJI Gimbal Lock, and additional protection can be provided using foam or non-aggressive adhesive bands. Drones must be powered off before locking the gimbal. Propellers should be removed and stored separately to prevent deformation and accidental activation.

To comply with LiPo battery regulations, they must be transported with a charge of no more than 30%, in accordance with IATA guidelines. For air travel, batteries must be carried in hand luggage, and the allowed energy limit should be verified (e.g., <100 Wh). Proper labeling, such as “Lithium Battery” and “Fragile,” must be applied, and a declaration of conformity should be included. General regulations require checking customs restrictions for drones, adding contact information labels, and using hard cases for road or rail transport. Before traveling, it is important to consult IATA regulations and airline policies to avoid transport issues. Damaged batteries must not be transported for maximum safety.

CHAPTER 4

Repair and Component Replacement Procedures

The aim of this chapter is to provide a practical guide to the maintenance, repair and part replacement processes of unmanned aerial vehicles (UAVs). In particular, the technical knowledge, methods and practical applications required for individuals trained as UAV technicians to perform systematic and safe interventions will be conveyed in detail.

4.1. Materials Required for UAV Maintenance, Repair and Replacement Processes and Work Area Setup

Before starting UAV maintenance, repair and replacement operations, it is of utmost importance to correctly identify the tools to be used and to prepare them appropriately for the application (Figure 4.1). In this section, an annotated list of the basic tools commonly used in such operations is presented (Table 4.1). The function of each tool and how it can be used together with which parts are briefly and simply stated.

Figure 4.1 *Materials Required in UAV Maintenance, Repair and Replacement Processes*

Table 4.1Materials Required in UAV Maintenance, Repair and Replacement Processes

BASIC HAND TOOLS	
Material	**Description**
Screwdriver Set (Mini)	Used for unscrewing small parts such as flight controller, ESC, camera. Mostly Philips (star), flat and Allen (hexagon) bits are required.
Tweezers (Antistatic)	Used for precise positioning of small cables and connectors. Especially effective in cable positioning after soldering.
Pliers and needle-nose pliers	Used for pulling jammed cables or holding small parts.
Wire Stripper and Side Chisel	It is necessary to open the cable ends and cut off excess lengths. The cable end must be opened before soldering.
Scissors (Electrician Type)	For cutting insulating tape, thermal sheath or plastic fasteners.

ELECTRONIC INTERVENTION TOOLS	
Material	**Description**
Soldering Station	A temperature regulated soldering iron device ensures the correct connection of wires and components in soldering processes.
Solder Wire and Paste	Conductive solder is used to ensure electrical connections. The solder paste is important for heat conduction and connection quality.
Multimeter	For voltage measurement, short circuit testing and checking cable continuity. Especially used in ESC and PDB tests.
Heat Gun (Hot Air Gun)	For heat shrinkable tubing and delicate part removal. Used in cases such as the removal of soldered BGA parts.

MOUNTING AND FIXING MATERIALS	
Material	**Description**
Screws and Spare Screws (M2, M3)	Metal or plastic screws of different sizes used for fastening parts.
Anti-Vibration Pad (Damping Pad)	Placed under the flight controller, it prevents vibration and improves sensor efficiency.
Cable Ties (Zip Tie)	It is used for fixing the cables and for a tidy appearance after assembly.
Heat Sensitive Tubing (Heat Shrink Tube)	To insulate and protect the soldered ends. When heat is applied, it shrinks and adheres to the cable.

TEST AND CALIBRATION DEVICES	
Material	**Description**
ESC Programmer / BLHeli Tool	For updating the ESC software and making calibration adjustments.
IMU and Compass Calibration Software	Calibration operations are performed through software such as Betaflight, iNav, Mission Planner.
Servo Tester (optional)	Used for manual testing of ESC or engine response. For training purposes.

SECURITY AND PROTECTION EQUIPMENT	
Material	**Description**
ESD Wristband and Mat	To prevent damage to electronic components from static electricity.
Nitrile or Latex Gloves	Provides hand protection in sensitive interventions, oil-proof.
Protective Goggles	Against the risk of spatter and sparks during soldering.
LiPo Safety Case	Used for safe storage and transport of batteries.
Fire Extinguisher (Small CO_2 Type)	It should be kept in the working environment for intervention to battery fires.

WORK DESK AND ENVIRONMENT LAYOUT	
Feature	**Description**
Lighting	Powerful, shadowless table lamps are recommended, from which the entire area can be clearly seen.
Antistatic Table Cloth	Standard for electronic mounting surfaces.
Part Boxes and Labels	So that each part is kept organised and not mixed up.
Spare Parts Stock List	Having spare parts such as ESC, FC, engine, propeller makes your job easier.

Workspace Setup:

- A clean, tidy and well-lit table should be preferred. It is recommended to use a smooth and light-coloured surface to prevent small parts from getting lost.
- Protect electronic components from electrostatic discharge by using an antistatic wristband or antistatic mat.
- Organising tools and equipment in an easily accessible way reduces errors and time loss during the process.

- A heat-resistant soldering area ensures the safe use of soldering irons and other heating equipment.
- When working with sensitive parts, tweezers, pliers, screwdriver tools and labelling materials should be available.

Security Protocols:

- Before each operation, the battery of the drone must be removed and make sure that the entire system is de-energised.
- It is important not to inhale fumes during soldering operations and to ensure that the work area is well ventilated.
- Connections should be checked by using a multimeter for short circuit tests; incorrect cable connections should be avoided.
- Precautions such as safety bag, metal surface and fire extinguisher should be taken in LiPo battery operations with fire risk.
- All equipment used must be cleaned and stored safely after the process is completed.

Making these preparations completely contributes to the efficient, safe and error-free execution of repair and part replacement processes.

4.2. Drone Parts Introduction, Replacement and Failure Types

This chapter aims to introduce in detail each of the basic parts that make a drone work, explaining step by step how these parts can fail and how to replace them when necessary. In each sub-heading; the function of the part, common failure types encountered, safe disassembly and assembly methods, and maintenance tips will be included.

Figure 4.2 *Example Drone Image*

At the end of the chapter, the user will have the knowledge and skills to recognise all the parts that make up a UAV (Figure 4.2), to identify faulty parts and to perform basic interventions.

4.2.1. Flight Controller

The Flight Controller (Figure 4.3) is the central processing unit and control system of a drone.

Figure 4.3 *Drone Flight Controller Component*

The inertial measurement unit (IMU) integrated on it collects raw data from sensors such as gyroscope, accelerometer, barometer, magnetometer and processes them in real time (Figure 4.4). It also communicates with motor drivers (ESC), GPS module and other peripheral components. In this way, it continuously calculates and analyses flight dynamics such as the drone's position, speed, direction and acceleration. It interprets the commands given by the pilot or autonomous systems and sends controlled commands to the motors and other actuators, thus ensuring stable, balanced and safe flight of the drone.

Figure 4.4 *Flight Controller Internal Structure and Components*

4.2.1.1. What does it do?

- Maintains stable and balanced flight of the drone in horizontal and vertical planes.
- It instantaneously detects deviations caused by wind, air currents and other external influences and generates corrective control signals.
- By changing the speed and direction of the propellers, it provides the steering and manoeuvrability of the drone.
- Manages autonomous flight modes; executes functions such as GPS-assisted route tracking, waypoint navigation, position hold and return to home.
- It provides real-time telemetry data and transmits flight parameters to the ground control station, enabling operational control and monitoring.

4.2.1.2. Symptoms of Failure:

- The drone may behave unstable at take-off or during flight and may tumble or lose control.
- Stability problems, vibrations or sudden deviations may be observed during the flight.
- Delayed, incomplete or no response to pilot commands indicates a processing or communication problem of the flight controller.
- Certain fault codes flash on the LED indicators on the flight controller, allowing diagnostics.
- Flight modes may not function properly as a result of sensor calibration errors or communication interruptions.

4.2.1.3. Exchange and Assembly Procedure

Step 1

Disconnect all power supplies to the drone (Figure 4.5). Make sure the system is completely de-energised, especially by removing the battery. This is critical to avoid the risk of electrical short circuits and component damage.

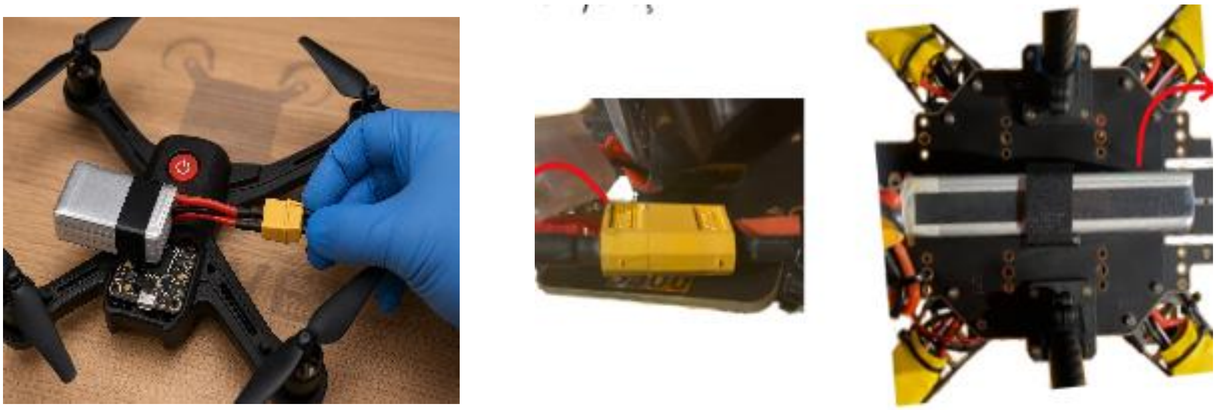


Figure 4.5. De-energising the Drone for Safe Intervention

Step 2

Determine the physical location of the flight controller (FC). It is usually located in the centre of the drone body, in a vibration isolated area. It has many cable connections and integrated sensors (IMU, barometer, compass).

Step 3

Carefully disconnect all cables connected to the flight controller (ESC signal cables, GPS antenna cable, receiver connections, sensor data lines, etc.). To prevent incorrect connection of the cables, make sure to label the location of each connection or record it by taking high resolution photographs.

Step 4

Remove the screws or mounting brackets securing the flight controller. Retain the anti-vibration pads or silicone sealing tapes used during assembly or replace them as necessary.

Step 5

Carefully place the new flight controller in its original position and orientation. Most flight controllers have an arrow pointing in the front direction; make sure this pointing is parallel to the front of the drone.

Step 6

Cut and securely attach all connecting cables to the correct ports in accordance with labelling and photographs. The strength of the cable ends and the cleanliness of the solder joints are critical to flight safety.

Step 7

Calibrate the flight controller. This can be done both by manual control and by using software such as Betaflight, Mission Planner, iNav.

- IMU calibration: The drone must be on a stable and horizontal surface.
- Compass calibration: The drone should be rotated 360° in an open area away from magnetic field effects.
- Accelerometer calibration: Ensures the accuracy of the drone's accelerometer sensors.
- Heading adjustment: Correct heading must be set for compass and GPS compatibility.

Step 8

Perform a test flight after calibration and connection. Perform the first flight at low speed and low altitude.

- Test the drone's slow take-off, stable position hold and steering controls.
- If any abnormality, vibration or uncontrolled movement is detected, recalibrate and check the connection.

4.2.2. ESC (Electronic Speed Control Unit)

ESC (Electronic Speed Control Unit) is the electronic circuit that precisely controls the electric current and signal sent to the drone motors (Figure 4.6). It converts the speed and direction commands received by the pilot from the controller or flight controller into the electrical signal required by the engines. In this way, the speed and direction of rotation of each engine are controlled independently. ESCs are generally compatible with three-phase brushless motors and ensure stable motor performance.

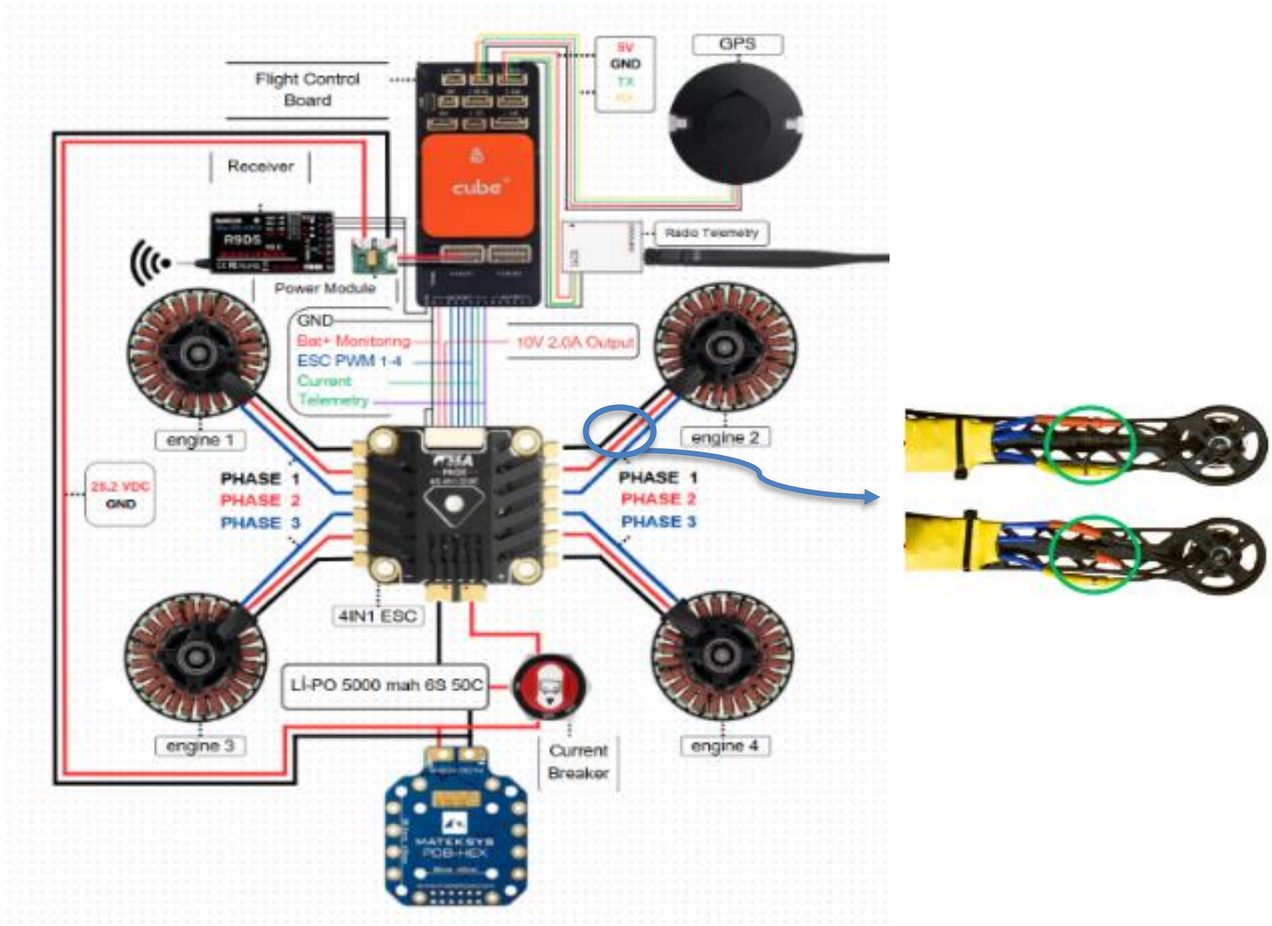


Figure 4.6 *Drone Electronic Speed Control Unit (ESC)*

4.2.2.1. What does it do?

- It enables the motors to rotate at the desired speed and direction.
- It instantly applies the speed changes required for balance and direction control in flight.
- Usually, one ESC is used for each motor; some systems may have combined ESC boards (4-in-1 ESC) that control four motors.
- It provides protection of motors against situations such as overcurrent and overheating.

4.2.2.2. Symptoms of Failure:

- One of the engines does not start at all or stops suddenly during flight.
- The drone somersaults by abnormal movement during take-off or flight.
- ESC overheating and emitting a burning odour.
- LED indicators on the ESC are not illuminated or blinking abnormally.

4.2.2.3. Exchange and Assembly Procedure

Required Ingredients:

- Soldering set (temperature-controlled soldering iron)
- Heat-resistant tweezers
- Thermal paste (required for heat dissipation in some ESC models)
- Multimeter (for circuit continuity and short circuit test)

Step 1

Completely de-energise the drone by removing the battery.

Step 2

Determine the location of the ESC on the drone. The ESC can usually be located next to the motor or in the lower layer of the drone body, individually or as a 4-in-1 board.

Step 3

Carefully inspect all cable connections connected to the ESC:

- Motor cables (usually 3 phase cables)
- Power cables (red = positive, black = negative)
- Signal cable (connection between ESC and flight controller)

Step 4

Label and photograph the ports. This avoids the risk of incorrect connection when connecting the new ESC.

Step 5

Carefully disconnect the old ESC cables by heating the soldering tip. Take care to remove the cable ends and solder points without damaging them.

Step 6

Solder the new ESC to the same ports as the old ESC:

- The signal cable must be connected to the flight controller.
- The three motor cables must be correctly soldered to the respective motor phases.
- Power cables should be connected to the PDB or directly to the battery line.

Step 7

Carefully check the solder joints. Test for continuity with a multimeter to make sure there is no short circuit.

Step 8

Review all connections before reconnecting the battery. Then make a test flight to verify proper operation of the ESC and motor.

4.2.3. Motor

The motor is the basic motion actuator of the drone. It converts electrical energy into mechanical energy and rotates the propeller, thus enabling the drone to take off, manoeuvre and fly stably (Figure 4.7). Each motor is controlled by an Electronic Speed Control Unit (ESC) connected to it.

Figure 4.7 Drone's Electric Motor - Main Actuator Providing Propeller Movement

4.2.3.1. Symptoms of Failure:

- Leaning to one side or uncontrolled somersaulting while the drone is taking off or in flight.
- The engine makes abnormal noises or stalls or hesitates during operation.
- The corresponding motor does not rotate or produce power even though the ESC is working properly.
- The motor overheats or the propeller does not rotate at the required speed.

4.2.3.2. Exchange and Assembly Procedure

Required Ingredients:

- Mini screwdriver
- Hexagon (Allen) spanner (usually M2 or M3)
- Soldering station
- Tweezers and pliers
- Heat-resistant tubing (for insulation) and scissors
- Multimeter (optional, for connection testing)

Step 1

Completely de-energise the drone system by removing the battery. This is mandatory for process safety.

Step 2

Diagnose the faulty motor. This is usually done by checking whether the motor moves with the ESC test.

Step 3

Remove the screws with which the motor is fixed to the drone body. Mostly motors are mounted with 2 or 4 screws. The propeller must be unscrewed.

Step 4

Identify the 3 wires between the motor and the ESC. These wires are usually soldered or connectorised.

Step 5

Carefully remove the old motor cables using a soldering station. Take care not to damage the connections.

Step 6

Mount the new motor securely in the same holes where the old motor was screwed in.

Step 7

Solder the three wires of the motor to the same phase leads on the ESC.

Note If it is desired to change the direction of rotation of the motor, this can be achieved by changing the location of the two-phase cables.

Step 8

Insulate the soldered connections with tubing and test for a short circuit using a multimeter.

Step 9

Switch on the system by connecting the battery and check the direction of rotation of the motor.

If necessary, the motor direction can be adjusted using software such as Betaflight.

4.2.4. Propeller

The propellers utilise the rotary motion of the drone motors to create an airflow, thereby allowing the drone to generate lift (Figure 4.8). This buoyancy allows the drone to take off, descend, and move back and forth and left and right in the horizontal plane. The propellers rotate clockwise (Clockwise - CW) and anti-clockwise (Counter-Clockwise - CCW) as a dual system, thus providing stability and directional control.

Figure 4.8 *Drone propeller*

4.2.4.1. What does it do?

- The propellers convert the mechanical energy produced by the motors into propulsive force, allowing the drone to take off.
- With its turns in CW and CCW directions, it enables stable flight and manoeuvrability of the drone.
- The drone's stability, control precision and flight performance are largely dependent on the accuracy, balance and structural rigidity of the propellers.

4.2.4.2. Symptoms of Failure

- Vibration, shaking or unstable movements are observed in the drone during flight.
- The propeller may have physical damage (fracture, crack, bending).
- During take-off, the drone loses orientation or tends to tip over.
- The resulting airflow is insufficient or irregular; the drone loses lift.

4.2.4.3. Exchange and Assembly Procedure

Required Ingredients:

- Ability to disassemble the propeller with a spanner or by hand
- Spare CW and CCW propeller set
- Small torque spanner if desired (to prevent over-tightening)

Step 1

Completely disconnect the battery and de-energise the drone.

Step 2

Identify the propeller in need of replacement. Visual inspection or in-flight symptoms can be instructive.

Step 3

Note the direction of rotation of the propeller (CW or CCW). It is usually indicated by an arrow on the propeller.

Step 4

Carefully remove the propeller by hand or with a propeller spanner.

Note: Clockwise rotating (CW) propellers must be removed in anti-clockwise direction and CCW propellers must be removed in the opposite direction.

Step 5

Place the new impeller on the motor shaft with the correct direction of rotation (Figure 4.9).

- Only CW propeller should be fitted on CW engines and only CCW propeller should be fitted on CCW engines.
- Installing it in the wrong direction causes complete loss of drone control.

Step 6

Tighten the impeller, but avoid over torquing.

- If there is a fixing gasket or washer, be sure to insert it.
- Check by hand that the impeller is not loose.

Step 7

After all propellers have been replaced, the direction of rotation should be checked using motor testing software (e.g. Betaflight's Motor tab).

Figure 4.9. Drone Propeller Assembly - Direction and Tightness Control

4.2.4.4. Test Flight

- Perform the first flight at low speed and low altitude.
- Pay attention to the directional stability of the drone.
- In case of possible problems such as vibration, noise or deflection, the propeller should be checked again and, if necessary, disassembled and reassembled.

4.2.4.5. Tips

- The looseness of the propellers should be checked before each flight.
- After a fall or impact, the propeller must be physically and functionally examined.
- CW and CCW propellers should not be confused in spare propeller sets; they are usually distinguished by differences in colour or markings.

4.2.5. Battery (LiPo Battery)

LiPo (Lithium Polymer) batteries are the main energy source of drone systems (Figure 4.10). They are widely used especially in multicopters due to their light weight and high energy density. The capacity (mAh) and health of the battery directly affect the flight time and performance of the drone. LiPo batteries can have a number of cells, usually 3S (3-cell), 4S (4-cell) or more. The nominal voltage of each cell is approximately 3.7V.

Note: The higher the number of cells, the higher the total voltage of the battery. For example, a 3S battery provides approximately 11.1V.

Figure 4.10 *Drone Battery (LiPo Battery)*

4.2.5.1. What does it do?

- It supplies energy to all electronic components such as ESC, engine, flight controller and camera.
- The number of cells and capacity are important for the drone's power requirement and flight time.
- Voltage (V) and capacity (mAh) are the main criteria that determine the performance and flight time of the drone.

Note: High capacity (mAh) means longer flight time, but may increase battery weight.

4.2.5.2. Failure Symptoms and Safety Risks

- Swelling or deformation of the battery is dangerous and must be replaced immediately.
- Overheating or voltage imbalance between cells increases the risk of fire.
- If the flight time is unexpectedly shortened, the battery capacity may be low.
- Sudden voltage drops can cause the drone to suddenly switch off in mid-air.

Note: Swollen batteries should never be used, they are a safety hazard.

4.2.5.3. Exchange and Assembly Procedure

Required Ingredients:

- XT60 or XT90 power connectors (for cable compatibility)
- Velcro battery strap or fixing device
- Heat-resistant work surface or mat
- LiPo safety bag (recommended for fire risk)

Step 1

Carefully remove the old battery, holding it only by the connectors without pulling on the cables.

Step 2

Check the battery connection cable and connector. If not compatible, the appropriate adapter can be used.

Step 3

If there is a strap or apparatus securing the battery to the drone body, carefully loosen it.

Step 4

Place the new battery in the correct orientation (label on top, cables at the back). It is important not to disturb the centre of gravity (Figure 4.11).

Step 5

Secure the battery firmly with the Velcro strap (Figure 4.11).

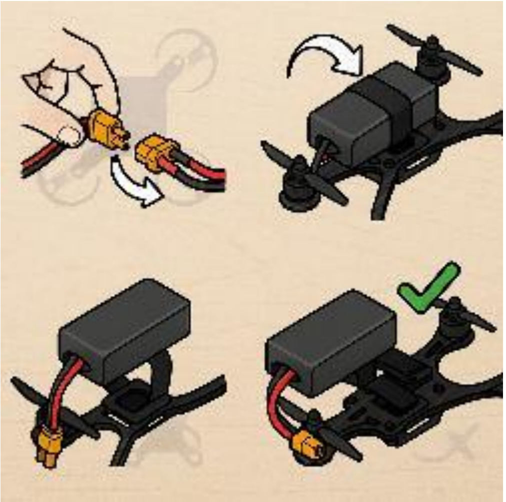


Figure 4.11 *Correct Positioning and Fixing of the Drone Battery*

Step 6

Connect the power cable according to the correct polarity. Incorrect connection may damage the battery and flight controller (+ marked ends should be connected together, - marked ends should be connected together).

Note: It is very important to observe polarity, otherwise electronic equipment may be damaged.

Step 7

Measure the cell voltages of the battery. The ideal range is between 3.7V (nominal) and 4.2V (fully charged).

Step 8

Switch on the system and verify that power is being received by checking the LED indicators.

4.2.5.4. Testing and Safety

- Keep the flight time short on the first flight and monitor the battery voltage.
- Check the cell balance before each charge.
- Use only LiPo compatible and high quality chargers.
- If you will not use the batteries for a long time, store them in a LiPo safety bag and protect them from direct sunlight.

Note: LiPo batteries are sensitive; improper handling increases the risk of fire, care must be taken.

4.2.6. PDB (Power Distribution Board)

The Power Distribution Board (PDB) is the electronic circuit that centrally distributes electrical energy from the battery to all electronic components in the drone (Figure 4.12). ESCs (Electronic Speed Control), flight controller, video transmitters (VTX), LED systems and other modules are fed through the PDB. Many PDBs have 5V and 12V voltage regulators to meet different voltage requirements, filters, and current sensors to measure power dissipated during flight.

Figure 4.12 Drone Power Distribution Board (PDB)

4.2.6.1. What does it do?

- It distributes the high voltage from the battery by converting it into safe and regular voltages suitable for the needs of the drone components.
- It provides direct power to the ESCs and flight controller.
- PDBs with 5V or 12V outputs enable energy transmission suitable for sensors and devices operating at different voltages.
- Models with current sensors optimise battery management by monitoring energy consumption during flight.

4.2.6.2. Symptoms of Failure

- The drone does not switch on at all, or the entire system switches off suddenly during flight.
- Physical damage such as burn marks, odour or blackening is observed on the PDB.
- The ESC or flight controller will not receive power and will not operate.
- Abnormal values such as unbalance or 0V are measured at the voltage outputs.
- There is no continuity at the PDB outputs when tested with a multimeter.

4.2.6.3. Exchange and Assembly Procedure

Required Ingredients:

- Soldering station (temperature controlled soldering iron)
- Solder wire, flux, solder pump
- Multimeter (for testing)
- Heat-resistant tubing
- Tweezers and pliers

Step 1

De-energise the entire system by removing the drone battery.

Step 2

Label all cables connected to the PDB and document the connection points by taking high-resolution photos (Figure 4.13). This is very important for proper connection.

Step 3

Carefully disconnect the ESC, flight controller and all other wiring connections with the soldering tip (Figure 4.13).

Step 4

If the PDB has fixing screws, unscrew them and remove the old PDB from the housing.

Step 5

Secure the new PDB to the drone body, noting its original position and orientation.

Step 6

Solder the wires in sequence to the appropriate terminals (Figure 4.13):

- ESC power inputs (+ and -)
- Device outputs such as flight controller (FC), VTX, LED
- Battery input connector (usually XT60 socket)

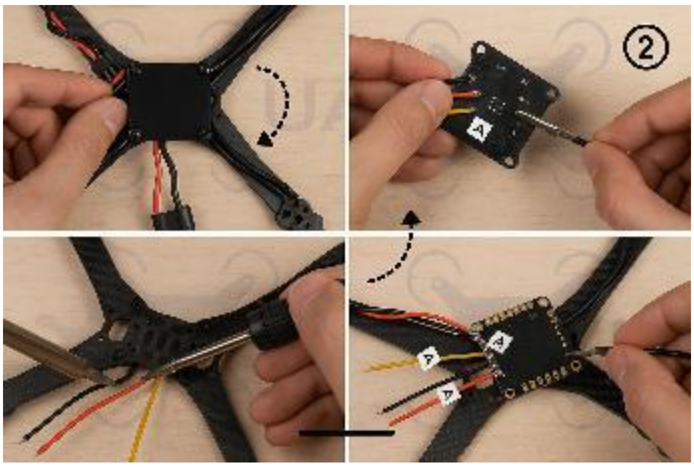


Figure 4.13 *PDB Replacement and Assembly*

Step 7

Check the solder points with a multimeter to ensure that there is no short circuit and that continuity is maintained and - make sure that the lines do not touch each other.

Step 8

Make a final visual check and if the connections are secure and correct, connect the battery and energise the system.

4.2.6.4. Test and Calibration

- Measure the PDB output voltages (5V, 12V) with a multimeter.
- Verify the ESC and flight controller are energised.
- If there is a current sensor on the PDB, check that this sensor is correctly connected to the flight controller and that it is defined via the software (Betaflight, iNav).

4.2.6.5. Tips

- Solder quickly but carefully, taking care not to damage the solder pads by excessive heat.
- Short and thick power cables are important for high current carrying capacity and prevent overheating.
- The part of the PDB that contacts the drone body must have an insulating pad or plastic protector; this eliminates the risk of a short circuit.

Note: Proper operation of the PDB is critical to the overall power management and safety of the drone.

4.2.7. Receiver

The receiver is the electronic module that transmits radio frequency (RF) signals from the remote control to the flight controller on the drone (Figure 4.14). The commands sent by the pilot from the remote control - such as throttle, orientation, altitude control - are first received by the receiver and then transmitted to the flight controller. Therefore, the receiver plays a critical role in manual or semi-autonomous control of the drone.

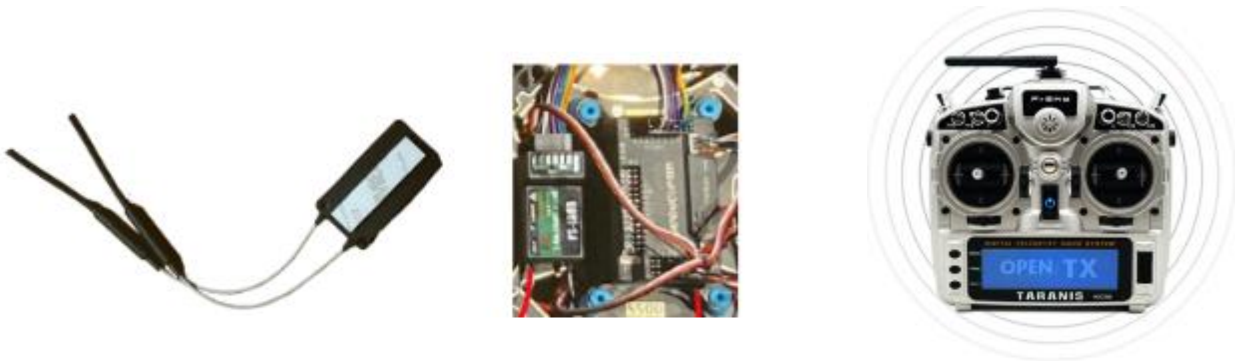


Figure 4.14. Drone Receiver Component

4.2.7.1. What does it do?

- Receives signals sent from the remote control.
- It provides drone movements by transferring the received signals to the flight controller.

- It uses different data transfer protocols (PWM, PPM, SBUS, iBUS, CRSF - Crossfire).
- Some receivers switch to failsafe (emergency) mode for safety in the event of a lost signal.

Note: The Failsafe function allows the drone to behave safely in case of signal loss (e.g. landing).

4.2.7.2. Symptoms of Failure

- The drone gives a "no signal" warning when switched on.
- There is no connection with the remote control.
- The LED indicator on the receiver lights solid red or does not light at all.
- The ESCs do not work because the flight controller cannot receive the signal.

4.2.7.3. Exchange and Assembly Procedure

Required Ingredients:

- Mini screwdriver
- Soldering station (for some models)
- Tweezers
- 3M tape or double-sided mounting tape
- Multimeter (optional for connection testing)

Step 1

Completely de-energise the system by removing the battery.

Step 2

Locate the current receiver on the drone. It is usually located close to the flight controller.

Step 3

Carefully disconnect the signal wires (3 pins: signal, +5V, GND) connected to the flight controller. If soldered, disconnect the wires using a soldering tip.

Step 4

Remove the old receiver from the tape or fixing bracket.

Step 5

Place the new receiver in the same position and secure it securely with double-sided tape. The antenna should be orientated outwards and, if possible, in a vibration-free location.

Step 6

Connect the signal, +5V and GND wires to the correct pins. Connect to the SBUS or iBUS port on the flight controller.

Step 7

Perform binding with the remote control. Switch on the receiver, usually by pressing and holding the bind button, and switch the remote control to bind mode.

Step 8

The connection is successful if the LED on the receiver lights green. Perform the motion tests in the software interface (e.g. Betaflight > Receiver Tab).

4.2.7.4. Test and Calibration

- Move the joysticks and observe the commands in the software.
- Check that the channel sequence (TAER / AETR) is correct.
- Configure the Failsafe settings to determine what the drone will do in the event of a signal failure.

4.2.7.5. Tips

- Locate the receiver and antennas away from motors that generate magnetic and electrical interference.
- Signal strength increases if the antennas are positioned at 90° angles on the drone.
- Regularly monitor signal quality and logs on long range flights.

Note: Receiver and antenna positioning is critical for signal quality and flight safety.

4.2.8. GPS Module

The GPS (Global Positioning System) module enables the drone to determine its precise position on the earth via satellites (Figure 4.15). This position information is critical for the drone's autonomous flight modes, position hold, return to home (RTH) and waypoint missions.

Figure 4.15 *Drone GPS (Global Positioning System) module*

4.2.8.1. What does it do?

- It detects the instant latitude, longitude and altitude coordinates of the drone.
- It provides speed and heading data.
- Indispensable in autonomous flight missions (e.g. predetermined route following).
- The RTH function allows the drone to return safely to the starting point in case of loss of control signal.

  Note: In case of GPS signal loss, the drone can switch to safety mode.

4.2.8.2. Symptoms of Failure

- Failure to connect to satellites or no GPS signal at all.
- The drone can't switch to GPS mode.
- GPS coordinates are not visible in the software interface.
- Delayed, inaccurate or inconsistent position data.

4.2.8.3. Exchange and Assembly Procedure

Required Ingredients:

- Mini screwdriver
- Tweezers
- Soldering station (may be required for some GPS models)
- GPS mounting plate or tape
- Multimeter (for control purposes, optional)

Step 1

De-energise the system by disconnecting the drone from the battery.

Step 2

Locate the GPS module on the drone. It is usually mounted on the top of the drone, isolated from vibration, facing open space.

Step 3

Disconnect the 4-wire cable connecting the GPS antenna cable to the flight controller. These wires usually consist of TX (transmitter), RX (receiver), 5V and GND lines.

Step 4

Carefully remove the tape or mounting bracket securing the module.

Step 5

Mount the new GPS module in the same position and orientation.

- For best satellite reception, the antenna should be pointed upwards and should not be surrounded by metal or magnetic field sources.

Step 6

Plug the TX and RX leads into the flight controller by cross-connecting them (TX → RX, RX → TX). Also connect the GND and 5V wires to the correct pins.

Step 7

Switch on the drone and check the GPS connection via the software (e.g. Betaflight > GPS Tab).

Step 8

Wait for the GPS module to "lock" by establishing a connection with 6 or more satellites. After locking, the system is ready for flight.

4.2.8.4. Test and Calibration

- A controlled test flight can be made to test the RTH function.
- Speed and direction data received via GPS should be monitored on the software interface.
- Flight history and location accuracy should be verified by analysing GPS log files.

4.2.8.5. Tips

- The GPS antenna should be placed as far as possible from metal surfaces and magnetic fields generated by motors.
- The antenna should always be orientated upwards and isolated from vibration.

- GPS modules may take longer to lock on initial power-up, especially in new or poor signal areas; patience is advised.

Note: The location and mounting of the GPS module is critical to the drone's navigation success.

4.2.9. Camera and Imaging Sensors

The camera is an optical component that allows the drone to see the outside world and transmit this image to the pilot's FPV (First Person View) screen or goggles in real time (Figure 4.16). Imaging sensors are electronic elements that convert the camera's light information into a digital signal; the most common types are CMOS sensors. The camera allows the pilot to perceive the environment, avoid obstacles, track targets and record in both manual piloting and autonomous flight missions.

Figure 4.16 *Drone Camera and Imaging Sensor*

4.2.9.1. What does it do?

- Provides real-time image transmission (FPV system).
- Records video and still images; usually recording is done on an SD card.
- Supports motion decisions based on visual data in autonomous tasks.
- It is used in advanced functions such as visual detection, target tracking and landing platform recognition.

4.2.9.2. Symptoms of Failure

- No image on the FPV screen.
- Display problems such as black screen or bad pixels.
- Image interruptions due to loose camera connections.
- Light detection problems: overly dark or overly bright images.

- Interference or intermittent transmission in the FPV image.

4.2.9.3. Exchange and Assembly Procedure

Required Ingredients:

- Small screwdriver
- Soldering station (some models may require)
- Tweezers
- Mounting tape or anti-vibration pad
- FPV connection cable (usually 3-4 pin)

Step 1

Completely de-energise the system by removing the battery.

Step 2

Locate the position of the camera on the drone body (usually on the front face).

Step 3

Disconnect the camera connection cable. FPV cameras usually have 3 pins: video output (VTX), power (5V) and ground (GND).

Step 4

Carefully remove the screws or tape securing the camera. On some models, the camera may be screwed into the side frame.

Step 5

Place the new camera in the same mounting position (Figure 4.17). Use an anti-vibration rubber pad if necessary.

Figure 4.17 *Drone Camera Replacement and Assembly*

Step 6

Connect the wires in sequence:

- Video cable → to VTX input
- +5V and GND → PDB or flight controller to power connection

Step 7

Start the drone and test the image with the FPV display or goggles.

Step 8

If the image is available, adjust the camera angle to the pilot's viewing direction and stabilise it.

4.2.9.4. Test and Calibration

- The clarity of the camera image should be checked; if blurred, the lens should be cleaned.
- The image quality should be assessed according to the light conditions (whether there is distortion in the dark).
- Video transmission over VTX must be uninterrupted and stable.
- Image latency should be kept as low as possible.

4.2.9.5. Tips

- The use of a lens cap is recommended to protect the camera lens from scratches.
- Camera and VTX cables should be kept away from components such as motors and ESCs that create magnetic fields.
- High quality FPV cable improves signal quality and transmission stability.
- The exterior of the camera should not be exposed to excessive dust and moisture. **Note** Stable and reliable operation of the camera and imaging system is vital for FPV flight safety.

4.2.10. Sensors (IMU, Barometer, Compass, etc.)

Sensors are electronic units that continuously transmit data to the flight controller by sensing the drone's environment and its own movements (Figure 4.18). These sensors help to ensure stable and controlled flight by measuring the drone's balance, orientation, height and position information.

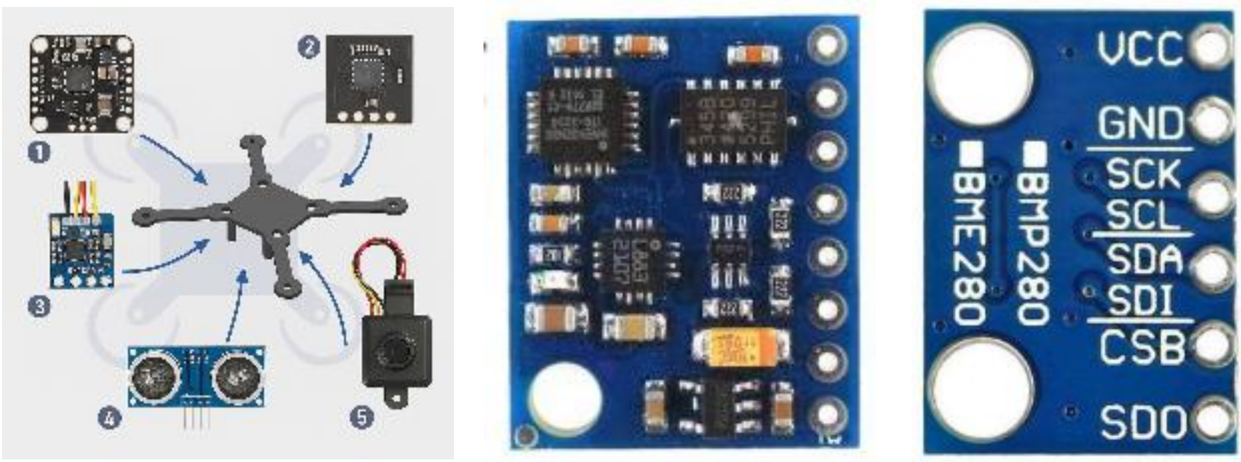


Figure 4.18 *Drone Sensors*

4.2.10.1. What do they do?

- **IMU (Inertial Measurement Unit):** Includes accelerometer and gyroscope. It provides movement and orientation information of the drone in three axes.
- **Barometer:** Calculates the altitude of the drone by measuring the air pressure. It is used in altitude stabilisation and altimeter functions.
- **Compass:** Determines the drone's orientation relative to magnetic north. Critical for GPS-assisted route tracking and auto-routing.
- **Optical Flow or TOF Sensor:** Measures the distance to the ground during landing or performs motion detection for stationary stance.

Note: Together these sensors form the spatial awareness of the drone and are indispensable for flight safety.

4.2.10.2. Symptoms of Failure

- The drone is constantly sliding or skidding in one direction.
- Twitching, jumping or directional deviations are observed during landing and take-off.
- GPS mode does not work or direction lock cannot be achieved.
- The height cannot be stabilised due to a barometer error.
- Error warnings such as "Sensor Error", "Gyro Not Found", "Bad Compass Health" appear on the software interface.

4.2.10.3. Exchange and Assembly Procedure

Required Ingredients:

- Soldering station (for soldered sensors)
- Micro connector removal pliers

- Tweezers
- Static electricity protection wristband
- Calibration software (Betaflight, iNAV, Mission Planner)

Step 1

De-energise the system by removing the battery.

Step 2

The module or external sensor containing the faulty sensor is identified (usually located on the flight controller (FC)).

Step 3

The connection connector of the sensor (such as I2C, SPI or UART) is carefully disconnected. If the sensor is directly soldered, it is gently separated with a soldering station.

Step 4

The new sensor is mounted on the same module in the correct orientation and pin order. Since most of the sensors are directional, mounting them upside down will result in incorrect data generation.

Step 5

After the connections are completed, the system is re-energised.

4.2.10.4. Sensor Calibration (with Software)

- IMU Calibration: The drone is placed on fixed planes in different axes (e.g. done in the Betaflight > Setup menu).
- Compass Calibration: The drone is rotated 360° on each axis and magnetic field values are collected.
- Barometer Calibration: Usually done automatically, but manual testing in a ventilated environment is recommended.
- GPS - Compass Alignment: Direction and compass matching is checked.

4.2.10.5. Tips

- Sensors should be located as far as possible from motors, ESCs and other components that generate magnetic fields.
- Calibration should be performed in an open area, away from electromagnetic interference.

- If the sensor integrated in the flight controller (FC) fails, a complete replacement of the FC board is usually required.
- Optical sensors placed under the landing gear must be protected from dust, dirt and moisture.

Note: The healthy operation of the sensors is critical for the flight stability and safety of the drone.

4.2.11. Landing Gear and Protective Elements

The landing gear is the structural part where the drone contacts the ground and protects the electronic and mechanical components by absorbing impact energy during landing (Figure 4.19). It ensures a soft landing and helps the drone to sit on a stable and balanced platform.

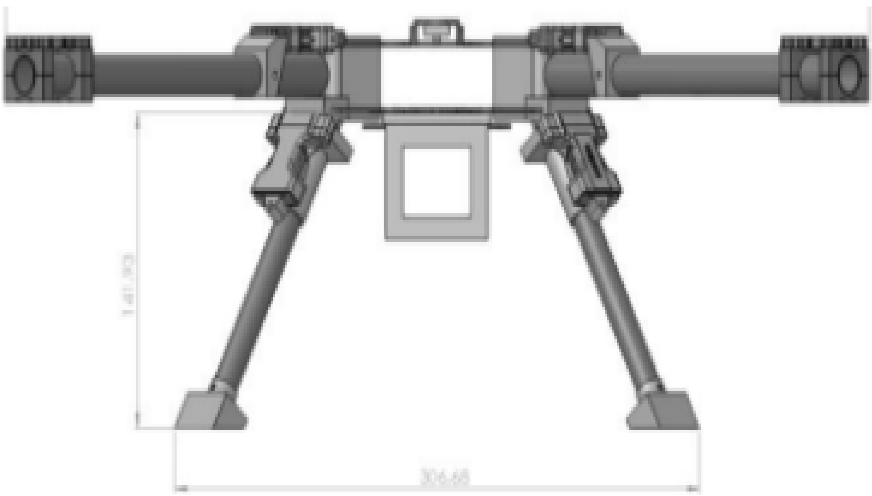


Figure 4.19 *Drone Landing Gear*

Protective elements include propeller guards, body supports, shock absorbing rubbers, antenna shields and similar parts (Figure 4.20). These components ensure that the drone is protected against physical impacts such as falls, impacts or friction.

Figure 4.20 *Drone Protective Elements*

4.2.11.1. What do they do?

- **Landing Gear:** Protects the drone body and internal components by absorbing shock waves during contact with hard ground.
- **Propeller Protector:** Prevents the propellers from being broken or damaged in case of an accident.
- **Body Protector / Shock Absorber:** Prevents sensitive electronic parts from being damaged by physical impacts.
- **Antenna Stabiliser:** Prevents FPV antennas from breaking and dislodging.

4.2.11.2. Symptoms of Failure

- The drone is unstable on landing or on the ground, tilting to one side.
- The landing gear may be cracked, broken or stretched.
- Protective elements may have been loosened or dislodged in the impact.
- If increased vibrations are observed during flight (especially if soft landing pads are not available).

4.2.11.3. Exchange and Assembly Procedure

Required Ingredients:

- Mini screwdriver (usually M2 or M3)
- New landing gear or spare protective kit
- Tweezers

- Double-sided tape or mounting pads (for some models)
- Plastic connection clamp (zip tie)

Step 1

Disconnect all power sources of the drone, the system must be de-energised.

Step 2

Identify broken, damaged or malfunctioning landing gear parts. It usually consists of 2 or 4 parts fixed to the drone base.

Step 3

Remove the screws or mounts securing the landing gear. Some models may have a system of snap-on tabs, remove them carefully.

Step 4

Install the new landing gear in its original position and symmetrically. Height stability directly affects take-off and landing performance.

Step 5

Insert the protective elements:

- The propeller guard is usually fixed at the propeller level or in the engine mount.
- Shock absorbing pads are adhered to the drone base with double-sided tape.
- Antenna shields or supports are mounted on the rear of the drone to prevent breakage of FPV antennas.

Step 6

Place the drone on a flat and hard surface. Make sure all parts are of equal height and symmetrical.

4.2.11.4. Test and Pre-Flight Controls

- The drone must be on level and stable ground before take-off.
- After each landing, the screws, tapes and mounting elements of the landing gear must not be loose.
- It should be checked that the protective elements do not vibrate during flight.

4.2.11.5. Tips

- Carbon reinforced or light aluminium materials should be preferred instead of plastic landing gear; durability increases.
- The use of propeller guards is mandatory for drones used for educational purposes.

- Protective parts should not be too heavy and should not adversely affect the flight dynamics and performance of the drone.

4.2.12. Gimbal

The gimbal is an electronic and mechanical stabilisation system that enables the camera on the drone to provide a stable and balanced image without vibration (Figure 4.21). It is usually equipped with 2-axis (pitch-yaw) or 3-axis (pitch-yaw-roll) motors. Even if the drone moves, the camera on the gimbal remains fixed in the horizontal plane, thus obtaining clear images or video. The gimbal can operate both with manual control and automatically.

Figure 4.21 *Gimbal*

4.2.12.1. What does it do?

- It ensures that the image remains stable by absorbing vibrations and shakes that occur during drone flight.
- Provides high image quality in professional video and photo shooting.
- Allows remote control of the camera angle (e.g. via FPV controller).
- In autonomous missions, it is used in image capture and object tracking functions at a certain angle.
- Provides image processing algorithms with a fixed reference point.

4.2.12.2. Symptoms of Failure

- If the camera is constantly shaking, fluctuating, or the orientation stabilisation function does not work.
- If mechanical noises or heating from the gimbal motors are observed.

- If the gimbal does not make calibration movements when the drone is switched on.
- If the gimbal does not react or change angle with the remote control.
- If the image angle does not remain constant, but drifts according to the direction of flight.

4.2.12.3. Exchange and Assembly Procedure

Required Ingredients:

- Mini screwdriver and Allen key
- Tweezers and pliers
- Soldering station (some models)
- Replacement gimbal (compatible model)
- Connection cables (UART, servo signal etc.)

Step 1

Completely de-energise the system by removing the drone's battery.

Step 2

Determine the position of the existing gimbal module. It is usually located at the front bottom of the drone and mounted with anti-vibration rubber straps.

Step 3

Carefully disconnect the camera connection cables, power line and signal cables. Label each connection or take a photo.

Step 4

Remove the screws and brackets securing the gimbal. Carefully remove any suspension rubbers.

Step 5

Place the new gimbal in place in the same orientation and axis. The camera lens should be aligned facing the front of the drone.

Step 6

Connect the gimbal power cables and signal connections to the appropriate pins (e.g. UART1 TX/RX).

Step 7

Perform the gimbal calibration via software (e.g. Betaflight, Mission Planner, gimbal firmware).

Step 8

Take a test flight to observe the gimbal for proper operation, image stability and camera movement.

4.2.12.4. Test and Calibration

- The gimbal should perform a self-calibration movement at start-up.
- There should be no flicker or directional shift in the image in the FPV system.
- Tilt and pan movements made via the control should be smooth.
- If necessary, the PID settings and the motor power balance must be reconfigured via the software.

4.2.12.5. Tips

- Do not force the gimbal motors by hand, this may damage the motors.
- The camera and gimbal should be cleaned regularly to protect them from excessive dust, moisture and vibration.
- Camera and gimbal cables must be short and tightly secured, loose cables may interfere with the gimbal.
- Gimbal software and firmware updates should be checked regularly.

Note: Proper operation of the gimbal system is critical for image quality, FPV safety and professional filming.

4.2.13. Cabling and Connectors

Wiring in drone systems is the basic infrastructure that enables all electronic components (motors, ESC, flight controller, battery, GPS, receiver, camera, etc.) to be connected to each other. It is categorised into three basic groups: power transmission cables, signal carrier lines and data transmission lines. Wiring layout is of great importance for the drone's electrical efficiency, signal stability and safety.

4.2.13.1. What does it do?

- It ensures the safe transmission of electrical energy from the battery to ESCs, motors and control boards.
- It carries control signals between parts such as ESC, receiver, sensors.
- It provides data transmissions such as telemetry, image and GPS (UART, I2C, SPI, SBUS, etc.).
- Helps maintain correct polarity and voltage levels throughout the system.
- In modular systems, connectors facilitate parts replacement.

4.2.13.2. Commonly Used Cable and Connector Types

- Power Cables: 12-16 AWG thick silicone insulated cables (between battery-ESC-PDB)
- Signalling Cables: 26-30 AWG single or multiple jumper lines (FC-ESC-to-receiver)
- FPV Cables: 3-4 pin video transmission lines (camera to VTX)
- Connector Types:
  - XT60 / XT90: For battery connections
  - JST / PH / SH: Receiver and sensor connections
  - Servo (3 pin): For signal + 5V + GND
  - USB / Micro-USB / Type-C: For configuration and updates

4.2.13.3. Symptoms of Failure

- The system does not switch on at all (cable break or incorrect connection)
- ESC or FC switching off and on due to irregular power delivery
- Sudden power interruptions or signal loss during flight
- Failure to transmit telemetry data, loss of images
- Short circuit due to incorrect soldering (burning smell, smoke)

4.2.13.4. Correct Wiring and Connection Procedure

Required Ingredients:

- Soldering station and quality solder wire
- Scissors, pliers, tweezers
- Heat-resistant tubing and heat gun
- Multimeter (for continuity and voltage testing)
- Connector set (XT60, JST, servo, etc.)
- Cable tie and organising spiral

Step 1

De-energise the entire system, remove the battery.

Step 2

Prepare the cables to be connected with suitable thickness and insulation. Their length should be short and suitable for their function.

Step 3

Carefully strip the cable ends to be soldered and pre-coat (tinning) them with solder wire.

Step 4

Solder quickly and cleanly.

- Solder pads for power cables must be strong
- Avoid reverse connection of signal cables

Step 5

Insulate with tubing after soldering, use a heat gun if necessary.

Step 6

Test the correctness of the connectors with a multimeter (especially + and - terminals).

Step 7

Use cable ties or insulating pads to secure the cables. Loose and wiggling connections can be a source of future failure.

4.2.13.5. Test and Calibration

- Voltage test should be performed on all power lines with a multimeter.
- Check whether the signal cables ports (UART1, SBUS, i2C) are connected to the correct port.
- Verify that all connected components are recognised from the software interface (ESC, receiver, GPS, etc.).
- Before switching on the system, all cable routes should be rechecked.

4.2.13.6. Tips

- Signal cables must be kept away from motor cables (anti-interference)
- Use colour coding: Red (+), Black (-), White/Yellow (signal)
- Pay attention to the quality of the soldering; poor solder will lead to long-term failure.
- Schematically planning the cable routes in each new system provides ease of maintenance in the future.
- Avoid unnecessarily long cables; they add weight and clutter to the system.

Note: Healthy wiring and connector usage is essential for the safe and trouble-free operation of a drone. The smallest cable error can put the entire system at risk.

4.3. Software Installation and Update Procedures

This chapter provides a comprehensive guide to installing, updating and testing the functionality of drone flight control software. It also includes basic information on drone software architecture, simulation technologies and the global software ecosystem (Figure 4.22). The aim is to enable even users with no experience in software to understand and apply basic concepts. In this way, both theoretical knowledge and practical application are presented together.

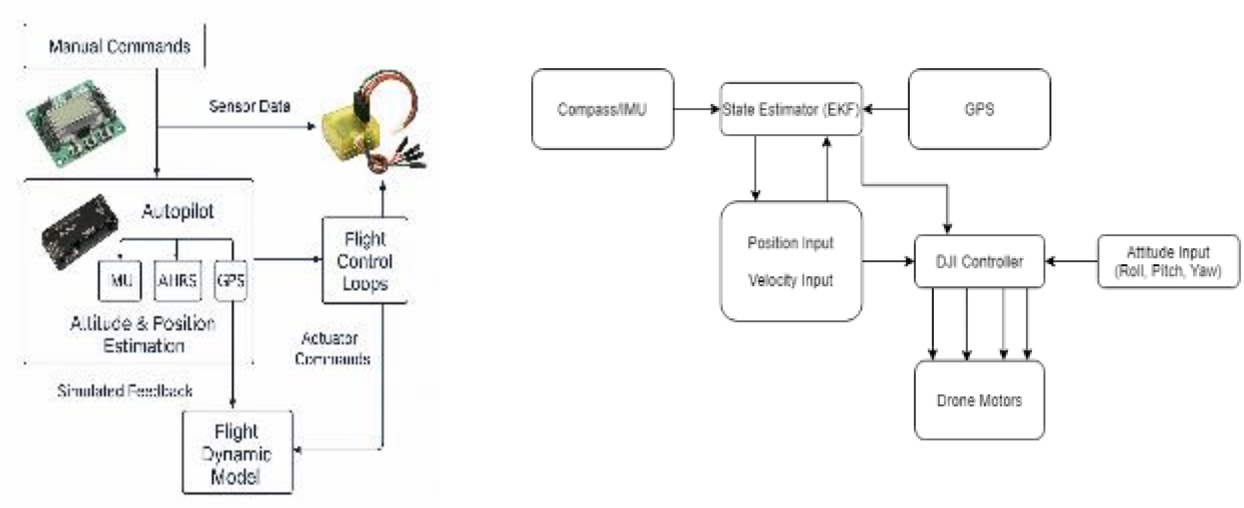


Figure 4.22 *System Diagrams of Drone Flight Control Software and Architecture*

4.3.1. What is Drone Software?

Drone software is a set of software that regulates the flow of data between the flight controller, sensors, GPS, motors and other electronic components, integrates the systems and executes the drone's flight operations. This software is usually organised in two main layers:

- **Flight Control Software (Firmware):**
  It detects the drone's instantaneous flight status, processes sensor data, transmits flight commands to the motor drives and ensures stable, safe flight of the drone. This layer interacts directly with the hardware and creates the real-time decision mechanism. For example, open source PX4 and ArduPilot firmware fall into this category.

- **Ground Control Station (GCS):**
  The software layer that enables drone operators to communicate with the drone, plan missions, determine flight routes and monitor telemetry data in real time via a

computer or mobile device. Popular GCS software includes QGroundControl and Mission Planner.

- **Additional Layers and Integration:**
  Some advanced systems may include additional software layers such as autonomous flight, artificial intelligence and image processing modules. These modules increase the drone's capabilities for environmental sensing and performing complex tasks.

The main components of the drone software can be summarised as in Table 4.2.

Table 4.2 . Drone Software Basic Components

Component	Description
FC (Flight Controller)	It acts as the central brain of the drone, processing all sensor data and sending commands to the motors.
Firmware	It is the basic software layer installed on the FC. It can be updated and determines flight performance.
GCS (Ground Control Station)	It is the software that runs on the user's computer or mobile device, providing flight planning, data monitoring and software updates.
USB / Serial Driver	Drivers that enable data exchange between the drone and the computer.
IMU / AHRS / INS	Sensor systems that determine the orientation, acceleration and position of the drone (IMU: Inertial measurement unit, AHRS: Attitude and Heading Reference System, INS: Inertial Navigation System)
MAVLink	It is a lightweight and standardised protocol that enables communication between the drone and the ground control station.
Bootloader / DFU Mode	Special operating modes used during firmware installation and update.

4.3.2. Importance and Functions of Software

Drone software is critical not only for controlling the hardware, but also for the safety, accuracy and efficiency of flight. The right software increases the drone's stability, accurately processes sensor data and triggers automatic interventions (e.g. RTH - Return To Home) in emergency situations.

4.3.3. Drone Software Architecture

The drone autopilot software system follows the following operation during flight:

- Sensor Data Collection: Sensors such as IMU, GPS, AHRS and INS collect the drone's motion, position and direction information in real time.
- Control Loop: The collected data is transferred to the flight control loop, where it is analysed and a decision mechanism is created.
- Command Generation: The controller sends commands to motors and other actuators in line with the processed data.
- Manual and Telemetry Communication: Manual control and remote monitoring are provided with RC control signals and telemetry data.
- Driver Management: Serial drivers manage both input (from sensors) and output (to motors and other actuators) data flow.
- Flight Dynamic Model: Flight performance is tested by simulating flight characteristics (especially used in simulations).

4.3.4 Software Installation Procedure

Preparation:

Step 1

The drone is connected to the computer via USB cable.

Step 2

The required software (e.g. Betaflight Configurator) is installed on the computer.

Step 3

Serial port drivers (e.g. Zadig) must be installed.

Software Installation Process:

Step 1

Connect the Flight Controller to the computer via USB.

Step 2

The GCS application (Betaflight, iNav, Mission Planner, etc.) opens.

Step 3

Select the flight controller model (e.g. STM32F405).

Step 4

Select the appropriate firmware version from the "Firmware Flasher" tab.

Step 5

Press the "Flash Firmware" button to start the installation.

Step 6

After the firmware is loaded, the FC reboots and the system is automatically recognised.

Note: In some flight controller models, it may be necessary to press the "BOOT" button on the device or switch to DFU (Device Firmware Upgrade) mode to load the firmware.

ESC (Electronic Speed Control) Update

Step 1

The drone battery is installed.

Step 2

ESC update software such as BLHeli Suite or BLHeli Configurator opens.

Step 3

ESCs are introduced and firmware update is done if available.

Step 4

Motor directions are tested via software and reversed if necessary.

4.3.5. Advanced Drone Software Platforms

Advanced drone software platforms can be summarised as in Table 4.3.

Table 4.3 *Advanced Drone Software Platforms*

Platform	Feature
PX4 Autopilot	It is an open source and modular flight control software suitable for industrial use.
ArduPilot	Open source software supporting multiple platforms such as fixed wing, multicopter, land and sea vehicles.
DJI SDK	SDK for advanced mobile applications and closed system drone integrations developed by DJI.
ROS	The Robot Operating System is used for AI-assisted flight logic, autonomous missions and SLAM (Simultaneous Localisation and Mapping) applications.

4.3.6. Simulation Systems: SITL and HITL

SITL (Software in the Loop): SITL is a flight simulation performed at software level without actual hardware. Flight control software is run in a virtual environment on a computer and flight dynamics are simulated (Figure 4.23). This method accelerates software development and testing processes, eliminates the need for hardware, and enables the examination of risky situations in a safe environment. It is especially used for the verification of flight control algorithms.

HITL (Hardware in the Loop): HITL simulation is done by integrating the actual flight controller hardware into the simulation environment. In this way, software and hardware are tested together. Sensor data and control commands are transferred between the hardware and the simulator in real time. HITL is critical for evaluating the actual performance of the flight controller and detecting hardware-software integration problems.

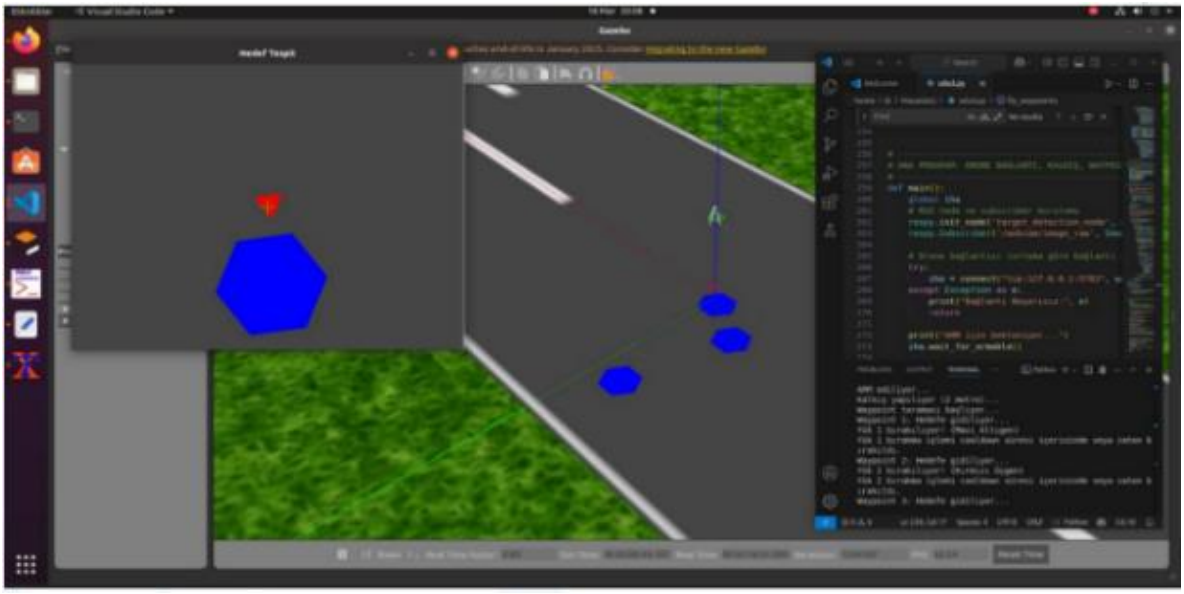


Figure 4.23. Software-in-the-Loop (SITL) Drone Simulation Environment

Detailed comparative information on drone simulation tools is summarised in Table 4.4.

Table 4.4 Comparative Simulation Tools

Simulator	SITL Support	HITL Support	ROS Support	Description
AirSim	✓	✓	◆ (indirect)	Unreal Engine based simulation platform developed by Microsoft. It is used for artificial intelligence tests of unmanned vehicles and image processing.
Gazebo	✓	✓	✓	It offers full integration with the Robot Operating System (ROS). Creates realistic drone flight environments with physics engines and sensor simulation.
JMavSim	✓	✓	✓	Lightweight and fast running simulator integrated into the PX4 ecosystem. Ideal for basic flight dynamics and navigation tests.
FlightGear	✓	✓	✗	Open source flight simulator with a large world map and realistic weather conditions. It is generally preferred for training purposes and general aviation simulations.
X-Plane	✓	✓	✗	Professional and commercial flight simulator. Provides high physical realism and detailed flight dynamics. Suitable for advanced users and commercial pilot training.
MATLAB/Simulink	✓	✓	◆	It is mainly used for academic and research purposes, control systems and dynamic modelling.

4.3.7. GCS (Ground Control Software) - Detailed Review

QGroundControl:

- Compatibility: PX4 and MAVLink protocol supported.
- Features: User-friendly graphical interface provides mission planning, live telemetry display, detailed setting of flight parameters and route drawing on the map. Available in mobile and desktop versions.
- Advantages: Open source, regularly updated, multi-platform support.

Mission Planner:

- Compatibility: Developed for ArduPilot based vehicles.
- Features: Detailed flight settings, sensor calibrations, advanced logging and post-flight data analysis (Figure 4.24).
- Area of Use: It is preferred by professional users and researchers.

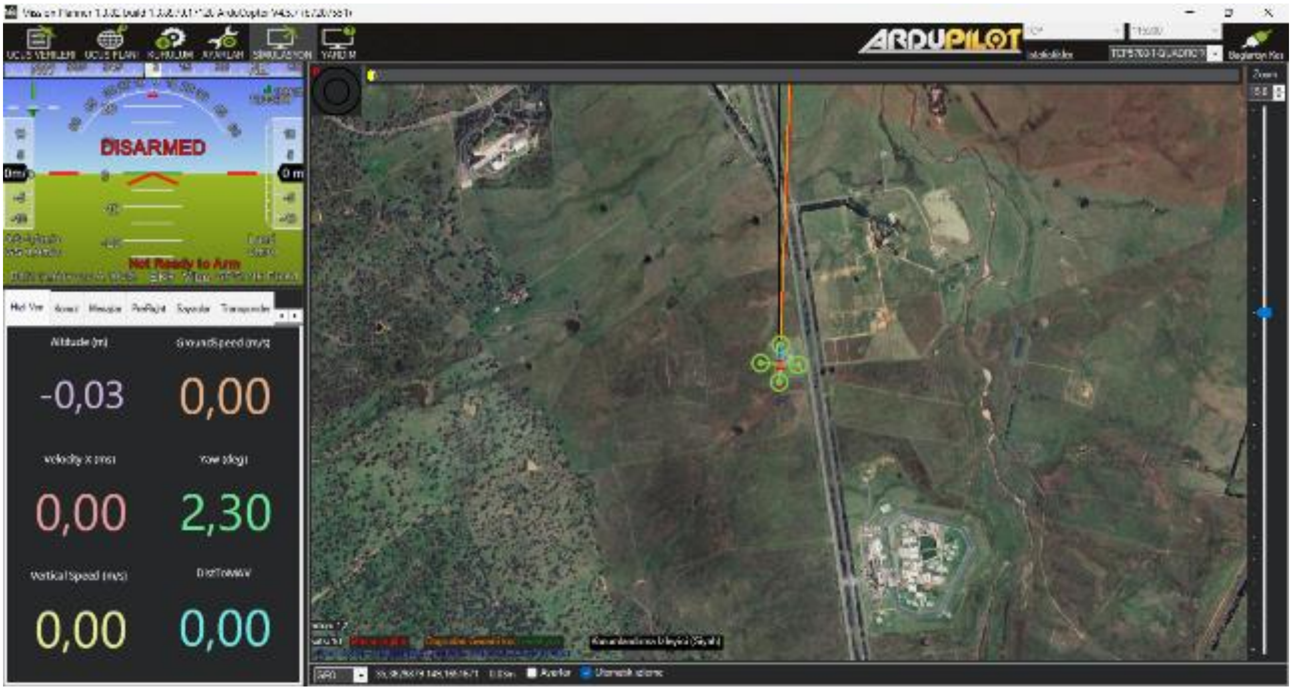


Figure 4.24 *Mission Planner Interface - Telemetry Data and Location Tracking on Map*

MAVProxy:

- Compatibility: Works with all MAVLink-based drones.
- Features: Command line based, provides control and automation operations via terminal with low resource consumption.

- Advantages Ideal for automation and integration projects with its lightweight structure.

UGCS (Universal Ground Control Software):

- Compatibility: Compatible with multiple drone platforms.
- Features: Provides professional solutions such as advanced map-based mission planning, fleet management, airspace management and mission automation.
- Area of Use: Suitable for commercial and industrial drone operations.

Additional Information

- MAVLink Protocol: The standard protocol for communication between the GCS and the drone. Telemetry data, commands and sensor information are transferred over this protocol.
- Importance of Simulations: Provides testing of software and hardware before actual flight, reduces costs and risks.
- Selection of GCS Software: Depends on user needs, drone type and mission scope. QGroundControl is preferred for simple missions, Mission Planner for advanced analyses or UGCS for commercial operations.

4.3.8. Parameter Backup / Restore Procedures

This chapter describes the process of backing up all configuration parameters (PID settings, sensor calibrations, flight modes, limit values, etc.) used in the drone flight control system and restoring them when necessary. This process prevents loss of time and effort in cases such as system reset, firmware update or transition to a different flight controller. It is a critical step for both safety and sustainable system management.

4.3.8.1. What is Backup and Why is it Important?

All settings made in the drone flight control software are stored in the system memory. These settings directly affect flight characteristics.

The backup process allows these settings to be saved as an external file and makes it possible to reuse the same configuration in case of system failure or replacement.

4.3.8.2. Advantages

- Easy restoration of all settings after firmware update
- Moving similar settings between different drone platforms
- Analyse historical parameters for problem detection and comparison
- Reproduction of standard settings in educational institutions

4.3.8.3. Parameters that can be backed up

- PID values
- RC settings and mode definitions
- ESC calibration information
- Sensor calibration data (IMU, Compass, Baro)
- Failsafe settings
- Gimbal, GPS, OSD configurations
- Automatic flight tasks (waypoints)

4.3.8.4. Backup Procedure

Required Software

- Betaflight Configurator (for Multicopter)
- Mission Planner (for ArduPilot based systems)
- QGroundControl (for PX4 systems)

1. System Connection:

Step 1

The drone is connected to the computer via USB cable.

Step 2

The relevant floor control software is opened and the connection is established.

2. Parameter Backup:

Betaflight:

Step 3

Switch to the "CLI" tab.

Step 4

Type diff all command → only the changed parameters are listed.

Step 5

The output is selected in its entirety and exported as a file with the extension .txt.

Alternative: all configurations can be retrieved with the dump command.

Mission Planner:

Step 6

Select "Full Parameter List" or "Full Parameter Tree" from the "CONFIG/TUNING" tab.

Step 7

Press the "Save to File" button at the bottom right and export as a file with .param extension.

QGroundControl:

Step 8

On the "Parameters" tab, click the backup icon from the top right.

Step 9

It is saved to the computer as a .params file.

Restore Procedure

Step 1

The new or reset flight controller is connected to the computer.

Step 2

Select parameter restore via GCS software.

Betaflight:

Step 3

Switch to the CLI tab.

Step 4

Paste the previously received diff all output into the CLI window.

Step 5

The system is restarted with the save command.

Mission Planner:

Step 6

The .param file is loaded with the "Load from File" option.

Step 7

The parameters are written to the system by pressing the "Write Params" button.

QGroundControl:

Step 8

The previously backed up .params file is imported.

Step 9

The system automatically recognises and applies the parameters.

4.3.8.5. Tips and Warnings

- The firmware version used before the restore operation must be compatible with the backed-up firmware version. Otherwise some parameters may be invalid.
- Care should be taken when transferring redundant parameters to drones with different hardware structures (e.g. different IMU or ESC), only common parameters should be applied.
- diff files can be edited; only the desired settings can be restored manually.
- Naming the backup files with date, drone model and firmware information prevents confusion.

4.3.8.6. Extra Safety Recommendations

- A new backup must be made after each important setting change.
- Backups should be stored in the cloud or on external discs.
- A centralised backup repository is recommended for training and fleet management organisations.

Note: Parameter backup and restore operations provide significant time and cost advantages, especially in development, testing and operational processes. Making this process a habit is critical for users at all levels.

4.3.9. Factory Reset Procedures

This section covers the restoration of the drone flight controller software to factory settings. Reset is required in cases such as complex configuration errors, unstable flight behaviour, incompatible parameters or handover to a new user. After this process, the device returns to the default factory settings of the software and becomes ready for reconfiguration.

4.3.9.1. What is Reset and When is it done?

A factory reset returns all parameters on the flight control card to their system predefined (default) values.

It is usually applied in the following cases:

- Inability to undo incorrect software settings

- Unexpected system behaviour after new firmware installation
- Restored parameters lead to unstable flight
- Resetting the system when transferring the drone to another user/student
- Clean start for troubleshooting PID, sensor or UART configurations

Warnings

- The reset cannot be undone. All current settings are deleted.
- It is strongly recommended to make a parameter backup before reset.
- If there is a hardware problem, reset will not work; physical test should be done first.

4.3.9.2. Reset Procedure (According to Software)

1. Reset with Betaflight Configurator

Step 1

The drone is connected to the computer via USB.

Step 2

Open Betaflight and connect to the flight controller.

Step 3

Switch to the CLI tab in the left menu.

Step 4

The following command is typed:

- *defaults*
- *save*

Step 5

The system reboots and all settings return to factory defaults.

Alternative:

Reset can also be done using the firmware loading screen with Reset Settings or Full Chip Erase option in the main menu.

2. Reset with Mission Planner

Step 1

Open Mission Planner, connect the drone.

Step 2

Go to the Config/Tuning tab.

Step 3

Under Full Parameter List, click Reset to Default option at the bottom right.

Step 4

The warnings are acknowledged and the system automatically returns to default values.

Step 5

Press Write Params button and restart the system.

3. Reset with QGroundControl

Step 1

Connect the drone via USB, start QGroundControl.

Step 2

Enter the Parameters tab.

Step 3

Select the Reset All to Defaults button on the top right.

Step 4

After confirmation, the system will automatically restart.

Reset with Hardware Button (Available on Some FCs)

Some flight controllers can be reset with physical "RESET" or "BOOT + POWER" combination.

Since the method of use varies according to the card model, the manufacturer's documentation should be checked.

Next Steps:

After returning to factory settings, the following steps should be followed:

- Sensor calibrations must be recalibrated (IMU, compass, baro).
- The flight modes and control settings must be reconfigured.
- ESC calibration and motor direction test should be done.
- If necessary, selected parameters can be restored with diff backup.

4.3.9.3. Tips

- Resetting after firmware update may prevent system incompatibilities.
- The defaults command only resets the parameters, it does not change the firmware.
- If you are moving the same board to a different drone platform, a reset provides a clean start.
- For drones used for educational purposes, it is recommended to reset before each student.

Note: Factory reset allows inexperienced users to get rid of misconfigurations and increase flight safety. Therefore, every user should be able to perform this procedure safely and consciously.

4.4. Practical Evaluation of Part Change Processes

The aim of this section is to assess the practical competence of individuals who carry out part replacement operations on Unmanned Aerial Vehicles (UAVs). The assessment covers only the 13 parts under **4.2 Drone Parts Identification, Replacement and Failure Types.**

Scope of Evaluation:

The replacement processes of the following 13 basic parts will be evaluated step by step with the criteria of application accuracy, compliance with safety rules, correct tool use and process time:

1. Flight Controller (FC)
2. ESC (Electronic Speed Controller)
3. Engine
4. Propeller
5. Battery
6. PDB (Power Distribution Board)
7. Receiver
8. GPS Module
9. Camera / Imaging Sensors
10. Sensors (IMU, Barometer, Compass)
11. Landing Gear
12. Protective Elements (Propeller Cage etc.)
13. Post-assembly test (power, connection, direction check)

4.4.1. Evaluation Methods

The Evaluation Process will be carried out as in Table 4.5. Sample checklist and scoring system are shared in Table 4.6 and Table 4.7.

Table 4.5. *Evaluation Process*

Method	Description
Practical Performance Task	Each student is randomly assigned a part and is expected to make a practical disassembly/assembly.
Observation with Checklist	The trainer observes and marks each step according to the checklist.
Time Criteria	Processing times are expected to be completed within certain limits.
Safety and ESD Compliance	ESD wristband, soldering safety and correct use of tools are assessed.

Table 4.6. *Sample Checklist (Flight Controller Change)*

Criteria	Score	Description
Interruption of the energy supply	5	Battery must be removed before starting the process
Marking and photographing the cables	10	Are all connections documented correctly?
Dismantling of the old part	10	Is the soldering done without damaging it?
Proper installation of the new part	20	Accurate direction and screwing control
Accuracy of connections	20	Is there any reverse polarity or free cable?
Solder quality	10	Risk of cold soldering / short circuit
Final test (USB connection / LED lighting)	15	Is FC initialising properly?
General order and work safety	10	Use of tools and equipment, workplace cleaning

Total: 100 points

Table 4.7. Scoring Scale

Score Range	Achievement Level
90 - 100	Excellent - All procedures followed completely and without error
75 - 89	Successful - Satisfactory except for minor errors
60 - 74	Needs improvement - Non-critical deficiencies present
0 - 59	Failure - Not familiar with the application procedure

Measurement Cycle and Certification

- An individual report is prepared for each student as a result of the evaluation.
- If necessary, the right of re-application and correction is granted.
- All operations are documented and filed with video/photographs.

4.5. Basic Equipment Usage and Applications in Drone

The main purpose of this section is to transfer the basic qualities of the equipment that the user can use during drone repair, maintenance, repair or troubleshooting and to demonstrate different techniques.

4.5.1. Multimeter Usage and Applications in Drone

4.5.1.1. Aim

In this chapter, the basics of using a multimeter and how and in which situations this device is used in drone systems are explained. Multimeter is an indispensable test device used in measuring electrical values such as voltage, current, resistance and fault detection. In drone systems consisting of electronic components, controls that can be performed with a multimeter make maintenance processes safe and effective.

In this chapter, users will learn the basic measurement techniques and will be able to understand how to perform practical troubleshooting, connection control and safety tests with a multimeter.

4.5.1.2. What is a Multimeter?

A multimeter is a digital or analogue measuring instrument capable of measuring multiple electrical quantities. It usually includes the following measurement modes:

- DC Voltage (V⎓): Constant voltage measurement (e.g. battery control)

- AC Voltage (V∿): Alternative voltage measurement (in some drone charging systems)
- Resistance (Ω): Measurement of resistance value in circuit or components
- Continuity Test (Continuity / Buzzer Mode): Checks for conductivity between two points (beeps)
- Current Measurement (A): Measures the current flowing through the circuit (usually in series connection)

Table 4.8. *Multimeter Usage Areas in Drone*

Application Area	**Measurement Type**	**Description**
Battery voltage control	DC Voltage	It is checked whether the lipo battery is in a healthy voltage range.
Short circuit test on power cables	Continuity (buzzer)	It is determined whether there is a short circuit between the battery + and - terminals.
ESC - Motor connection test	Continuity / Resistance	The connection of the cables from the ESC to the engine is checked.
Solder point integrity check	Continuity	Test whether the soldered ends are connected to each other.
Connector check	Continuity	The conductivity of connectors such as XT60, servo, JST is checked.
PDB output voltage control	DC Voltage	The power distribution board (PDB) outputs are measured for correct voltage.
Voltage regulator test	DC Voltage	5V and 12V outputs are checked for accuracy.
Passive component test such as fuse, resistor etc.	Resistance	It is checked whether the components work in accordance with the circuit.

4.5.1.3. Basic Use: Step by Step

Required Material:

- Digital multimeter
- Multimeter probes (red: positive / black: negative)

- Drone (recommended to start in de-energised state)

1. DC Voltage Measurement (Battery Test):

- Set the multimeter to the "DCV" position (e.g. 20V scale).
- The black probe is placed in contact with the minus (-) end of the battery and the red probe is placed in contact with the plus (+) end of the battery.
- Read value:
  - ≈11.1-12.6V for 3S battery
  - For 4S battery, it should be ≈14.8-16.8V.

2. Short Circuit Check (Continuity Test):

- The multimeter is switched to "Buzzer / Continuity" mode.
- The device beeps when two probes touch a short-circuited line.
- If a beep sound is heard between the positive and negative terminals in the battery connection socket, this is a sign of a short circuit.

3. Resistance Measurement (Solder or component testing):

- Switch the multimeter to the "Ω" position.
- The two probes are touched to the soldered or connected leads.
- A value between 0-1Ω means a healthy connection. If there is an infinite value or very high resistance, there may be a disconnection.

4. PDB Voltage Output Test:

- The battery is connected (with caution).
- A multimeter is used to measure the 5V or 12V output of the PDB.
- Low or zero voltage, PDB malfunction or solder fault.

4.5.1.4. Safety Alerts

- When measuring with the battery connected, handle the probes carefully to avoid causing a short circuit.
- If current measurement is to be performed, the device must be connected in series and the "10A" port of the device must be used.
- Do not perform the short circuit test with the battery connected.
- For high current carrying lines, voltage and then continuity test should be performed first.

4.5.1.5. Tips

- Securing the multimeter leads with coloured crocodile clips frees the hands.
- After each new installation, a short circuit test must be performed before switching on the system.

- The first place to look in case of failure: battery voltage and power lines.
- If working with multiple drones, creating labelled test points provides systematic control.

Notes: The multimeter is the most basic and critical tool not only for professional technicians but also for hobby drone users. When used correctly, it prevents many problems and makes maintenance processes safe.

4.5.2. Oscilloscope Basic Usage and Applications in Drone

In this chapter, signals (PWM, UART, ESC signals, sensor outputs) that can be tested with oscilloscope in drone systems will be introduced and users will be able to perform basic waveform reading, frequency, voltage and signal continuity analyses.

4.5.2.1. Aim

This chapter aims to teach the basic functions of the oscilloscope device, usage methods and application areas especially in drone systems. Oscilloscope is an indispensable test device for observing the time-dependent change of electrical signals, especially for signal quality, communication protocols and noise analysis.

4.5.2.2. What is an Oscilloscope?

An oscilloscope is a device that can instantaneously display the **amplitude-time (V-t)** graph of electrical signals in a circuit. It allows to analyse the characteristics of signals such as **shape**, **frequency**, **amplitude**, **period** and **noise content**.

Table 4.9. *Basic quantities that can be measured with oscilloscope*

Measurement Parameter	Description
Amplitude (Vpp/Vmax)	Voltage difference between the peaks of the signal
Frequency (Hz)	Number of repetitions of the signal in one second
Period (T)	Duration of the signal in one cycle
PWM Width (ms)	Pulse duration on ESC and servo signals
Noise / Ripple	Unwanted signal fluctuations on power lines
UART / SBUS	Accuracy and duration of serial communication protocols

Table 4.10. *Oscilloscope Applications in Drone Systems*

Application	Description
ESC PWM signal analysis	The pulse duration and frequency of the FC → ESC signals are tested.
UART connection control	The data flow between FC and GPS, receiver or telemetry module is analysed.
Sensor output test (e.g. barometer, IMU)	The voltage response of sensors with analogue output is observed.
PDB / regulator noise analysis	Ripple detection is performed on 5V / 12V output lines.
Gimbal / servo signal test	The smoothness and frequency of the PWM signals are controlled.

4.5.2.3. Basic Oscilloscope Usage: Step by Step

Necessary Equipment:

- Digital oscilloscope (minimum 2 channels)
- Probe set (with 1x/10x attenuation option)
- Open drone system or test board for application

1. Connecting the Probe:

- The black (GND) clip probe connects to the system ground.
- The end probe (usually BNC → hook end) is connected to the signal line to be measured.

2. Channel Settings:

- Channel 1 is selected, the **1x/10x probe attenuation** setting is positioned correctly.
- Volt/div and time/div settings are made (for example 2V/div - 1ms/div).
- The values are optimised until the shape of the signal appears on the display.

3. Trigger Setting:

- The trigger mode (Edge, Auto) is set to stabilise the signal.
- The rising or falling edge is selected, the trigger level is set to the centre of the signal.

4. Review:

- Frequency, amplitude, duty cycle (for PWM) and shape of the signal are analysed.
- If there is irregular waveform, noise, voltage drop, it is noted.
- Start/stop bits or baud rate accuracy is checked in serial data signals.

4.5.2.4. Practical Drone Test Example: ESC PWM Analysis

- When the flight controller is on, a probe is connected to the ESC signal pin.
- The frequency of the observed PWM signal is usually around **400 Hz - 600 Hz**.
- The PWM pulse duration varies from 1000μs (0%) to 2000μs (100%) depending on the throttle position.
- Irregular waveform → may be a sign of noise / connection problem.

4.5.2.5. Safety Alerts

- Do not measure the battery voltage directly with the oscilloscope; this may damage the device.
- If the probe ground lead is connected to the wrong line, there is a risk of short circuit.
- If measurements are to be made in different systems, the probe attenuation ratio must be checked.
- Probe positioning is very important on high frequency data lines (may cause interference).

4.5.2.6. Tips

- It is easy to cut any signal cable and create special test points for measurement.
- Oscilloscope storage modes can be used for long-term signal analysis.
- The regulator ripple level should be ≤50mV when testing the PDB outputs.
- PWM signals should appear as a square waveform on the oscilloscope.

Note: The use of oscilloscopes plays a critical role in advanced diagnostics and debugging of drone systems. Especially for the accuracy of signal levels, connection security and system stability, the correct use of this device is an indispensable skill for system engineers and technicians.

4.5.3. Soldering Techniques and Drone Applications

4.5.3.1. Aim

This chapter aims to explain in detail the **soldering** process, a fundamental skill in electronic circuit assembly, and to teach how this technique is applied in drone systems. Soldering enables the permanent joining of cables, connectors, circuit components and pads on the board. Correct soldering is vital for safe, durable and accurate signal transmitting connections in drone systems.

4.5.3.2. What is Soldering?

Soldering is the joining of two or more metal parts using **molten solder wire**. This process is heat assisted and provides both **mechanical strength** and **electrical conductivity** of the joints. Commonly used solder alloy is 60% tin - 40% lead (Sn/Pb) or lead-free RoHS compliant solders.

Table 4.11. *Basic Materials Used in Soldering*

Material	Description
Soldering Iron (Soldering Pencil)	Hand tool with different wattage options that generates heat from the tip
Solder Wire	Tin-based wire with flux inside
Flux (Flux Material)	Allows the solder to spread over the surface and remove oxides
Solder Pump / Wire Mesh	Used to remove faulty solder
Heat Resistant Tweezers / Pliers	Used for fixing components
Macaron and Heat Gun	Provides cable insulation after soldering

Table 4.12. *Main Points Requiring Soldering in Drone*

Component	Soldering Point
PDB (Power Distribution Board)	ESC power cables, battery connector
ESC - Motor Connection	3 phase motor cable → ESC pads
FC - Receiver / GPS / Telemetry	UART / I2C signal cables
Camera - VTX	Video and power lines
Sensor Modules	I2C, SPI or direct soldered connections

4.5.3.3. Basic Soldering Steps

1. Clean the Surface:The pad or cable end to be soldered must be clean and free of oxide. Wipe with alcohol and cotton if necessary.
2. Adjust Soldering Iron Temperature: 320-370 °C is ideal for general soldering. Excessive heat may damage the pads.
3. Prepare the Solder Wire and Tip: The tip is tinned (pre-coated) by lightly touching the solder wire to the soldering iron tip.
4. Soldering:

- Touch the soldering iron tip to the surface to be soldered.
- The solder wire is touched to the heated point and melted.
- The solder should spread evenly and be "shiny and smooth".
- After the soldering iron is withdrawn, the connection must be kept stationary (until it cools down).

5. Control and Cleaning: After cooling, the connection is checked. If necessary, flux residue is cleaned with isopropyl alcohol.

4.5.3.4. Drone Application Example: XT60 Battery Socket Soldering

Materials: XT60 connector, 12 AWG silicone cable, solder wire, tubing

Steps

1. The ends of the cables are stripped and tinned.
2. The + and - ends of the XT60 connector are determined.
3. The wires are soldered to the connector (in a short time, by contacting).
4. The solder points are insulated with tubing.
5. Continuity test is performed with a multimeter.

Table 4.13. *Common Soldering Errors*

Error Type	Description
Cold soldering (cold joint)	Dull and cracked surface, poor electrical contact
Excess Solder	Excess wire → risk of short circuit
Inadequate Heating	Solder does not adhere to the surface, poor connection occurs
Pad Breakage	Card pad may lift after prolonged exposure to heat

4.5.3.5. Safety and Tips

- Soldering must be carried out in a well ventilated environment (smoke is harmful).
- The use of goggles and gloves during soldering ensures safety.
- When soldering on the board, the soldering iron time should be kept short to avoid heat dissipation to other components.
- It is always recommended to test the solder points with a multimeter.
- After soldering, the cables must be fixed and must not be left dangling.

Note: A quality solder joint is the basic requirement for long-lasting, safe and stable operation of the drone system. Incorrect soldering, especially in ESC, battery and signal connections, can lead to system failures and fire risk.

CHAPTER 5

Documentation and Communication

5.1. Maintenance record forms

Before each use of an unmanned aerial vehicle, from now on referred to as a drone, ensure that it is in proper working order. To this end, it is recommended to keep detailed records of the drone's technical condition, servicing, repairs and maintenance. Depending on the complexity of the design, the type of tasks performed, the size of the drone, the means transported (including hazardous materials and substances), as well as the locations and scope of maintenance, this documentation may be kept in a single book or in several separate registers.

The documentation may also be kept in electronic form, for example in the form of a computer programme or mobile application, if permitted by national regulations. This data should be archived (with backups if necessary) so that the full history of repairs and maintenance carried out can be reconstructed, as well as information on the resources, materials, equipment and personnel involved.

If an unmanned aircraft is to be used, the personnel operating the drone must be able to determine its technical condition, whether it is fully, partially or not at all operational. The documentation specifying the technical condition of the drone is intended to determine its technical condition and confirm that all necessary periodic maintenance has been performed according to schedule and that the condition of the drone allows it to perform its intended task. The documentation of the technical condition of the drone should also include information on all software updates and drone system configurations that may affect the safety and functionality of the drone.

If the drone is fully operational, the operating personnel may perform the task using the drone. If the drone is not operational, tasks cannot be performed using the drone. However, if the drone is partially operational, the personnel must be aware of the malfunctions and limitations of the drone (a list of malfunctioning components and limitations in the use of the drone may be created). It should be noted that when using a drone for flight, personnel must have direct access to information on repairs and maintenance that reflects the direct technical condition of the drone and its usability. Detailed information on specific maintenance (performance, use of tools, resources, etc.) does not need to be directly available to the person performing the flights, but it must be archived and available for inspection as needed.

In order to ensure the correct repair and maintenance process, it is preceded by planning and the resources necessary to carry out repairs and maintenance to ensure the readiness of the UAV. Reporting documentation, on the other hand, provides information on the work carried out and allows the planning process to be carried out correctly.

Planning documentation refers to documents that are created before the start of service or maintenance activities. It is used to plan, organise and prepare all tasks related to drones. Planning documentation includes a maintenance schedule and a plan for regular inspections and maintenance of drones. In addition, the resource management plan covers the planning of human, material and financial resources necessary to keep drones in operational readiness. Planning documentation enables systematic and effective planning of services and ensures compliance with regulatory requirements, assists in resource allocation and minimises risk. This documentation must specify the frequency, scope and necessary resources and materials for performing maintenance. A very important factor is to determine the time required for personnel, equipment and maintenance locations, which is of great importance for the smooth execution of tasks. Financial planning and procurement are crucial here.

Periodic drone maintenance planning refers to regular maintenance activities that are necessary to keep the equipment in good working order and operational readiness. The planning documentation must specify the type of inspection, the frequency of its performance and the scope of work (including the resources involved – manpower, means and materials).

This documentation concerns:

- technical inspection – daily (checking the general condition of the drone, batteries, propellers and sensors before each flight);
- post-flight (checking that the drone has not been damaged during the mission and that all systems are functioning properly);
- maintenance after a specified number of flight hours – manufacturer-recommended inspections after a specified number of flight hours, which may include replacement of worn parts, software updates, sensor calibration and other technical activities;

- annual inspection – a more detailed inspection, which may include more comprehensive performance and safety tests, replacement of key components and software updates;
- repairs – ad hoc (removal of faults or failures that may have occurred unexpectedly) and post-incident (repair work following damage resulting from accidents or failures);
- updates and modifications – software updates (installation of the latest software updates to improve functionality, security or compatibility with new systems) and hardware modifications (adding new components or modifying existing ones to improve performance, durability or meet new operational requirements).

The planning documentation should include information on the performance of services, the date of the last service/maintenance and the date of the next one.

A separate issue is the regular training of persons performing repairs and maintenance of drones, which should also be planned and for which appropriate financial resources should be reserved. Planning documentation allows for the proper management of workshops and planning of supplies and materials for servicing and maintenance, as well as for planning the involvement of workshop space and personnel.

Executive documentation consists of documents that are created during the implementation of repair and maintenance activities. They are used to record the actual activities that have been performed. Executive documentation includes service reports, detailed reports on inspections and repairs carried out, containing dates, descriptions of work, listed resources and materials (including parts) and personnel involved. The operational documentation should also include data on post-repair tests, test flight results and any comments on the further operation of the drone. Operational documentation records actual activities, which enables the monitoring and analysis of processes, provides evidence of compliance with procedures and regulations, and facilitates the identification of problems and the implementation of corrective measures.

The documentation should contain accurate and transparent records of all servicing, repair and maintenance activities carried out on the UAV. The information contained in the documentation should include: the exact date of completion of each servicing, repair or maintenance task; a detailed description of the type of work performed (e.g., periodic inspection, damage repair, part replacement, software updates) or a reference to the relevant service procedure identifying the scope of work performed, materials, resources and tools used; information on all parts, resources and materials replaced, including catalogue numbers, quantity, condition before and after replacement; identification of personnel involved in service and repair work; confirmation of obtaining specialist accreditations and certificates, if the drone components or the means, materials or equipment carried by it require such accreditations and certificates; completion of repair or service (if required) after checking that the drone is functioning correctly. In the event of malfunction, failure to perform maintenance, etc., the documentation must clearly indicate that the drone cannot be used to perform tasks or can only be used with restrictions. It is recommended that the lack of approval be confirmed with appropriate information, and that the restoration of the drone to use also be authorised with appropriate information.

The documentation should also include a history of faults, diagnostic tests performed, test results and technical recommendations for further maintenance. The implementation documentation must include all consumables used (e.g. lubricants, fluids, filters) and specialised tools, together with their serial numbers and date of last calibration.

In addition, it is recommended to have technical documentation for specialised agents, such as safety data sheets for agents and materials, which contain the necessary information on the properties of agents and materials, how to handle them, health and safety information, fire safety information, etc.

Reporting documentation, after completion of activities, refers to documents that are created after the completion of repair and maintenance activities. It is used for analysis, reporting and archiving.

This category includes technical condition reports, periodic reports assessing the technical condition of drones, containing recommendations for future maintenance activities. Document archiving involves the systematic storage of all documents related to the operation and maintenance of drones, in accordance with regulatory requirements. Performance analyses are reports analysing the effectiveness of maintenance activities, containing conclusions and suggestions for optimisation. Post-activity documentation enables retrospective analysis of activities and drawing conclusions, ensures compliance with regulatory requirements for document storage, and assists in the continuous improvement of repair and maintenance processes. Reporting documentation should support the planning of spare parts, supplies and materials purchases, as well as the engagement of workshop facilities and personnel.

Regular reporting and analysis of documentation data enables the optimisation of logistics and operational processes, which translates into increased efficiency and safety of drone operation. This documentation should also include data on the disposal of hazardous materials.

To ensure transparency and consistency of the documentation, it is recommended that the documentation be reflected in paper or electronic form (service software, dedicated applications).

Templates for keeping records – e.g. daily inspection sheets, repair reports, periodic maintenance sheets. The forms should be standardised, transparent and uniform to allow for easy data entry and reading. This facilitates both the documentation of maintenance activities and the subsequent archiving and analysis of activities.

Authorisation procedures – the documentation should clearly indicate the persons responsible for approving the return of the drone to service after maintenance or repairs. The form of confirmation (signature, stamp, electronic authorisation) and the method of recording the decision in the registers should be specified.

Fault classification system – it is recommended to implement a uniform classification of faults into:

- critical – preventing the use of the drone,
- significant – limiting the scope of tasks,
- minor – not affecting flight safety, but requiring recording and planning for removal.

An important element is integration with the Safety Management System (SMS) – documentation should be linked to the SMS system for the purpose of analysing events, detecting fault trends and implementing preventive and precautionary measures.
Documentation retention period – it is recommended that documents relating to servicing, repairs and maintenance be retained for at least 5 years or in accordance with applicable national regulations. Documentation may be stored in paper or electronic form, provided that security, integrity and the ability to reproduce the full service history are ensured.

In a technical environment where unmanned aerial vehicle (UAV) repair and maintenance specialists operate, technical documentation serves not only as a record but, above all, as a means of communication. It is a key element in enabling the effective transfer of information between team members, supervisors, customers and supervisory authorities. Well-maintained documentation ensures compliance with procedures, enables the assessment of work quality, supports operational safety and provides a basis for audits and certification.

UAV technical documentation is not uniform – it consists of many different forms that serve separate functions and require different competencies. These documents must not only be factually correct, but also transparent, organised, complete and easily accessible to decision-makers. UAV professional standards (OSE) clearly indicate the need for comprehensive operational, maintenance and communication documentation and require technicians to be able to create, analyse and use it in repair and decision-making processes.

5.1.1. Documentation Types

5.1.1.1. Operational Documents

This category includes documents used during the ongoing operation of UAVs. These are primarily:

- Standard Operating Procedures (SOP) – standardised operational procedures describing step by step how to carry out inspections, repairs, tests and other activities.
- Work Orders (WO) – work orders containing specific instructions, a list of required materials, completion dates and responsible persons.
- Checklists – pre- and post-flight checklists to ensure that all stages are carried out in accordance with the procedure.

These are instructional and coordination documents – their purpose is to ensure that the entire crew operates in a uniform manner and in accordance with established standards.

5.1.1.2. Technical and Maintenance Documentation

This includes all documents related to UAV diagnostics, repairs and maintenance:

- Maintenance Logs – maintenance logs in which technical activities, dates, spare parts and responsible persons are recorded.
- Repair Reports – detailed repair reports containing a description of the fault, diagnosis, corrective measures taken and final test results.
- Service Bulletins and TSL (Technical Service Letters) – updates from UAV manufacturers regarding, for example, new maintenance requirements or detected manufacturing defects.

UAV technicians must be able to maintain such documentation independently, analyse its content and formulate recommendations for further action.

5.1.1.3. Communication documentation (Professional Communication Documents)

These are documents whose main purpose is to convey information between team members, with the customer or with the supervisory authority:

- Client Reports – final reports for the client, containing a description of the services performed, an assessment of the condition of the UAV and operational recommendations.
- Incident Reports – formal reports of faults, incidents, failures or non-standard situations, containing UAV data, circumstances, corrective actions and responsible persons.
- E-mail Communication & Notes – electronic documentation including e-mails, notes from technical meetings, summaries of briefings and debriefings.

Communication competence includes both the ability to draft such documents and to understand their significance in the context of teamwork and external contact.

5.1.1.4. Flight Operations Documentation.

This group includes:

- Flight Logs – flight logs containing dates, locations, flight duration, operator data and mission objectives.
- Telemetry Reports – telemetry data from UAV missions, used to analyse operating parameters and diagnose errors.
- Flight Permission & Regulatory Forms – documents related to obtaining flight permits, route planning and compliance with EASA or national regulations.

Technicians should be required to be familiar not only with operating procedures, but also with airspace regulations, which necessitates proper documentation of compliance with the law.

5.1.1.5. Quality & Evaluation Records

These are documents used for internal evaluation of technical activities:

- Audit Checklists – checklists used for internal and external audits.
- Preventive Maintenance Recommendations – conclusions from inspections and technical analyses, proposing preventive measures.

- Continuous Improvement Logs – documentation collecting observations and ideas for improving procedures.

A UAV technician should be able to analyse the collected data, identify irregularities and communicate the need for organisational or technological changes.

5.1.2. Components of Documents

Each of the above-mentioned types of documents contains a set of mandatory components, such as:

- header with date, UAV name, serial number,
- details of the person responsible for completing or verifying the document,
- description of the activity or event,
- a list of materials and tools used,
- reference to SOP or WO,
- comments, recommendations, signature or electronic authorisation.

The completeness, transparency and compliance of these documents with internal and external standards is crucial for the effective functioning of UAV teams, their legal operations, safety and professional responsibility.

In UAV professional standards, technical documentation is presented not only as a record of activities, but as a strategic tool for professional communication. It allows for the efficient exchange of information between specialists, ensures the safety of operations, supports regulatory compliance and enables the continuous improvement of technical processes. According to the OSE, a UAV technician must not only be able to keep records, but also use them as an analytical, coordination and advisory tool. This competence combines technical skills, linguistic precision and professional responsibility, and is therefore crucial for the quality and safety of the entire unmanned aviation sector.

5.2. Regulatory compliance information

Safety regulations and compliance requirements are a key element of drone (UAV) fleet management. Ensuring that all operations are conducted in accordance with applicable regulations is essential for maintaining a high level of safety, protecting property and complying with legal regulations.

All drone operations must comply with national and international regulations governing unmanned aircraft. In many regions of the world, the main regulatory bodies are institutions such as the European Aviation Safety Agency (EASA) in Europe and the Federal Aviation Administration (FAA) in the United States, which establish regulations for drone operations. These regulations cover various aspects such as drone registration, operator licensing, airspace flight rules, technical requirements, and safety and privacy regulations.

Under international regulations, all drones above a certain weight must be registered in the relevant national registers. This registration is required before operations can commence and must be updated in the event of changes in ownership, upgrades or decommissioning of the drone. Registration ensures the traceability of the drone and facilitates regulatory oversight.

Drone operators must hold appropriate licences and certificates confirming their qualifications and ability to fly safely. These licences include both theoretical and practical training, which must be renewed regularly. Personnel responsible for servicing the equipment must hold appropriate certificates confirming their qualifications and ability to operate and repair the equipment.

The operator licensing process includes theoretical and practical training, examinations and regular license renewal. Operators must be familiar with air traffic regulations, safety rules, emergency procedures and restrictions on drone operations. In addition, operators must be familiar with local privacy regulations, especially if drones are equipped with cameras or other monitoring devices.

Technical maintenance personnel should regularly attend training courses, pass examinations and, in the event of a long break in their duties, undergo a re-assessment of their skills and qualifications. It should be noted that in many cases, the same personnel perform both technical maintenance and test flights of drones after repairs, which requires extensive technical and operational skills.

When a drone carries hazardous materials or specialised equipment, additional regulations must be followed, which may include both safety and health considerations.

When designing, purchasing and operating drones, technical regulations that drones must comply with must be observed. Drones must comply with requirements for design, navigation systems, communications and safety systems. Regular technical inspections and maintenance are essential to ensure that drones remain airworthy and meet all technical requirements.

Any modification or upgrade to a drone must be reported to and approved by the relevant regulatory authorities. Operators must also keep detailed records of every operation, inspection and repair to prove compliance with regulations in the event of an inspection.
Drones that record images or collect data must operate in accordance with privacy regulations. Many countries have specific regulations governing the collection and processing of personal data. Operators must be aware of these regulations and ensure that their operations do not infringe on the privacy of third parties.

All persons responsible for the operation and maintenance of drones should have constant access to up-to-date technical documentation and applicable regulations concerning the operation of drones. Regular review and updating of these documents is essential to ensure compliance with regulations and operational safety.

It is recommended that manuals and operational documentation contain clear references to applicable laws, technical standards and guidelines from national aviation authorities. Documentation should also include procedures for reporting incidents and violations, as well as guidance on the operator's legal liability in the event of a breach.
It is also important to ensure that all regulatory updates are promptly incorporated into the documentation and communicated to staff.

5.3. Manufacturer guidelines

Manufacturer guidelines form the basis for the proper operation, storage and maintenance of unmanned aerial vehicles (UAVs) and their equipment. They have been developed on the basis of technical tests, operational experience and safety requirements. Compliance with these guidelines is essential to ensure equipment reliability, minimise the risk of failure and comply with applicable aviation standards and regulations.

5.3.1. Manufacturers' Recommendations

The manufacturer's recommendations should be developed in the form of:

- technical instructions – containing detailed data on the operating, storage and transport parameters of the UAV,
- operating procedures – specifying step-by-step how to carry out inspections, maintenance and repairs,
- data sheets and technical specifications – specifying permissible values (e.g. temperature, humidity, battery voltage, consumable life),

- updates and technical bulletins (service bulletins) – introducing changes resulting from technological developments or operational experience.

Instructions should be available in paper and electronic form, in the original language and in the user's language.

5.3.2. UAV Operators' Responsibilities

To ensure compliance with the manufacturer's guidelines, UAV operators should:

- follow the procedures described in the documentation before and after each flight,
- keep a record of technical activities in the UAV logbook or central database,
- use only parts and consumables approved by the manufacturer,
- train technical and operational personnel in accordance with the latest instructions and technical bulletins,
- apply a quality control system, including verification of the compliance of the activities performed with the manufacturer's documentation,
- regularly verify and update technical instructions and implement recommendations resulting from new editions of documentation. Storage conditions can be divided into warehouse equipment (i.e. what is permanently in the warehouse, so-called warehouse equipment and devices) and stored items. The warehouse equipment itself must meet specific requirements . The warehouse and its equipment must provide suitable conditions for storing property.

The conditions created in warehouses can be divided into conditions for the storage of fixed assets (parts, drone equipment), resources and materials with a limited lifespan (operating fluids) and hazardous materials (batteries, lubricants, weapons, etc.).

When creating storage conditions, it is necessary to identify the needs related to the purpose of the drone and its specific equipment.

The storage conditions for drones (UAVs) and their components are crucial to ensuring their longevity, reliability and operational safety. Proper storage minimises the risk of damage, corrosion and other negative environmental effects. Storage conditions must comply with all manufacturer recommendations and regulations regarding premises and stored property. This covers a range of areas, from unauthorised access, monitoring and notification systems, to manufacturers' requirements regarding the technical condition of property, health and safety regulations, fire safety regulations, etc.

The documentation of the storage conditions of equipment, components and the drones themselves is intended to document the actual state of the environment. This documentation consists of daily updated temperature and humidity charts. It is also crucial to document the efficiency and servicing of equipment that ensures appropriate conditions, e.g. air conditioners, dehumidifiers, etc. The documentation should include references to protection against light and pests.

It should be noted that fixed assets must meet a number of conditions (e.g. shelves must have adequate load-bearing capacity, etc.), while movable assets often require specialised certification confirming their efficiency (cranes, overhead travelling cranes, etc.).
Battery rooms or battery charging points must meet the requirements for battery charging points or battery rooms in accordance with the type of batteries used. This documentation should enable the identification of the quantity and technical condition of the batteries supplied, periodic inspections and the determination of the scope of work performed on the batteries in accordance with the procedures.

The documentation for the storage of hazardous materials must comply with the storage conditions for each material in accordance with the manufacturer's recommendations.
Reporting the technical condition of drones and recommending appropriate maintenance actions is a key element of effective unmanned aerial vehicle (UAV) fleet management. This process not only maintains a high level of safety, but also affects the operational reliability of drones, which is particularly important in commercial and specialised missions.
Each drone must undergo regular inspections and technical reviews in accordance with the schedule set by the manufacturer and the regulations in force in the country concerned. These inspections include several types of reviews and are documented in:

- Pre-flight inspection documentation: These inspections are carried out before each flight to ensure that the drone is fully operational for the mission.
- Post-flight inspection documentation: These inspections assess the technical condition of the drone after the operation to identify any damage or wear and tear.
- Periodic inspection documentation: These inspections are regular inspections in accordance with the manufacturer's recommended schedule, which allow problems to be detected before they become serious.
- Special inspection documentation: Conducted after incidents or failures, these inspections assess the technical condition of the drone and determine whether it requires repair or replacement of key components.

Each of these inspections should be properly documented and the results recorded in a central database or the drone's technical log. The documentation should clearly reflect the technical condition of the drone, as well as the condition of individual systems such as the propulsion system, navigation systems, batteries, motors and other key components.

5.3.3. Technical reports and their importance

Technical reports form the basis for assessing the technical condition of the drone and planning future maintenance activities. Each technical report should include:

- Description of the technical condition of the drone: Detailed information about the current condition of the drone, including any identified faults, damage or signs of wear and tear on components.
- Maintenance log: Information about any maintenance activities performed, such as cleaning, lubrication, system calibration, part replacement or repairs.
- Recommendations for further action: Based on the results of inspections and technical reports, technicians may recommend future maintenance or repairs that should be carried out to ensure the safe operation of the drone.

5.3.4. Maintenance and supply planning

Technical reports have a significant impact on maintenance planning and the logistics of supplying spare parts and consumables. Detailed reports allow you to:

- Plan staff involvement: Prepare work schedules for technicians and operators in advance to carry out necessary maintenance activities.
- Plan supplies: Based on the reports, you can order the necessary spare parts, such as batteries, motors, filters, or other key components, minimising the risk of operational downtime.
- Optimise workshop operations: Well-managed documentation and reports allow for better management of workshop resources so that all repairs and maintenance are carried out on time and efficiently.

5.3.5. The importance of reporting for regulatory compliance

Accurate reporting of drone status and documentation of all maintenance activities is essential not only for maintaining operational readiness, but also in the context of regulatory compliance. In many countries, reporting regular inspections, repairs and maintenance activities is a legal requirement, and failure to comply with these rules can lead to serious consequences, such as loss of licence or legal liability in the event of accidents.

Archiving technical reports enables:

- Monitoring the technical history of the drone.
- Sharing the necessary documentation with supervisory authorities in the event of audits or inspections.
- Ensuring full compliance with local and international aviation safety regulations.

In summary, regular reporting on the technical condition of drones and recommending maintenance activities are key aspects of UAV fleet management. They allow you to maintain a high level of safety, minimise the risk of failure and optimise the logistics of technical operations.

It is recommended that manufacturers' technical documentation include detailed guidelines on the transport of drones and their components, storage conditions in different climate zones, and recommendations on maximum storage periods for consumables. The manufacturer's instructions should also include procedures for dealing with deviations from standards (e.g. exceeding humidity, temperature, loss of battery capacity) and specify which components must be immediately withdrawn from service. These guidelines should be regularly updated and verified by manufacturers.

5.4. Spare parts lists

Effective management of spare parts and inventory is a key element in maintaining the operational continuity of a drone (UAV) fleet. Properly maintained spare parts records ensure the availability of components at the right time, minimise the risk of operational downtime, support regulatory compliance and enable control of operating costs. Spare parts documentation should be linked to the inventory management system and technical documentation of drones to ensure consistency and transparency of maintenance processes.

Inventory in the context of unmanned aerial vehicle (UAV) management is a key element in ensuring effective resource management, cost control, and regulatory compliance. This process involves identifying, recording, monitoring, and controlling all physical resources related to drone operations. Here is a detailed description of property inventory:

The asset register allows for the identification of all assets related to drone operations. These assets include:

- each unmanned aerial vehicle, including its serial number, model, date of purchase, and technical specifications.
- all spare parts, accessories, batteries, sensors, and additional equipment used in drones.
- specialised tools and equipment used for drone maintenance and repair.
- workshops, warehouses, charging stations, and other properties related to drone operations.

Each identified asset must be registered in the inventory management system. A distinction must be made between the registers of room (facility) assets and stored property assets. Asset registration includes:

- Each asset is assigned a unique identification number for easy tracking and management. It is best if it is linked to the manufacturer's number or barcode.
- A detailed description of the resource, including its technical specifications, manufacturer, model, serial number, date of purchase and value.
- The place of storage or use of the asset, which facilitates its location and control.
- The current technical condition of the asset, i.e. its storage category (e.g. new, used, under repair) and its status (e.g. available, reserved, withdrawn from service).

Regular monitoring of the condition of assets and updating of data in the warehouse system is crucial for maintaining the accuracy and timeliness of assets. This documentation should allow for:

- control and review of assets to verify their condition, location and compliance with the records in the register.
- updating asset data in the event of changes such as relocation, repairs, modifications or decommissioning.
- tracking the life cycle - monitoring the life cycle of assets, from purchase, through use, to decommissioning and disposal.
- Controlling stocks of spare parts and consumables to ensure the operational continuity of drones.

Effective spare parts management requires not only keeping records, but also implementing clear procedures for submitting requests on appropriate paper or electronic forms. This process should be organised in two modes:

Current (reactive) mode. Used in emergency situations when there is a need for immediate replacement of a damaged or worn-out component, the absence of which prevents further operation of the drone. Requests are submitted on the basis of inspection reports, ad hoc repairs or incidents. The documentation should include: a description of the fault, an indication of the required part, the catalogue number, the urgency of the request and the person responsible for the request. This mode allows for a quick restoration of the UAV's operational readiness, but involves a higher cost risk (e.g. urgent purchase, lack of price optimisation).

Planning mode (proactive). It is based on periodic maintenance schedules, manufacturer recommendations and historical data on part wear. Planned requirements are submitted in advance, which allows them to be included in the budget, optimise deliveries and reduce storage costs. Planning documentation should indicate: the type of part, the expected replacement date, the quantity and the storage location. This mode minimises the risk of downtime and increases the predictability of logistics processes.

The best results are achieved by combining both approaches – planning for consumable parts and typical consumables, while maintaining emergency request procedures.

The documentation should clearly specify: who submits the request (e.g. service technician, workshop manager), how it is approved (authorisation, signature, electronic system), where it goes (logistics department, warehouse, directly to the supplier) and when it should be fulfilled.

The ideal warehouse system is one that not only allows requests to be submitted, but also automatically generates orders, controls inventory levels and replenishes shortages on an ongoing basis, both in a planned manner and in response to ad hoc needs. It should include purchase planning based on service schedules, service cycles and the anticipated intensity of UAV operation, as well as real-time inventory management with ongoing monitoring of stock levels of parts, accessories, tools and consumables. An important element is the ability to handle current demands, i.e. the immediate generation of needs in emergency situations, such as sudden failure or the need for urgent replacement of parts. The system should be integrated with UAV maintenance documentation so that it automatically generates lists of parts necessary for maintenance based on repair, maintenance and inspection records. An integral part of the system is also the maintenance of purchase and consumption history, including part serial numbers, purchase dates, warranty periods, data on their shelf life, i.e.

limited usability due to the ageing of materials, and a complete record of their use. This allows for resource rotation planning, avoids the use of expired parts and minimises losses resulting from the expiry of their shelf life. The warehouse system should also have authorisation mechanisms that clearly define the persons responsible for approving orders and accepting parts into stock, and be linked to a financial system that enables budget control, fund reservation and reporting of costs related to UAV fleet maintenance. This ensures full control over the circulation of spare parts, minimises the risk of stock shortages, reduces response times in emergency situations, enables effective expenditure planning and guarantees that drones are operated in a safe, economical manner that complies with technical and regulatory requirements.

5.5. Occupational health and safety rules

Occupational health and safety (OHS) rules and regulatory compliance requirements are the foundation of unmanned aerial vehicle (UAV) fleet management. They are designed to protect the health and lives of operators and bystanders and to safeguard property and the environment. The responsibilities of operators and technical personnel, as well as the requirements for documentation and infrastructure supporting the safe operation of UAVs, must be clearly defined and known to all personnel.

All drone operations must comply with national and international regulations governing unmanned aircraft. In many regions of the world, the main regulatory bodies are institutions such as the European Aviation Safety Agency (EASA) in Europe and the Federal Aviation Administration (FAA) in the United States, which establish regulations for drone operations. These regulations cover various aspects such as drone registration, operator licensing, airspace flight rules, technical requirements, and safety and privacy regulations.

Under international regulations, all drones above a certain weight must be registered in the relevant national registers. This registration is required before operations can commence and must be updated in the event of a change of ownership, upgrade or decommissioning of the drone. Registration ensures the traceability of the drone and facilitates regulatory oversight.

Every organisation operating UAVs should have a person responsible for regulatory compliance (Compliance Manager) who monitors changes in the law and updates procedures.

Drone operators must hold appropriate licenses and certificates confirming their qualifications and ability to fly safely. These licenses include both theoretical and practical training, which must be renewed regularly. Personnel responsible for servicing the equipment must hold appropriate certificates confirming their qualifications and ability to operate and repair the equipment.

Operators must undergo regular health and safety training in UAV operation, field work and emergency response. In the event of a long break in duties, recertification is required.

When designing, purchasing and operating drones, the technical regulations that drones must comply with must be observed. Drones must comply with requirements for design, navigation systems, communications and safety systems. Regular technical inspections and maintenance are essential to ensure that drones remain airworthy and meet all technical requirements.

Where a drone carries hazardous materials or specialised equipment, additional regulations must be followed, which may include both safety and health considerations.
Any modification or upgrade to a drone must be reported to and approved by the relevant regulatory authorities. Operators must also keep detailed records of every operation, inspection and repair in order to prove compliance with regulations in the event of an inspection.

Records must be kept of the legalisation and calibration of measuring equipment used to operate UAVs (e.g. battery testers, diagnostic stations). Drone components with a shelf life (e.g. batteries, gyroscopes, pyrotechnic components) must be checked for expiry dates.
Drones that record images or collect data must operate in accordance with privacy regulations. Many countries have specific regulations governing the collection and processing of personal data. Operators must be aware of these regulations and ensure that their operations do not violate the privacy of third parties.

Data anonymisation procedures (e.g. blurring of faces, number plates) are required for material recorded by UAVs. Data should be secured in a system with backup and access control.

Keeping accurate records of drone (UAV) flights is essential for ensuring safety, regulatory compliance and monitoring the technical condition of drones. Each flight should be recorded in a flight log to enable retrospective analysis, tracking of equipment wear and tear, and identification of any technical issues.

The record of completed flights should include the following information:

- Flight date and time: Record the date and exact time of the start and end of the flight.
- Drone operator: Details of the person responsible for controlling the drone during the mission.
- Drone model and serial number: Identification of the equipment used.
- Flight duration: Total operational time of the drone in the air.
- Flight route and altitude: Information about the flight route, altitude and any changes during the mission.
- Mission objectives: A brief description of the tasks performed during the flight (e.g. monitoring, filming, inspection, etc.).
- Weather conditions: Information about prevailing weather conditions that may have affected the flight.
- Technical problems: Any malfunctions or problems encountered during the flight, such as loss of communication, system failure, navigation restrictions.

The flight log serves as a basic tool for analysing the technical condition of the drone and planning maintenance. This data allows for the assessment of component wear, battery life and other elements requiring regular inspection. The documentation must be digitally archived for at least 5 years and integrated with the mission planning and maintenance module.

In many countries, drone operators are required to have civil liability insurance in case of damage to third parties or property. This insurance is particularly important for commercial flights or flights over populated areas.

It is recommended that organisations operating UAVs also have equipment insurance against loss or damage.

UAV operators should be familiar with and follow emergency procedures, including procedures for power failure, loss of communication, emergency landing, lithium-ion battery fire, collision or damage to the UAV.

Each incident should be recorded in an Incident Report. The employer and the organisation responsible for the operation of the UAV are obliged to: provide employees with personal protective equipment (e.g. safety glasses, antistatic gloves), organise periodic training, supervise compliance with health and safety regulations, and implement a Safety Management System (SMS).

5.6. SOPs and WOs

Standard operating procedures (SOP) and work orders (WO) are the foundation of effective management of the operation and maintenance of a drone (UAV) fleet. They introduce order, systematise activities and ensure that all processes – from mission preparation to technical support – are carried out in accordance with accepted standards and legal regulations. SOPs define "how" a given task should be performed, while WOs indicate "what" is to be done, by whom and when. Together, they form an integrated system that ensures safety, high-quality operations and full documentation of processes.

5.6.1. Standard operating procedures (SOPs)

They are a key element of drone fleet management (UAV) management. SOPs ensure consistency, safety and efficiency of operations by establishing detailed, step-by-step guidelines for various aspects of drone operation. With SOPs, organisations can also minimise the risk of operational errors and ensure compliance with legal regulations.

Every organisation operating drones should develop and implement SOPs that are tailored to the specifics of its operations and comply with applicable regulations. This process involves risk analysis, identification of critical tasks and definition of standard procedures. SOPs should be regularly reviewed and updated in response to technological, regulatory and operational changes.

SOPs should also include emergency procedures that specify the actions to be taken in crisis situations, such as loss of communication, technical problems or drone system failures.

5.6.1.1. Pre-flight Procedures

Pre-flight procedures can be divided into two categories: preparing the drone for flight and preparing personnel for flight. Both of these categories are critical to ensuring that the drone is fully operational and ready for safe flight. SOPs should include:

- Detailed checklists covering inspection of the drone's technical condition, battery charge checks, navigation and communication system tests, and physical condition checks (e.g. mechanical damage, contamination, etc.).
- Staff preparation includes reviewing and approving the flight plan, taking into account weather conditions, flight restriction zones and mission objectives. Operators should also undergo a briefing on safety procedures and aviation regulations applicable in the airspace concerned. Operators should also prepare alternative plans in case conditions change.

Often, a pre-flight briefing is organised for operators, i.e. a meeting of the operational team to discuss the details of the mission, identify potential risks and assign roles and responsibilities. The briefing may also be recorded or documented in the form of a report for archiving and future analysis.

5.6.1.2. Post-flight procedures

Post-flight procedures are designed to ensure that the drone is properly secured and prepared for subsequent missions. The SOP includes the scope of post-flight inspection of the drone to detect any damage or wear and tear, as well as checking the battery charge status and recording the results in the flight log.

If the drone does not have a flight data recorder, manual documentation should be kept, in which data on the flight, including duration, route, objectives achieved and any problems encountered, should be recorded. This documentation is necessary to analyse the effectiveness of the operation and detect potential technical problems.

Records may also be kept of debriefing meetings, during which the course of the mission, any problems encountered and conclusions that may improve the effectiveness of future operations are analysed.

5.6.1.3. Standard Operating Procedures' Function

SOPs should define standard methods for performing various tasks, such as:

- Safe take-off and landing procedures, taking into account terrain conditions and technical requirements.
- Navigation procedures and maintaining communication with the operations centre, including regular reporting of the drone's position and status.
- Standard procedures for dealing with technical failures, loss of communication, collisions or other emergency situations.

- Safety procedures that ensure safe drone operations, including regular assessment of operational risks, identification and analysis of potential hazards, and development of strategies to minimise them.

SOPs should also include rules on the use of personal protective equipment (PPE) by operators and maintenance personnel.

To maintain a high level of safety and operational efficiency, SOPs should be treated as "living" documents, subject to regular updates. It is recommended that they be reviewed at least once a year or whenever new technologies are introduced, regulations change, or operational incidents occur. Another important element is the way in which documentation is managed – procedures should be available in both paper and electronic form, with a clearly defined method of distribution and archiving. SOPs should also be integrated with the safety management system (SMS) so that each procedure is linked to risk analysis, event monitoring and conclusions from reports. It is also necessary to ensure that all procedures include an indication of responsibility – who performs specific activities and who approves them. In this way, SOPs become not only work instructions, but also a tool for building a culture of safety and organisational order.

5.6.2. Work orders (WOs)

WOs are a key element of drone (UAV) operations and maintenance management. Work orders are created in response to planned inspections, maintenance, repairs and other operational tasks.

The process of creating work orders begins with identifying the need to perform a task, which may result from a maintenance schedule, inspection results, reported faults, or planned operations. These orders may also arise as a result of recommendations from reports on previous operations and repairs.

5.6.2.1. WO Content

A work order should contain the following information:

- Task identification: Unique work order number, date of issue, and drone identification (serial number, model).
- Detailed description of the task to be performed, including the scope of work, objective and required actions.
- Planned date and time of commencement and completion of the task.

- Required human resources (operators, technicians), materials (spare parts, tools, consumables) and any logistical support.
- Reference to relevant standard operating procedures (SOPs) and technical instructions.

Once a work order has been created, the task is assigned to the appropriate technicians or service teams. Task assignment takes into account staff qualifications and certifications, resource availability and task priority. Each assigned employee should receive a copy of the work order and all necessary instructions and materials.

5.6.2.2. Work order execution

Personnel proceed to execute the work order in accordance with specified procedures and standards. While performing the task, specialists:

- Record work progress, document the activities performed, materials used, parts replaced, and any problems encountered.
- Comply with SOPs: Ensure that all activities comply with applicable standard operating procedures.
- Communicate with supervisors: They regularly inform their supervisors about the progress of work and any problems that may require additional decisions or resources.

Work orders should be created and executed in a manner that allows for full tracking of their life cycle – from the moment the task is reported, through its execution, to its closure and archiving. Each WO should contain a clear identification of the task, details of the persons responsible and the signatures (paper or digital) of the persons performing and approving the task.

Documentation should be kept in a manner that allows integration with warehouse management – WOs can automatically generate requests for spare parts, consumables or tools. s also an important element, as is documenting conclusions from debriefings after tasks are completed – analysing the course of operations and problems not only allows for the improvement of future tasks, but also for the refinement of SOPs. Regular archiving and analysis of completed WOs enables the identification of trends, evaluation of the effectiveness of maintenance activities and implementation of organisational improvements, which directly translates into increased safety and reliability of the UAV fleet.

5.6.2.3. Quality Control Checks

After completion of the work, the supervisor or designated inspector performs a quality control check of the tasks performed. This check includes:

- Verifying that all activities have been performed in accordance with the work order and applicable procedures.
- Performing functional tests on the drone to ensure that it is fully operational and ready for operation.
- Confirming the completion of the task in the work order management system and updating the drone's technical documentation.
- Archiving and analysing the work order and related documentation. Regular analysis of archived work orders allows for the identification of trends, evaluation of the effectiveness of maintenance activities, and optimisation of operational processes.

Organisations should regularly conduct internal reviews and audits of work orders to ensure compliance with regulations and procedures and to improve management processes. These audits may include reviewing documentation, evaluating technician performance, and analysing resource management effectiveness.

5.7. Liability (insurance, incident reporting)

Reporting drone incidents and accidents is an important part of ensuring safety and compliance with regulations around the world. Every drone operator should be familiar with local incident reporting rules, keep detailed records, and report any irregularities within the specified time limits. These actions contribute to increased operational safety and the prevention of future problems. Although reporting methods and details may vary depending on the regulations in force in a given country, the key principles remain similar. Each country usually has its own incident reporting system that complies with international aviation safety standards.

5.7.1. Incident Reporting

An employee who witnesses an incident or is involved in an accident should immediately report the event to their supervisor or the appropriate organisational unit. Therefore, a method or document should be established for employees to report events (whether they require immediate response or not).

The organisation must clearly identify the person responsible for authorising the report (e.g. manager, compliance manager).

Incident reporting is usually mandatory when drones are involved in serious incidents or accidents.

5.7.1.1. Possible Incidents

Incidents may include:

- Technical failure: Mechanical damage, navigation system failures, problems with engines, batteries or other critical components of the drone.
- Loss of communication: Interruption of communication between the operator and the drone, which may lead to uncontrolled flight.
- Collisions: Collision of the drone with objects (natural or artificial) during flight.
- Safety hazards: Any situation that could endanger the life, health or property of bystanders.
- Regulatory violations: Flying in prohibited areas or exceeding the limits set by legal regulations.

5.7.1.2. Ways of Reporting Incidents

Incidents and accidents must be reported within a specific time frame, which may vary from country to country: Incidents should generally be reported within 72 hours of occurrence, while accidents should be reported immediately, usually within 24 hours.

Although specific reporting methods may vary from country to country, there are generally two main ways to report incidents:

- Online reporting: Many countries have electronic incident reporting systems that allow you to quickly and easily submit incident details online.
- Reporting forms: In some cases, you can also download forms, fill them in by hand, and send them to the relevant authorities electronically or on paper.

5.7.1.3. Content of Incident Reports

Each incident should be reported immediately and recorded in an incident management system, which should include the following information:

- Date and time of the event: The exact moment when the incident occurred.
- Location: The exact place where the incident occurred.
- Operator details: Information about the person responsible for operating the drone at the time of the incident.

- Drone details: Model, serial number and other technical information about the drone involved in the incident.
- Participants
- Description of the incident: Detailed information about the incident, including all relevant circumstances.
- Consequences: Description of any material damage, damage to the drone and injuries to bystanders.
- Actions taken: Description of the steps taken to prevent the incident from escalating and to ensure safety.
- Recommendations: Conclusions and recommendations for improving procedures or techniques to prevent similar incidents in the future.

5.7.1.4. Other Considerations

Rapid reporting of incidents is crucial for quick analysis and the possible introduction of preventive measures.

Incidents should be regularly analysed by the technical team, and any conclusions should be reflected in modifications to operating procedures, staff training and technical improvements to equipment.

Proper incident reporting not only helps prevent future problems, but also increases operational safety and builds confidence in drone management procedures.

These reports should enable incident analysis, risk identification and the implementation of procedures to improve the situation.

In many countries, drone operators are required to have civil liability insurance in case of damage caused to persons third parties or property. This insurance is particularly important for commercial flights or flights over populated areas.

To increase the effectiveness of incident and accident reporting and improve safety, the organisation should integrate the reporting system with the Safety Management System (SMS). This ensures that each incident report becomes part of a broader risk analysis and allows for the development of effective preventive measures.

Another important aspect is the implementation of a "just culture", i.e. an environment in which employees can report incidents without fear of disciplinary sanctions, unless there has been gross negligence. This approach promotes openness, increases the number of incidents reported and allows for more effective identification of hazards. In the event of serious incidents or accidents, operators are required not only to report the incident internally, but also to notify the relevant regulatory authorities, such as the national civil aviation authority (e.g. EASA in Europe, FAA in the USA, ULC in Poland).

In addition to ongoing incident reporting, the organisation should prepare regular summary reports (e.g. monthly or annual) to enable trend analysis, assessment of the effectiveness of corrective actions and planning of further preventive measures. These reports can be used both internally and forwarded to supervisory authorities.

A well-designed incident reporting system, combined with mandatory insurance, not only increases operational safety but also builds trust among customers, regulators and the public in the organisation managing the drone fleet.

5.8. Effective professional communication

In the working environment of a technician involved in the operation and maintenance of unmanned aerial vehicles (UAVs), professional communication plays a key role in ensuring the smooth running of operations, the effectiveness of repairs and the safety of the entire operational process. One of the most important tools for this communication is properly maintained technical documentation. This documentation not only enables the transfer of information between team members, but also forms the basis for contact with customers, supervisors, auditors and representatives of supervisory institutions. In this context, professional communication takes the form of an orderly transfer of technical, operational, logistical and formal information, using appropriately prepared and standardised documents.

However, in order for documentation to fulfil its communication tasks, it must be supported by a set of rules and components of effective professional communication. The effectiveness of this communication includes, among other things: clarity and unambiguity of the message, the use of a common language and standardised formats, up-to-date information, as well as data availability and security. Professional technical communication also requires a logical document structure, compliance with procedures, and openness to feedback. Every technician should also have the language and digital skills to navigate the multi-channel documentation environment efficiently. All these components together form the basis for effective and responsible information exchange, which is essential when working with UAVs.

The types of technical documents that serve a communication function are diverse and include documents related to both ongoing operation and planning and reporting of activities. The most important documents are technical reports, which are created by service technicians after performing UAV maintenance, repairs or inspections. Such a report contains a detailed description of the technical condition of the device, detected faults, component wear, tests performed, as well as recommendations for further action. This type of documentation is forwarded both internally – to supervisors or technical planners – and externally, e.g. to the customer, who receives feedback on the condition of the entrusted equipment. The professionalism of this document is reflected in its clarity, compliance with documentation standards, and the technician's ability to formulate conclusions precisely and objectively.

Another important type of document supporting professional communication are work orders. These types of documents are issued by persons responsible for planning or managing technical maintenance and contain specific instructions regarding the scope of activities, deadlines, necessary resources and assigned personnel. A work order serves as a formal communication of a task that must be performed in accordance with specified procedures. Once the work has been completed, the document is often returned to the issuer with a note on the course of implementation, any problems encountered and the final results. In this way, it constitutes a two-way communication channel: from the client to the contractor and back, ensuring full transparency and operational accountability.

Standard operating procedures, or SOPs, are also particularly important in team and organisational communication. Documents of this type define in detail how to perform specific activities, from preparing the drone for flight, through the rules for safe take-off, navigation and landing, to maintenance, material disposal and emergency procedures. SOPs serve an educational and coordinating function, enabling all team members to operate according to uniform, proven patterns. Communication via SOPs eliminates guesswork, ambiguities and individual interpretations, leading to greater predictability and repeatability of work results. They also form the basis for training, certification and internal quality audits.

Service logs and technical notes, which are operational in nature and kept up to date, also play an important role in everyday technical practice. They record all activities performed on the UAV on a given day, materials used, tools used and comments on further use of the equipment. Such documents are particularly useful when several technicians work on one device on a rotational or shift basis. The service log enables the smooth transfer of information and continuation of work without the need for time-consuming training of new personnel in the current situation. From an internal communication perspective, it is a basic tool for maintaining continuity of operations.

When repairs, inspections or flight operations are carried out at the customer's request, the final report provided to the customer becomes an extremely important document. This type of document should be prepared in a professional, accessible and unambiguous manner. It should contain both technical data and an interpretation of the results of the work, information about potential risks and suggestions for further steps. Professional communication with the client in the form of a written technical report is key to building trust, ensuring transparency of services and maintaining high standards of commercial relations.

The role of notification and incident reports cannot be overlooked either. In the UAV operating environment, emergencies, malfunctions, airspace violations and other irregularities often occur. Each such event must be properly documented and reported internally, and often also to external institutions. In addition to a description of the event, the incident report contains the operator's details, the drone's details, the place and time of the event, and the actions taken. This type of documentation is an extremely important crisis communication tool, enabling rapid response, situation analysis and the implementation of corrective measures. At the same time, these documents have a legal function and may form the basis for control, insurance or corrective measures.

In the context of professional communication, one must not forget about less formal but still important documents, such as email templates, meeting notes, and debriefing and briefing minutes. Although seemingly less technical, these forms of documentation are also an integral part of the daily functioning of UAV teams and affect the effectiveness of cooperation. A well-prepared message template can speed up the response to a customer request, facilitate flight result reporting, or improve team organisation.

In summary, UAV technical documentation not only serves to record data and ensure compliance with procedures, but also forms the foundation for effective professional communication in a technical environment. By selecting and using the right types of documents and following the principles of effective professional communication, it is possible to convey information accurately, plan and execute tasks effectively, respond quickly to crisis situations, and build relationships based on trust and transparency. The proper use of this documentation directly affects service quality, operational safety, and the development of the entire technical team's competencies.

To complement effective professional communication in the UAV environment, attention should also be paid to the role of modern digital tools that support reporting, archiving and information exchange processes. CMMS (Computerised Maintenance Management System) systems, mobile applications and integrated UAV fleet management platforms are increasingly being used to enable real-time documentation, automatic flight parameter recording and ongoing reporting on the technical condition of equipment. Such solutions enable rapid data sharing within the team, as well as easier monitoring of fault trends, planning of inspections and analysis of operational efficiency. An important element of effective professional communication is also the appropriate training of personnel in soft skills.

In addition to technical training, operators and technicians should regularly participate in training on report writing, technical note preparation, pre-flight and post-flight briefings, and proper feedback delivery. These training courses allow for the standardisation of communication within the team, eliminate the risk of misinterpretation and ensure that all data provided in the documentation is clear, unambiguous and compliant with standards. The integration of digital tools with the communication skills of staff creates a coherent information exchange system that directly affects the quality of technical service, operational safety and the transparency of the entire organisation's activities.

UAVET

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