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MODULE 03

TRAINING PROGRAMME

DRONE DYNAMICS AND MAINTENANCE

Table of contents

1. Objectives of the module ... 6

2. Flight mechanics ... 7

2.1 Aerodynamic lift ... 7

2.2 Aerodynamic drag ... 8

2.3 The propeller makes the movement and the lift ... 9

2.4 Direct a multi-rotor UAV by unbalanced propeller forces ... 11

2.5 Axes of motion of an aircraft ... 12

2.6 Balance of forces – air mass movement ... 13

3. Essential parts of a multirotor drone ... 14

3.1 Receiver ... 15

3.2 Flight controller ... 16

3.3 IMU – Inertial Measurement Unit ... 17

Barometric altimeter: height relative to the take-off point ... 17

Magnetometer: direction and attitude (compass) ... 17

Gyroscope: attitude ... 18

Accelerometer: speed change in all directions ... 19

Thermometer ... 19

3.4 Ultrasonic proximity sensors ... 20

Vertically under the drone: low altitude to the ground ... 20

Horizontally on the sides of the drone ... 20

3.5 Imaging proximity sensors ... 21

3.6 GNSS global navigation satellite system ("GPS") ... 22

GNSS drone positioning: relatively to the take-off point ... 22

Improved precision: RTK, centimetric positioning ... 22

3.7 Electric motors and their ESC ... 23

3.8 Propellers ... 24

3.9 Power unit (power distribution board) ... 25

3.10 Batteries ... 26

4. Remote control (rc) ... 30

4.1 Transmission ... 30

4.2 Controls ... 31

Control modes 31
5. Maintenance 36
5.1 Maintenance records 36
5.2 Content of the maintenance program 37
5.3 First check after assembly 38
Review of all elements 38
Functional ground test 38
Functional flight test 38
Battery 39
5.4 Periodic reviews. 40
5.5 OTHER REVIEWS 42
6. Uas maintenance record example 43

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1. Objectives of the module

This module is divided in two main parts:

Sections 1, 2 and 3: essential knowledge about how the drone uses aerodynamic forces to fly, with simple flight mechanics information. Followed by a description of the role and function of a drone's various flight components. Finally the general operation of the joystick is explained.

Sections 5 and 6: how to maintain the drone in good condition for flying, and record the maintenance operations according to a professional plan.

The module focuses on multirotor drones which are the most widely used drones by pilots in training.

A full explanation of the physics involved in flying drones is outside of the scope of this module.

2. Flight mechanics

2.1 Aerodynamic lift

Around a wing or propeller moving in the air, there is a compression of air under the airfoil (intrados, the lower surface) and a depression on the top of the airfoil (extrados, the upper surface).

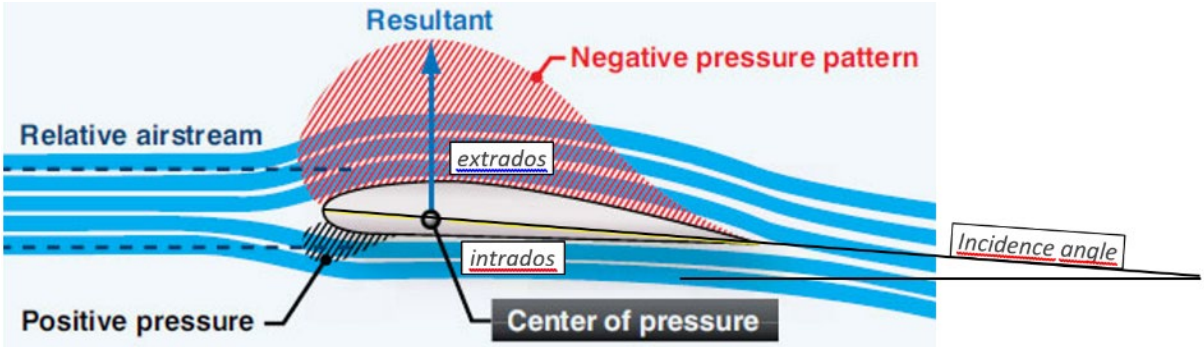


Figure 1 Wing lift - (flight-mechanic.com-modified)

Thanks to this lift, the weight of the aircraft is compensated and the aim craft can fly.

Note the importance of the "incidence angle": if the angle is too low, the lift will be poor, if the angle is too high, the wing will "stall", it means that the lift will drop drastically, the aircraft can fall.

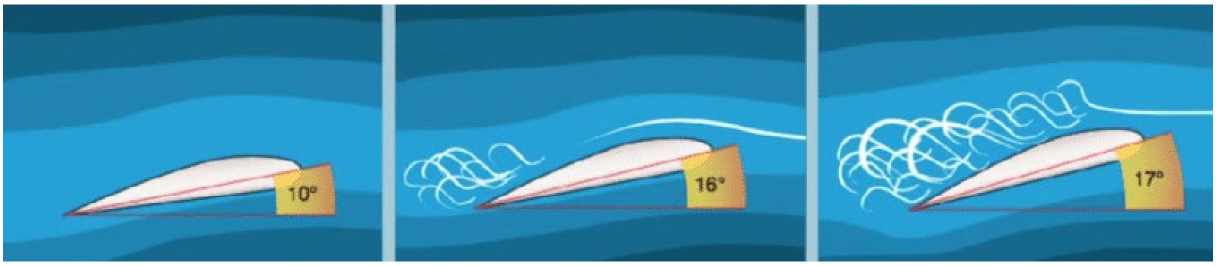


Figure 2 Incidence Angle (researchgate.net/profile/Mariateresa-Sestit)

Above the incident angle is too high on the 16° and 17° drawings: the air flow no longer sticks to the wing, the depression no longer exists (replaced by an aerodynamic drag) and the lift force is annihilated.

2.2 Aerodynamic drag

If the shape of a body moving through the air is not tapered, the airflow may cause a vortex that prevents the element from moving forward and is referred to as aerodynamic drag.

The drag, the vortex, the turbulence, the wake that is created depends on the shape.

This turbulence creates a force that holds the aircraft back, in the opposite direction of movement and moreover this drag increases as the square of the speed.

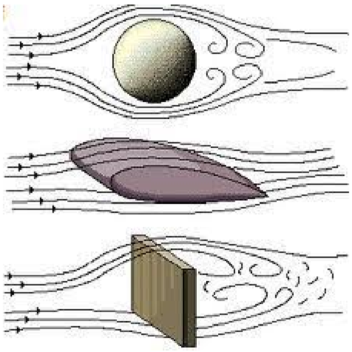


Figure 3 aerodynamic drag-(cyclingdynamics.com)

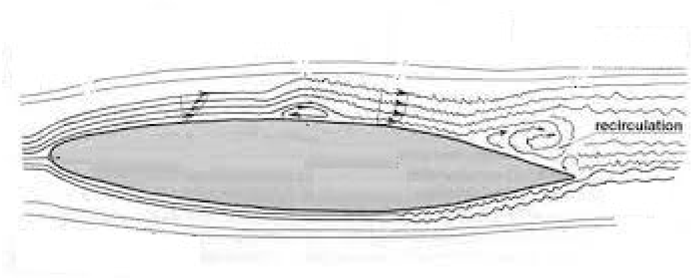


Figure 4 Drag on a profile

Even an aerodynamic profile can present turbulence and so it is important that the propellors on an aircraft are maintained in a good condition to maintain the aircrafts efficiency.

2.3 The propeller makes the movement and the lift

On winged drones, as on airplanes, there are four forces at work:

- The lift of the wings
- The weight of the aircraft
- The propulsion of the propeller which ensures only the displacement
- The drag which hinders the movement

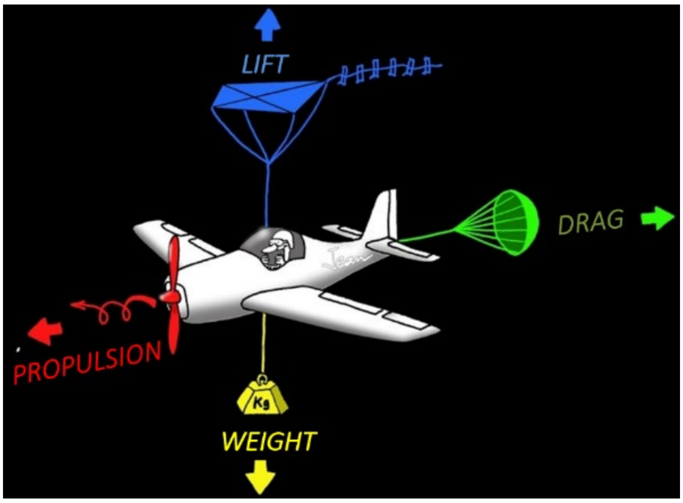
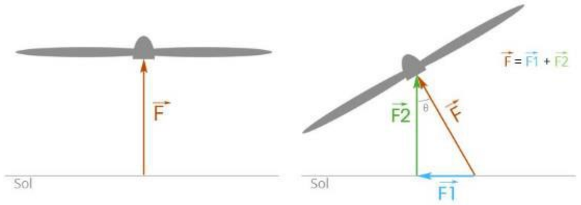


Figure 5 The 4 forces involved in flight

Figure 6 Fixed wing drone "Disco"-(technique-ingenieur.fr)

On multi-rotor drones, it is the tilt of the propellers that makes the aircraft move



When the propeller is tilted, a part of its aerodynamic force ensures the movement of the drone. Like on a helicopter

Figure 7 Propeller lift and propulsion-(firediy.fr)

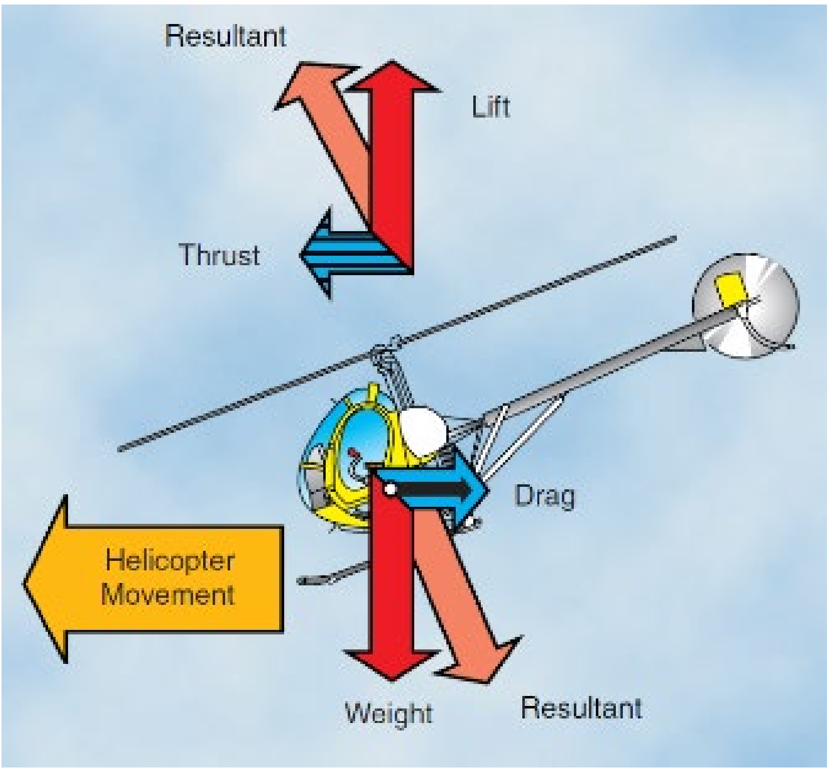
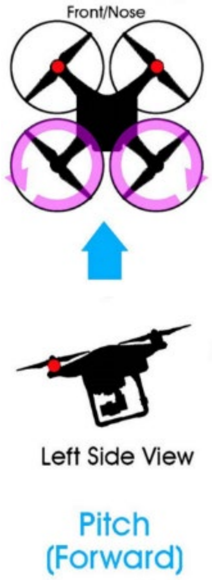
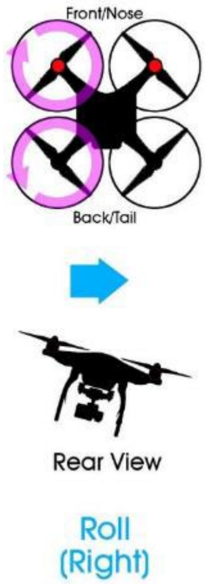


Figure 8 A helicopter tilts forward to go forward-(aircraftsytemstech.com)

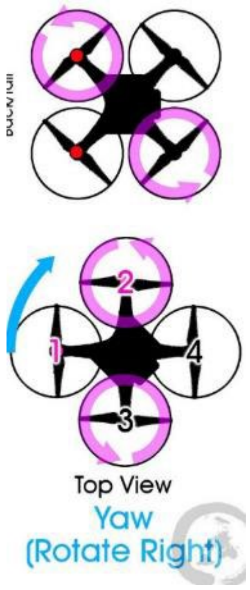
2.4 Direct a multi-rotor UAV by unbalanced propeller forces



FORWARD: By reducing the rotational speed of the front motors and increasing the rotational speed of the rear motors, the drone turns around its **pitch axis**, tilts forward, and moves forward.



MOVING LATERAL: By reducing the rotational speed of the left motors and increasing the rotational speed of the right motors, the drone turns around its **roll axis**, tilts, and moves to the left. Same for the right.



ROTATE ON ITSELF: By decreasing the speed of rotation of the diametrically opposed motors, the drone rotates around its yaw axis, changing its direction. This change in rotation speed affects the overall drag torque (see above) and causes the drone to rotate around its **yaw axis**.

Figure 9 Propellers actions to direct a multirotor drone (i.pinimg.com)

Weather conditions or air characteristics (temperature, density) can affect these forces and therefore the drone's performance. We can remember that an increase in temperature or a decrease in pressure (at altitude for example) degrades the lift.

2.5 Axes of motion of an aircraft

- The roll: longitudinal axis around which the drone turns; roll clockwise direction will result with drone moving to the right, anticlockwise to the left.
- Pitch: lateral axis around which the drone turns, it allows drone to go forward or backwards
- The yaw: vertical axis around which the drone turns to change the orientation (heading).
- The attitude (with two "t") is the position of the drone in relation to the horizontal axis

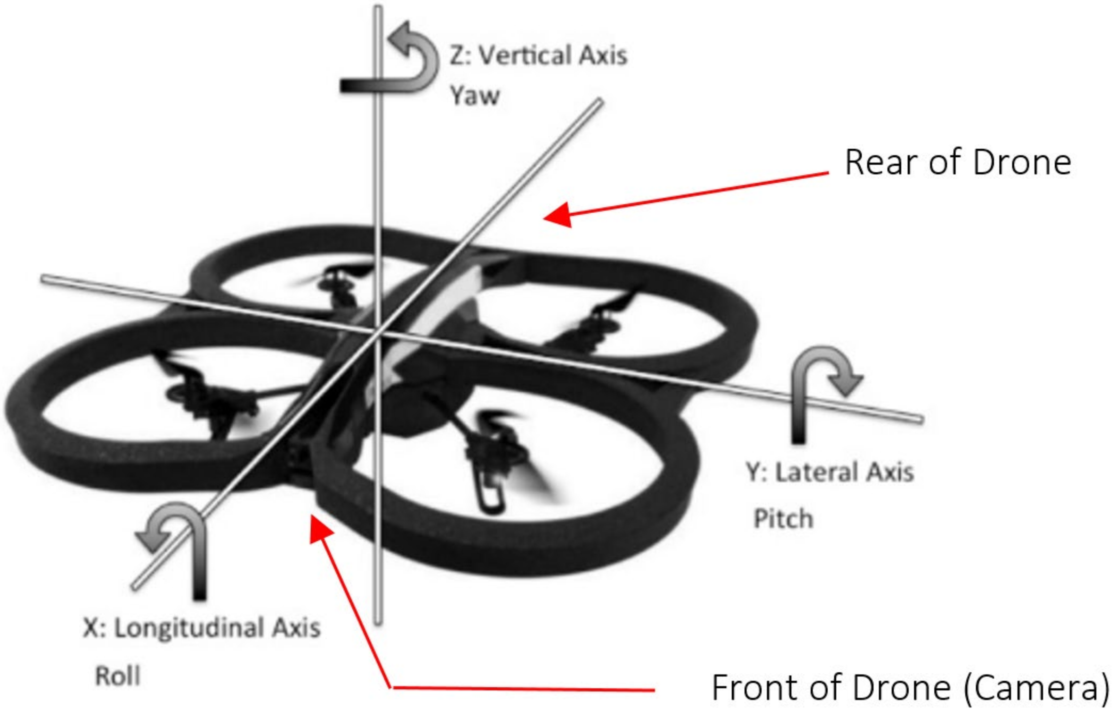


Figure 10 Drone (and plane) axis names (parrot.fr)

2.6 Balance of forces – air mass movement

The LIFT is a force generated mainly by the wings of a plane or by the propellers of a quadcopter produced by its motion. LIFT ← BALANCES → WEIGHT of the plane or a drone.

The TRACTION, is produced by drone`s propellers, it moves the air downwards by moving drone propelling the drone forward. Traction ← BALANCES → DRAG, the resistance that brakes the drone.

But any aircraft is supported by the air mass and moves with it, so to move relatively to the ground, the drone must move inside the air mass.

- A drone hovering still over the ground in a windy day is in fact moving in the air mass!
- A drone moving against the wind direction is moving much faster in the air mass than if it was moving in the wind direction.

As a result, a lot of sensors must exist in the drone to ensure its handling.

The GNSS (Global Navigation Satellite System) sensor (or GPS in everyday language) and the downward-pointing camera, enable the drone to maintain a stable position in relation to the ground in hovering flight mode. This is achieved by GNSS sensor adjusting drone`s ground speed to counter the wind effect.

Thanks to a compass, magnetometer and gyroscope installed on the drone it is possible to set and maintain the flight course.

The accelerometer and gyroscope are used to provide information on attitude and movement of the drone.

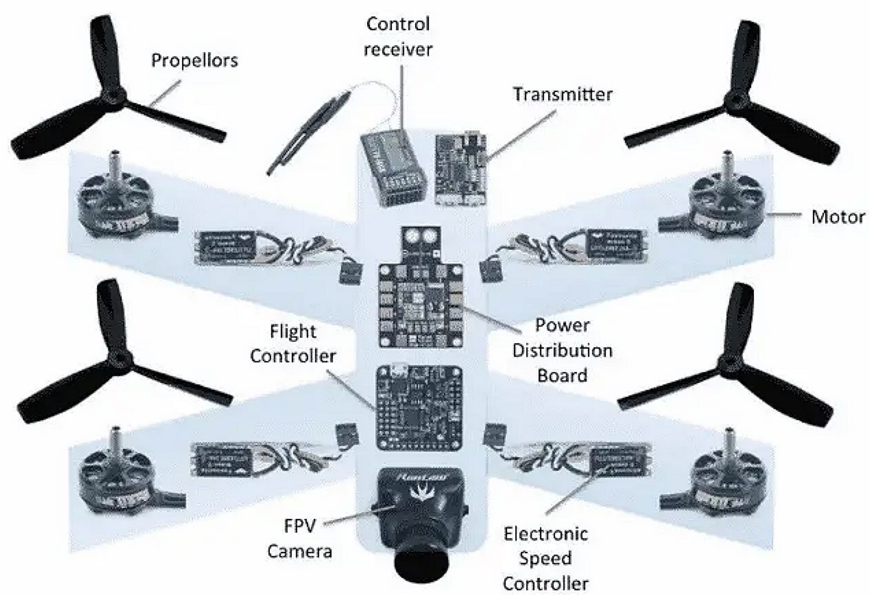
The barometer provides information on changes in altitude.

The proximity sensors indicate when the drone is approaching an obstacle or the ground.

3. Essential parts of a multirotor drone

Here are the basic components: - Control receiver - Flight controller - Sensors - Transmitter - Battery -Power board – ESC – Motors.

How does it work? The control receiver receives the orders or signals from the remote control, and then transfers them to the flight controller. The flight controller uses information from all the sensors on the aircraft to know its attitude, its speed, its tilt, its position and for obstacle detection. The flight controller transfers this information to the ESC to accelerate or slow down the motors, individually. The transmitter sends the flight information to the remote control and also the video stream. The battery unit dispatches the power to each function, most of it to the ESC and therefore to the engines.



Not represented here are all the sensors that give information to the flight controller.

Figure 11 Drone electronic components (I0.wp.com)

In the IMU, Inertial Measurement Unit includes the following components:

- Altimeter
- Magnetometer
- Gyroscope
- Accelerometer
- Thermometer

Independent components on the aircraft include:

- GNSS
- Sonic proximity sensors
- Video proximity sensors

3.1 Receiver

This device is linked to the remote controller via electromagnetic waves at a specific frequency. The 802.11 is an industry standard that is currently used as means of connectivity for drones. The most commonly used frequency and electromagnetic waves are 2.4 GHz and 5.8 GHz. 2.4 GHz frequency band can have range up to 10 km (depending on obstacles, power and sensibility). 5GHz frequency band has shorter range for the same power but is less disturbed and faster connections; better for video transmission without lag. The receiver requires a small antenna to ensure it is capable of receiving the information over potentially long ranges. A simple smartphone can handle the transmission for low distances.

Since 2022 (European regulation 2022/179), it is possible to use frequencies from 5.17 to 5.25 GHz with a transmission power of 200 mW. Currently being deployed by manufacturers.

For all frequencies, due to atmospheric loss, the most powerful RC will have longer range transmissions, but the it is highly depending on the receiver's sensitivity: A receiver with 95dB sensitivity and 200mW transmitting power is the same as one with 90dB sensitivity and 800mW transmitting power. To get a good range, please choose a receiver with high sensitivity (> 95dB).

Other frequencies like 1.3GHz, 900MHz or 433MHz are interesting for long distance transmissions and obstacle pass-through; the lowest the frequency, the longest the range, but with a longest lag in video transmission or lowest resolution.

The historic 27MHz or 72MHz used for scale model aircraft are no longer used for drones because of disturbance and long antenna. Typically, the lower the frequency, the longer the antenna that is required.

As an example Parrot Anafi drone has WiFi 2.4 and 5.8 GHz and 4 km range, MAVIC 3E same frequencies and 8 km range, Autel EVO II 2.4GHz and 5 Km range.

Some drones have begun to use the 4G antennas to connect the drone, the frequency can vary from 700MHz to 2.6MHz (depending on the country) and of course, the range is extremely large thanks to relays.

The receiver transmits all the orders to the flight controller.

3.2 Flight controller

The flight controller is essentially the **brain** of the drone.

It is the electronic part ordering the ESC to rotate according to the pilot's orders and the aerodynamic conditions. It is directly linked with the sensors (gyroscope, compass, altimeter, proximity, GPS eventually) and allows the stability of the flight and the good response to the commands.

Figure 12 flight controller - dronenodes.com

The invention, miniaturization and subsequent reduction in price of this key component has led to the actual development of drones.

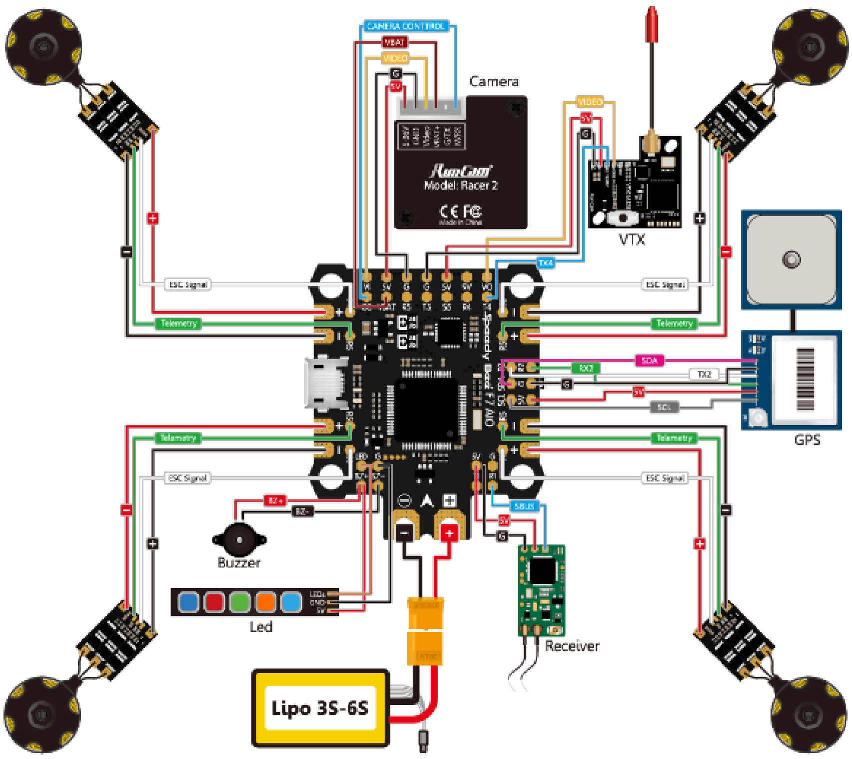


Figure 13 Links to the flight controller - phaserfpv.com.au

3.3 IMU – Inertial Measurement Unit

The majority of the sensors that directly assist the flight controller and the pilot are concentrated in the IMU.

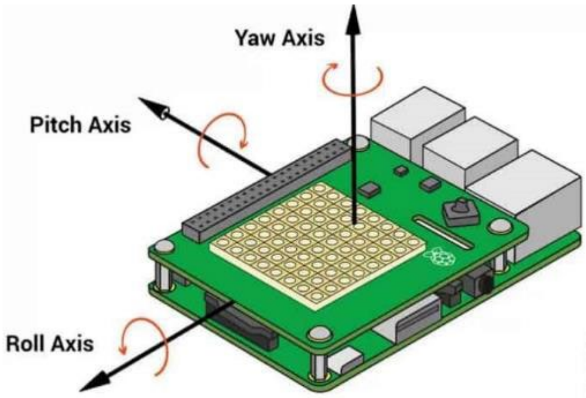


Figure 14 Arduino IMU (ddcountermeasures)

Figure 15 DJI Mavic 2 pro IMU (drone-parts-center.com)

Barometric altimeter: height relative to the take-off point

By measuring the variation in air pressure between the point of take-off and the point of flight, the drone obtains, with the precision of its instrument, an estimate of its altitude to within 25cm. We speak of QFE altitude (Query Field Elevation, used for planes to calibrate "zero meter" at a specific airfield elevation) and sometimes by excess of AGL (above ground level, official aeronautical term) but this last term is supposed to refer to the ground directly under the drone and not to the take-off point.

It is not able to know its altitude in relation to sea level (AMSL above medium sea level), unless it is calibrated at take-off for QNH (Query Nautical Height which varies during the day).

Magnetometer: direction and attitude (compass)

The magnetometer reacts to the earth's magnetic field to know the orientation of the drone in relation to magnetic North and also its "attitude": its inclination in relation to the horizontal.

This is not very accurate so another instrument (the gyroscope) helps to clarify this information.

Calibration: the magnetometer must be calibrated from time to time by moving the device along its 3 axes, at the request of the remote control.

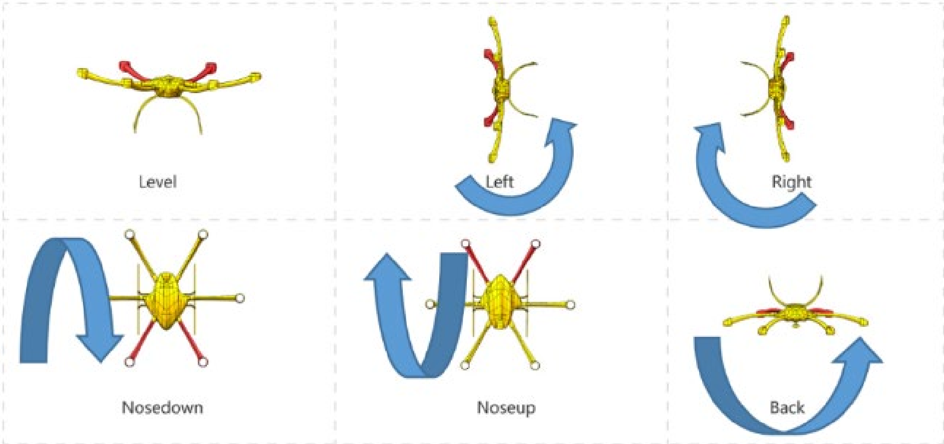


Figure 16 Compass calibration movements around each axis - yangdaonline.com

Gyroscope: attitude

Formerly rotating mass gyroscopes have evolved to become miniature circuits. The gyroscope enables the orientation variation of a drone around its centre of gravity to be calculated.

There is a gyro for each axis: yaw, pitch, roll; so the device always knows "how much" it is turning, and in which axis.

Calibration: the gyroscope must be calibrated from time to time by moving the device along its 3 axes, at the request of the remote control.

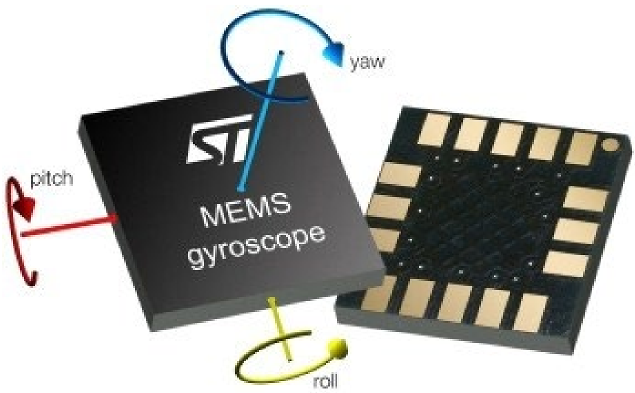


Figure 17 MEMS gyroscope (STmicroelectronics)

Accelerometer: speed change in all directions

Measures the state of acceleration of the drone around its 3 axes and informs the flight controller.

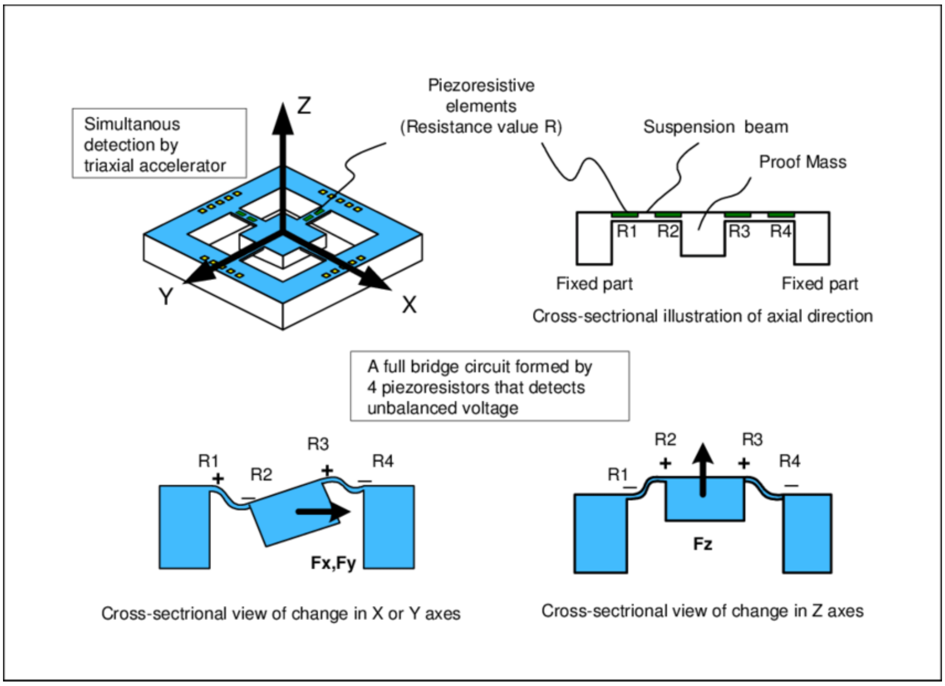


Figure 18 Micro-accelerometer principle (researchgate.net, Xuemin-chen publication)

Thermometer

Used to adjust the sensibility of the sensors, the motor speed variation (cool air is denser), the power from the battery and the altitude.

3.4 Ultrasonic proximity sensors

Vertically under the drone: low altitude to the ground

Underneath the device is an ultrasonic emitter/receiver that indicates to the drone its distance from the ground (or an obstacle below). It is used only at short distance, 3 to 4 meters at most.

Figure 19 Ultrasonic emitter and receiver - eye4i.ch

Horizontally on the sides of the drone

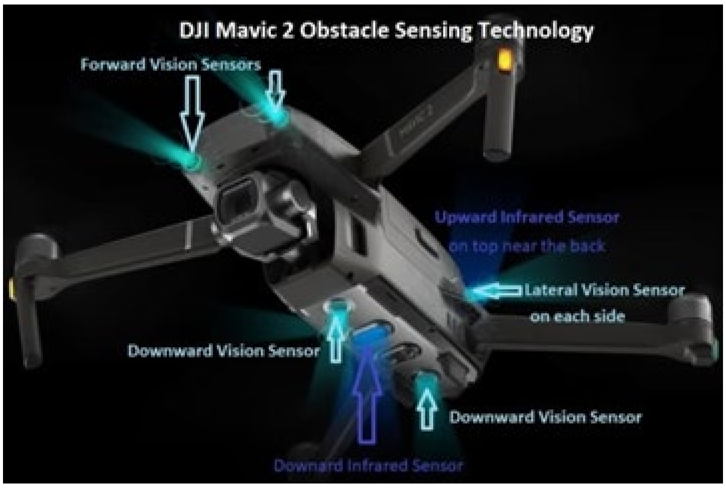
Same devices, but to sense the sides of the drone and avoid collisions in translation or forward/reverse.

Not all drones are equipped with side sensors, but all "professional" models are.

Figure 20 vertical and horizontal ultrasonic sensing - microcontrolertips.com

3.5 Imaging proximity sensors

Typically, drones would have cameras that can to detect approaching objects. There are three types of sensors: ultrasonic, infrared and radar.



As depicted on presented drone has various types of proximity sensor positioned around its body.

Figure 21 Proximity sensors on a drone (drone-festival.com)

3.6 GNSS global navigation satellite system ("GPS")

By receiving satellite signals (20,000 km apart), a calculator obtains the position of the drone in relation to the ellipsoid WGS84 in Longitude, Latitude and ellipsoidal height (see Module 6 geolocation).

Unfortunately, the system itself is not more accurate than a few meters and so at the scale of a drone it is not always very useful.

GNSS drone positioning: relatively to the take-off point

This module enables the drone to know its spatial position on the earth: latitude, longitude, and ellipsoidal height.

First the drone must stay still on the take-off position for a few minutes to get a correct position by the GNSS, usually called "GPS". The precision here is metric (around 3 meters), but when the drone is flying then the position **relative to this take-off point** is decimetre-level, so 10 to 30 cm, which is better. This allows the drone to return to the same precise location when the "return to home" button is pressed.

Improved precision: RTK, centimetric positioning

To know a drone's position to the nearest centimetre, it must be equipped with a Real Time Kinematic (RTK) system that requires data reception by phone (SIM card or WIFI) and a subscription to an RTK service (position computation correction database in real time). This configuration allows a better photogrammetric process because the positions of the photos are easier to obtain. We also obtain directly and precisely geolocated photos for GIS applications.

Figure 22 GPS receiver - Beitian corp.

3.7 Electric motors and their ESC

The motors are brushless type (electric current is passed through coils without physical contact between its components): their rotation is caused by the sequential supply of fixed electromagnets, which will attract the central rotating permanent magnets in turn. The motor will turn at a speed depending on the power of the magnets and the speed of the sequence. Controlling the power supply to the magnets is a critical function to ensure that the motors work properly. The ESC carries out This function (Electronic Speed Controller), there is one per motor.

➔ As they are open for cooling, protect the motors from water (but most of drones can resist to a gentle rain) against dust and especially sand intrusion.

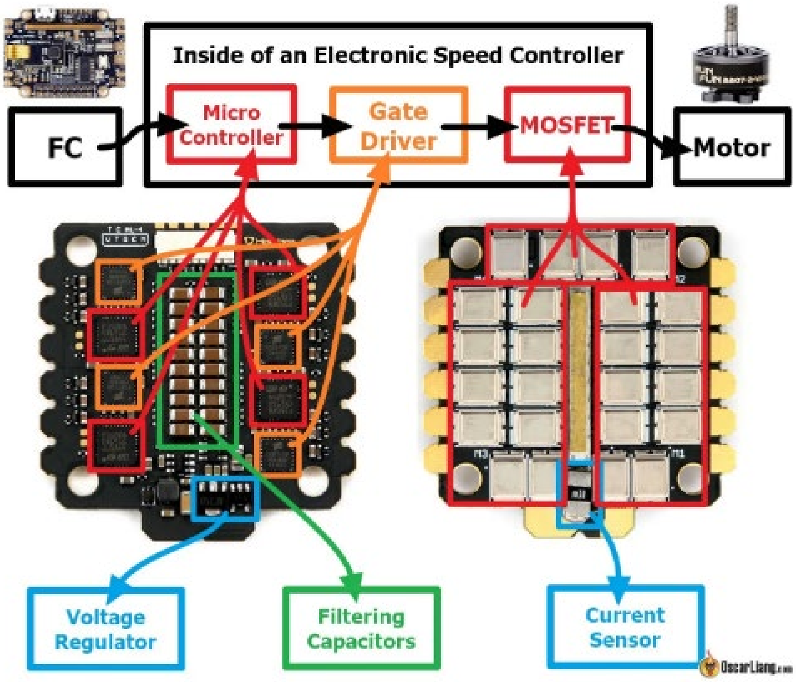


Figure 23 ESC - oscarliang.com

3.8 Propellers

Driven by the engine, the propellors ensure the lift and the movements of the drone. Their characteristics are their diameter and their pitch, two figures written on the propeller with their direction of rotation.

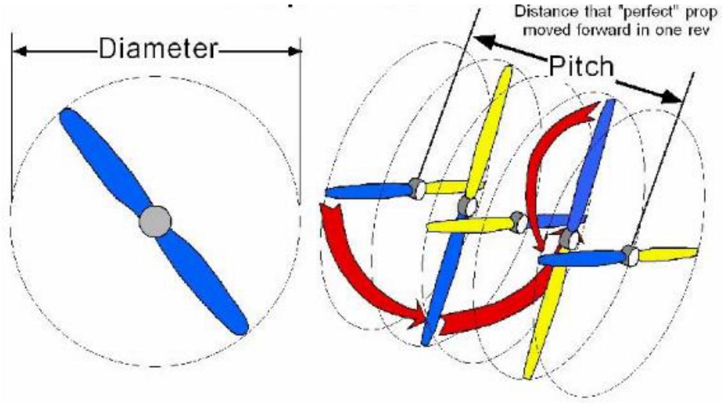


Figure 24 Propeller definition (bowersflybaby.com)

- ➔ Regularly check they are in good condition: any damage will create drag and need more power to fly (therefore less flight time) or instability.
- ➔ Check their correct fitting: they are not interchangeable; each propeller has its own motor!

Figure 25 Propeller -DJI

Typical propellers are foldable, easy to store and less dangerous in the event of contact with an obstacle (explosion) or a human being.

Their specific shape at the extremity avoids drag (more efficient) and noise (more acceptable for those around).

Indeed, the motors do not all turn in the same direction (see above), it is advisable to pay attention to the good matching of the propeller and the position of the motor.

3.9 Power unit (power distribution board)

The power unit dispatches electric power to the different components, it ensures that the correct voltage and amperage is distributed, according to the needs and the capacity of each component. It ensures a control on the battery and informs the flight controller of its state.

Figure 26 Drone power distribution board - hobbyking.com

3.10 Batteries

Usually lithium-polymer batteries; they provide direct electrical current. Its voltage varies according to the brand.

The available energy of a battery is measured in Ah (Ampere-hours): the higher this number is, the more electricity the battery can deliver. A 10 Ah battery can deliver a current of 10A for 1 hour, or 1A for 10 hours before being "empty".

It can also be expressed in Wh (Watt-hour), i.e. in power deliverable during one hour. This is the same as P=U.I, so if we know I (in Ah) and U (in Volt) we have the Wh.

Example: a 4S battery delivers 4 x 3.7 = 14.8V. A 3S2P battery delivers 3 x 3.7 = 11.1 V, but with 2 rows that increase the current.

Example : 2700Ah battery under 7.6V delivers 2.7 x 7.6 = 20.52 Wh

The duration of operation depends on the current consumed by the drone: if it consumes 1A with a battery of 5Ah then it can fly 5 hours.

But you should never completely empty the batteries, this gradually reduces their charge capacity, it is best practice to stop the stop the flight or mission at 20% remaining to land at 15% minimum.

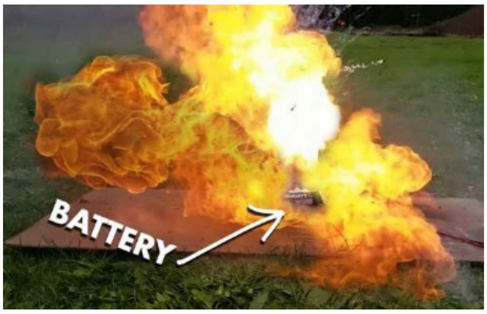
In reality, currently fly time of drones is typically between 20 and 45 minutes. Example of the Parrot Anafi: the battery is 2700mAh (2.7Ah) under 7.6V, and it flies 15 minutes (average) before being discharged to 20%.

So: 2700 x 0.8 = 2160 Ah consumed in 15' =15/60= 0.25 hour

- the drone consumes 2.16/0.25 = 8,64 A which is quite enormous.
- But as the voltage is only 7.6V, it only makes a power of 7.6 x 8.64 = 65.7 W (reminder P = U.I in direct current).

Sensitivity of the batteries:

- incorrect charging: there is no possibility to exceed the charging capacity = a battery has a maximum current that it can receive, however beyond that it deteriorates and can even catch fire. USE ONLY THE MANUFACTURER'S CHARGER
- heat/ do not store behind glass in direct sunlight, risk of fire
- shocks : the layers of material can be damaged and create an incendiary chemical reaction
- Rapid charging: avoid as much as possible, use "slow" or normal charging when there is no emergency and DO NOT LEAVE CONNECTED FOR AN ENTIRE NIGHT ON CHARGERS OTHER THAN THE MANUFACTURER'S - RISK OF FIRE -.
- When storing for a long time: store at half-charge, occasionally recharge batteries to half-charge



Over-charged
batteries
Or
stored for more than
3 days Fully-charged
Or
Damaged batteries
May cause a fire.

Figure 27 Battery on fire due to full-charge storage - swellpro-uk.co.uk

Figure 28 Warning sticker - fromkristies.blogspot.com

Most batteries have an auto-discharge safety system: when fully charged and not used for more than 3 days, an internal system lowers the charge to ½ charge; thus, before running your drone, give the batteries a charge to get them back to full capacity.

Figure 29 Battery on 1/2charge is good for storage - generation-nt.com

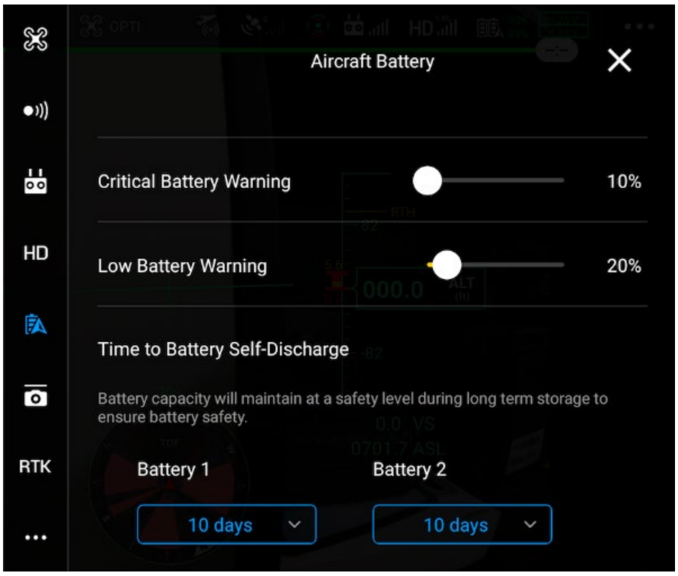


Figure 30 battery alert settings - DJI

When using the drone, try not to go below 20% capacity, as this prematurely ages the batteries, check it on the screen of the remote control, set a warning in the parameters.

Here it is also possible to set the number of days before automatic self-discharge

Battery Cell analysis and settings: the voltage of the cells (main components of the battery) should always be checked. Typically, the RC should be able to display it otherwise controller app is checking this status automatically. There should be no difference greater than 0.1V between the cells, if it is that would indicate a cell/battery fault. If this is the case, change the battery and dispose of the faulty battery in a fireproof bag, as there is a risk of it catching fire. Figure 31 presents status of each battery cell in Volts. In this case each cell has the same reading which indicates correct operation of the battery.

The low battery warning percentages can be adjusted i.e.:

- Set to 25% of battery remaining for a simple warning,
- Set to 10% of battery remaining for an immediate landing warning.

The return to home (RTH) can also be set to automatic at 20% battery, for example.

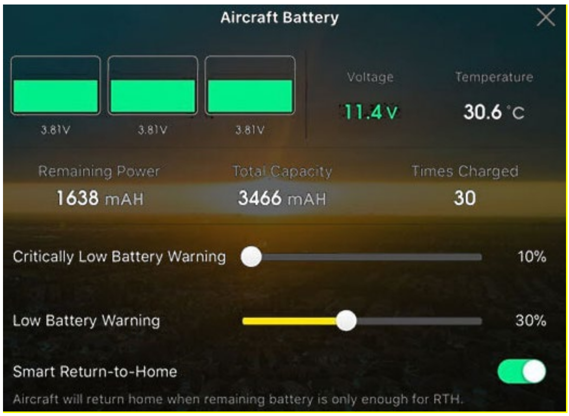


Figure 31 Battery cells levels and settings expressed in Volts.

Batteries are made up of "cells", each rated at 3.7 V.

- If the cells are connected in series (one behind the other), then the voltages add up. The series connection is indicated by the letter "S" in front of the number of cells in series. The number of deliverable amperes remains unchanged.
- If the cells are connected in parallel, this does not change the voltage but the number of deliverable amperes. The parallel connection is marked with the letter "P".

Lastly, the maximum current a battery can deliver "all at once" is a multiple of its capacity in Ah preceding the letter "C": a 3500mAh battery, i.e. 3.5Ah type 25C, can deliver a current of 3.5 x 25 =

87.5 A, but only for a very short time.

4. Remote control (rc)

4.1 Transmission

- Allows the pilot to control the trajectory of the drone. The link is provided through communication protocols on dedicated and authorized frequency ranges.
- Generally, the trajectory control information is transmitted on the 2.4 GHz frequency. This frequency is common with those used for Wi-Fi. This is why interference between the remote control and the drone may occur when flying in urban and/or populated areas.
- When the drone is equipped with cameras, the video return is transmitted on another frequency, usually 5.8 GHz. This higher frequency allows for higher data rates (necessary to transmit images), despite a shorter range compared to the 2.4 GHz frequency.
- Other frequencies are 1.3GHz, 900MHz or 433MHz. The historic 27MHz or 72MHz used for scale model aircraft are no longer used for drones because of disturbance and long antenna. The lowest the frequency, the longest the antenna.
- For all frequencies, due to atmospheric loss, the most powerful will transmit further, see your drone's specifications.
- Some drones for strictly professional purposes can use the telephone network (4G) for transmission, so their range is extremely extended.
- During flight, the remote pilot must verify that the signal is strong enough and that the drone is within reception range to maintain control. Signal strength and quality are usually indicated on the remote control display.

4.2 Controls

Control modes

It is possible to set the controller in different configurations:

Mode 1 is the current "model plane" command used by pilots for winged drones.

Mode 2 is the usual multirotor command, all pilots use it (some little toy drones have only this mode). Left joystick for up/down and rotation, right joystick for forward/reverse and left/right translation.

Mode 3 and mode 4 can be used in special situations.

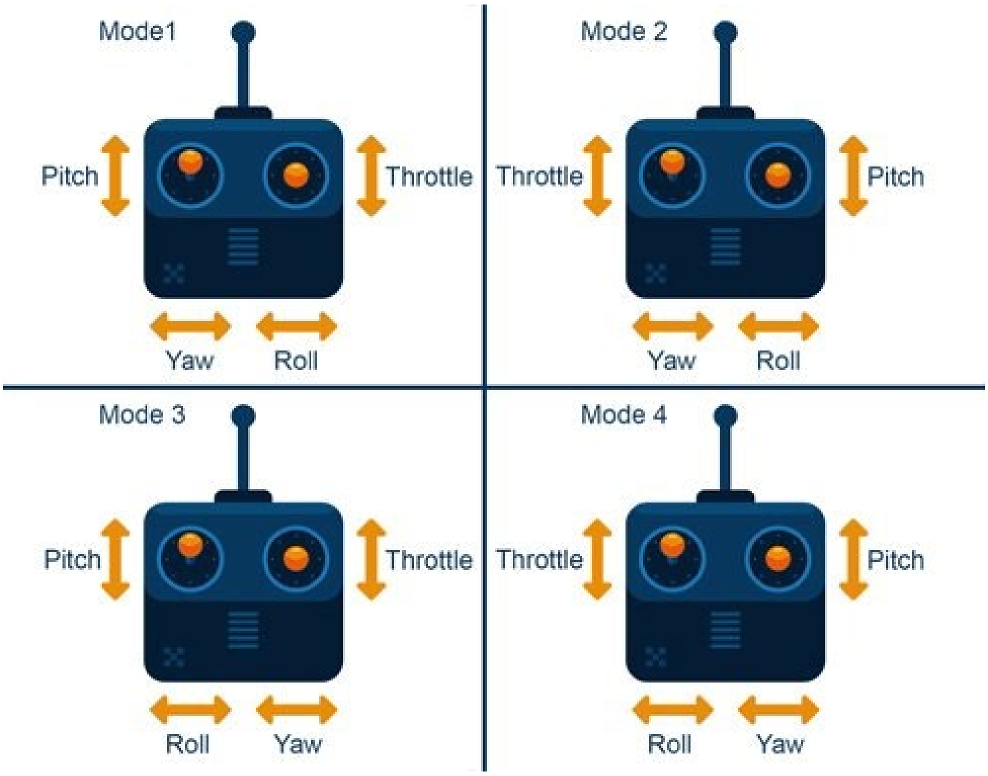


Figure 32 control modes (gitplanet.com)

MODE 2 movements in detail

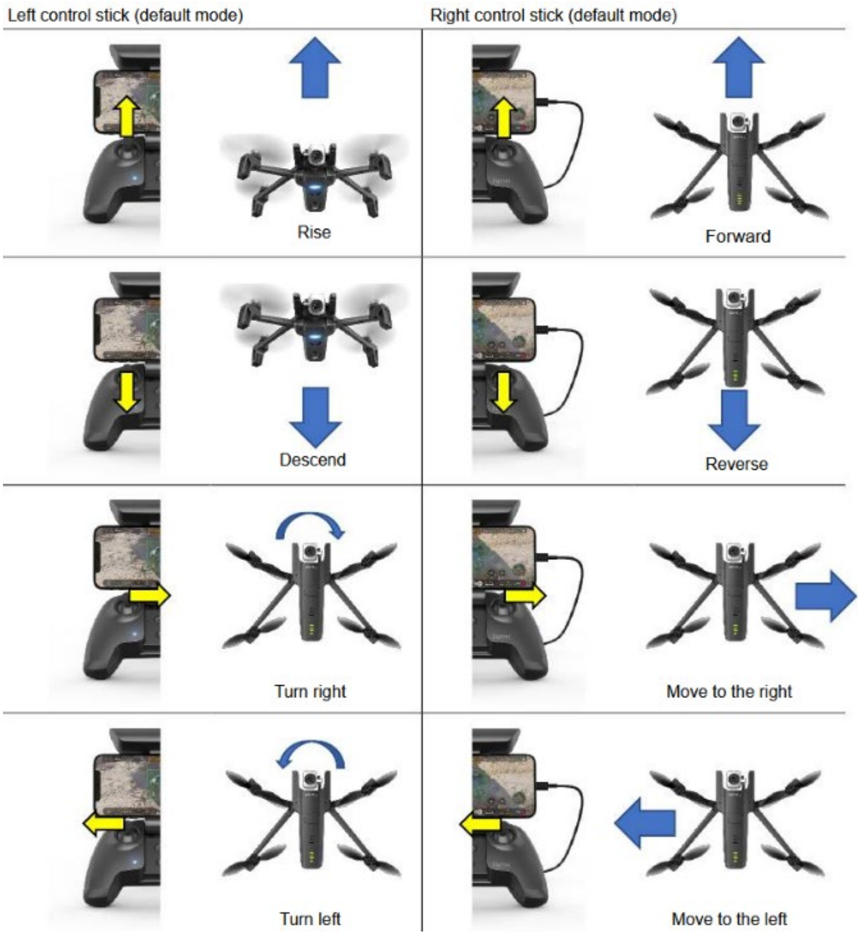


Figure 33 Drone control in Mode 2 (Parrot Anafi manual)

Different types of drone controller

Figure 34 rear of Parrot Anafi controller (Parrot)

Figure 35 Tactical Mobilicom controller (Mobilicom)

Figure 36 DJI smart controller (DJI)

Depending on the manufacturer (and the price), the screen can be part of the controller, or a smartphone/tablet to switch to the command.

camera video return,

+ information screen

+ tablet

= a very informative controller !

Figure 37 GCS professional cinematographer's controller (pinterest.fr)

Parameters in the display

Example of the Anafi

Figure 38 Anafi controller display (Parrot)

Above, the Anafi screen is divided in 4 parts around the central view of the camera (that can be replaced by the map, seen inside the little circle on the side).

Drone flight information: Speed // altitude // distance from take-off point	**Batteries and GPS information:** Batt level and GPS ok in the remote // batt level in the drone and GPS ok
Camera Zoom Value camera view (or map)	Camera tilt (circle: map or camera view)
Type of flight mode: General response mode // manual or auto // selection of "cineshots": (follow me, turn around a point, keep a point centred while moving...)	Camera operation: Photo or video recording // shutter speed, aperture, luminosity setting, file compression // possible number of photos or video minutes in the memory // photo or video trigger

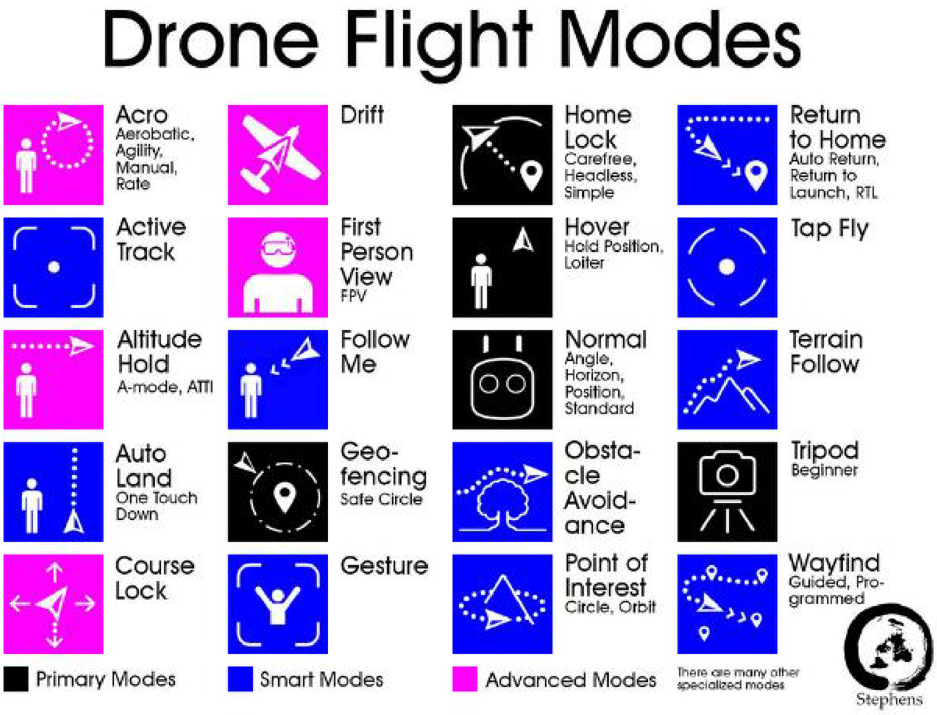


Figure 39 Examples of flight modes (Stephens - Flickr.com)

5. Maintenance

5.1 Maintenance records

The manufacturer of a UAS or, where appropriate, the holder of its type certificate must prepare and develop a manual or set of manuals that describe its maintenance and inspection. These manuals must include guidelines to carry out the necessary inspection, maintenance and repair tasks at the appropriate and specific levels of the aircraft and its associated systems.

The operator is responsible for the maintenance and conservation of airworthiness, and must be able to demonstrate at all times that the UAS and its associated systems maintain the airworthiness conditions with which they were manufactured. In addition, the operator must comply with any continuing airworthiness requirements declared mandatory by the manufacturer and/or EASA.

For these purposes, the operator must establish a data recording system relating to:

- Flights made, flight time, pilot, drone, location, category, mission, etc.
- The deficiencies occurred before and during the flights, for their analysis and resolution.
- Significant events related to safety.
- Inspections and maintenance actions and replacement of parts carried out.

In any case, the maintenance and repairs that proceed must be carried out following the guidelines of the manufacturer or, where appropriate, of the holder of the drone type certificate.

5.2 Content of the maintenance program

The UAS maintenance program will specify the details of all maintenance tasks that must be carried out based on its maintenance manual supplied by the manufacturer, including their frequency and any specific tasks related to the type and specificity of the operations.

You must define the types of reviews applicable to the UAS, as well as with what periodicity they are carried out, either by operation, hours, calendar, flight cycles (take-off/landing), or a combination of them. In addition, the operator must comply with any airworthiness maintenance requirement declared mandatory by AESA/EASA.

Continuing airworthiness is understood as all the processes that ensure that the UAS complies with the airworthiness requirements in force at any time during its operational life, and that therefore it is in a condition to carry out safe operation. Other requirements such as physical security must be taken into consideration.

The program must include the list of tools that will be used, as well as the periodicity of the calibration of those that require it.

5.3 First check after assembly

Once the UAS is assembled and before its first flight, a complete revision will be carried out, which will include a verification of the structure in general, of the configuration and of the operability of the system:

Review of all elements

Structure, casing, equipment and systems, motors, ESCs, power distributor, propellers/rotors, transmissions, electrical connectors, wiring, general screws, lights, paint, emergency systems, identification plate fixing, rotors, rods, oscillating plate, blade holders, shafts, stabilizers, pinions, crowns, gas bag, nacelles, pipes, filters, tanks... (specification of each element for the type of aircraft).

Functional ground test

- Calibration and verification of sensors and equipment necessary to carry out the intended operations (calibration of transmitter controls and sticks, receiver link and correct channels, ESC calibration, correct numbering and direction of rotation of electric motors, correct positioning of the propellers, correct balancing of the propellers).
- Installation of the appropriate software version and verification of its operation.
- Operation of communication equipment-data link, operation of video transmission equipment. Signal strength and quality.
- Check its operability (including flight controls at least 30 m away from the aircraft).
- Execute the functional tests defined by the manufacturer, if applicable.
- Check correct operation of the navigation equipment (autopilot and stabilizer) and on-board sensors (GPS, IMU, barometer, gyroscope, magnetometer...). Configuration and calibration.
- Check correct setting and operation of the payload.

Functional flight test

Check its operability. (Check the correct operation of the aircraft in its different flight modes and test all advanced functionalities, safe flight termination systems, emergency systems, transponder, detect and avoid).

Operation of communication, navigation and video transmission equipment (if applicable).

Battery

For proper and safe maintenance follow the instructions below:

- Only use specific chargers for Lithium Polymer (LIPO) batteries for safe and effective charging. Most LiPo batteries should be charged at a maximum of 4.2 volts per cell. In case of misuse or poor charging of the LIPO battery, it could cause fire, injury or damage to persons or objects.
- You must monitor the battery at all times during the charging process.
- Do not charge batteries near flammable or electrically conductive materials. For more precaution, use special fireproof bags to introduce the LiPo for charging.
- Never charge a swollen, enlarged, damaged or damaged battery.
- Never overcharge the battery, when the charging process is complete, disconnect the battery from the charger.
- Unplug the battery charger when not in use.
- Store batteries in a metallic or ceramic container or fireproof bags specially prepared for it. Always store the battery at room temperature, extreme temperatures are not recommended. Store batteries in places with temperatures between 4 and 27 degrees to keep them in perfect condition. When transporting batteries, the temperature should always be kept between -5° and 66°C.
- Always store batteries away from fire or other sources of heat. Do not expose batteries to direct sunlight for long periods of time.
- Always store batteries with a partial charge (30%) if they will not be used for some time. Do not store them fully discharged. Batteries lose approximately 5% per month when stored in good condition.
- Do not store damaged batteries in plastic bags.
- After using the batteries, wait approximately 25 minutes for them to cool down in order to recharge them safely.
- Make sure the connections have been made correctly. A placement reversing the polarity can cause risk of damage, fire and even explosion.
- Never short-circuit the battery, nor cut or break it.
- Check the battery after an impact. In case you have to discard it, remember to comply with the current legal provisions for waste disposal.
- Never insert or remove the battery when the vehicle is running.
- Disconnect the battery immediately if you detect a strange odour, noise, or smoke.
- In case of fire do not try to extinguish the flames with water. Use a fire extinguisher.
- Always leave the battery disconnected from the aircraft when not in use.

- Never completely discharge the battery, the voltage of each element should never drop below 3 volts, if it drops below that limit, it will irreparably damage the battery. It is recommended not to discharge the battery below 12-18% of its total capacity or a voltage of 3.4 volts for each of the elements that make up the battery.
- In any case, always follow the manufacturer's recommendations.

5.4 Periodic reviews.

Defined by the manufacturer and/or in the operator's manual:

- **Documentation:** Data of the Operator, Maintenance Technician, manufacturer's maintenance manuals. Last revision date, type, model and registration of the aircraft.
- **Aircraft structure:** Check for bumps, cracks or misalignments in the chassis, fuselage, stabilizing surfaces, landing gear, arms, fairing, antennas, mobile surfaces (aircraft), envelope and gas charge (airships), centre of gravity. Fixation of the screws with anti-vibration glue. Replacement of servos if necessary. Identification plate (correct conservation and fixing).
- **Rotors:** Review of cleanliness, bumps, cracks or misalignments in the power transmission system, moving surfaces and stabilization of the swash plate, collective plate and rods (helicopters), blade holders, transmission shaft, stabilizer, screws, pinion, crown, etc…
- **Motors (electric):** General cleanliness, blade hubs, attachment to the arms, absence of strange odours. Replacement of bearings if applicable, cleaning/replacement of bearings, lubrication of moving parts, replacement of worn circlips and silent blocks, replacement of overheating variators.
- **Motors (Combustion):** General cleaning, blade hubs, engine mounting to the base, check fuel supply, cooling, lubrication, ignition, fuel tank check for impurities. Cleaning fluid deposits, tubes, spark plugs and ignition system, check engine mount and fasteners. Change fuel and air filters.
- **Propellers or Blades:** Adjustment of the same and direction of rotation, physical state (Clean, without erosions or wear), correctly balanced.
- **Batteries:**
  - Aircraft Batteries: visual check, no blows, swollen, or perforated. Verify cell balance with tester. Measure charge level pre-flight and post-flight. Condition of cables and connectors (absence of carbon). Battery fastening.
  - Transmitter Batteries: visual check, no bumps, swollen, or perforated. Verify cell balance with tester. Measure charge level pre-flight and post-flight. Condition of cables and connectors (absence of carbon).
- Batteries of the FPV screen: visual check, without blows, nor swollen, nor perforated. Verify cell balance with tester (no more than 0.1V difference between cells). Measure charge level pre-flight and post-flight. Condition of cables and connectors (absence of carbon).

    - Payment Charge Batteries: visual check, without blows, swelling or perforations. Verify cell balance with tester. Measure charge level pre-flight and post-flight. Condition of cables and connectors (absence of carbon). Battery fastening.

- **General Wiring:** State cables, without breaks or wear, connectors in good condition.
- **LED lights and/or paint:** Position/Navigation and code lights not fused. Correct conservation of paint.
- **Payload:** Fixation and correct movements of the gimbal, (in case of gyro-stabilized payload) and correct fixation in case of another type of payload.
- **GPS and Compass Positioning and Calibration:** GPS set and memorized, calibrated compass. If RTK: good connection and centimetric positioning accuracy.
- **RC-Ground Station:** Correct position of switches (Altitude, GPS, Fails Safe, etc.), Sticks in position 0, free movements of the sticks, antennas correctly fixed, restraint straps and harness in good condition, aircraft selection in the display, timer activation, battery level.
- **FPV screen:** Correct information and IOSD transmission, FPV image, signal strength, number of satellites, anti-glare visors correctly adjusted.
- **Software Update:** Verify the version implemented and its correct operation.
- **Checking the power and quality of the signal.**
- **Functional Test:** Ignition of the aircraft, check diagnostic lights and sounds, engine starting, correct turn and speed verification of all, absence of vibrations, stationary take-off 2 meters from the ground, smooth forward and backward pitching, right bank and left, right and left yaw turn. In airplanes, check on the ground the correct movement of the mobile control surfaces (ailerons, elevator and rudder, flaps, ensure that the controls are not inverted).
- **Repeat functional ground test**
- **Repeat flight test**

5.5 OTHER REVIEWS

Outside of the scheduled basic maintenance, there may be extraordinary reviews, such as in the case of detecting anomalies during the operation of the aircraft, the application of modifications to the aircraft, the need to apply repair work or replacement of pieces.

The maintenance program will identify any additional maintenance tasks that must be performed by the specific aircraft type, aircraft configuration, and the type and specificity of the operation.

For instance:

- Revisions of components with a limited useful life and fundamental components for flight safety.
- After the period established by their manufacturers, where appropriate: engine, propellers, control system (communications/navigation).
- Bulletins issued by the manufacturer.
- Application of Manufacturer Modifications.
- Repairs.
- Revisions included in maintenance manuals of specific components that make up the UAS.
- Airworthiness directives for RPAS that have a Type Certificate, issued or accepted by AESA.
- Special operational approvals.

6. Uas maintenance record example

RECORD OF MAINTENANCE ACTIONS OF THE UAS [Type, manufacturer, model and serial number] OF THE OPERATOR XXXXXXX							
DATE OF REALIZATION	PLACE OF REALIZATION	CLASS (INSPECTION, REVISION, REPAIR)	TOTAL AIRCRAFT HOURS	COMPLETED TASKS (If it is a repair, indicate diagnosis and corrective action)	OBSERVATIONS	DETAILS of the person performing the maintenance (name, organization, etc.)	SIGNATURE of the person performing the maintenance

RECORD OF MAINTENANCE ACTIONS OF THE UAS [Type, manufacturer, model and serial number] OF THE OPERATOR XXXXXXX					
DATE OF REALIZATION	PLACE OF REALIZATION	DETAIL OF THE MODIFICATIONS AND THEIR MANUFACTURER REFERENCE (Modifications that vary the performance of the Aircraft)	OBSERVATIONS	DETAILS of the person who performs the maintenance (name, organization, etc.)	SIGNATURE of the person responsible for the modification

Table 1 Maintenance book

List of figures

Figure 1 Wing lift – (flight-mechanic.com-modified)....7
Figure 2 Incidence Angle (researchgate.net/profile/Mariateresa-Sestit)....7
Figure 3 aerodynamic drag-(cyclingdynamics.com)....8
Figure 4 Drag on a profile....8
Figure 5 The 4 forces involved in flight....9
Figure 6 Fixed wing drone "Disco"-(technique-ingenieur.fr)....9
Figure 7 Propeller lift and propulsion-(firediy.fr)....9
Figure 8 A helicopter tilts forward to go forward-(aircraftsytemstech.com)....10
Figure 9 Propellers actions to direct a multirotor drone (i.pinimg.com)....11
Figure 10 Drone (and plane) axis names (parrot.fr)....12
Figure 11 Drone electronic components (I0.wp.com)....14
Figure 12 flight controller - dronenodes.com....16
Figure 13 Links to the flight controller - phaserfpv.com.au....16
Figure 14 Arduino IMU (ddcountermeasures)....17
Figure 15 DJI Mavic 2 pro IMU (drone-parts-center.com)....17
Figure 16 Compass calibration movements around each axis - yangdaonline.com....18
Figure 17 MEMS gyroscope (STmicroelectronics)....18
Figure 18 Micro-accelerometer principle (researchgate.net, Xuemin-chen publication)..19
Figure 19 Ultrasonic emitter and receiver - eye4i.ch....20
Figure 20 vertical and horizontal ultrasonic sensing - microcontrolertips.com....20
Figure 21 Proximity sensors on a drone (drone-festival.com)....21
Figure 22 GPS receiver - Beitian corp....22
Figure 23 ESC - oscarliang.com....23
Figure 24 Propeller definition (bowersflybaby.com)....24
Figure 25 Propeller -DJI....24
Figure 26 Drone power distribution board - hobbyking.com....25
Figure 27 Battery on fire due to full-charge storage - swellpro-uk.co.uk....27
Figure 28 Warning sticker - fromkristies.blogspot.com....27
Figure 29 Battery on 1/2charge is good for storage - generation-nt.com....27
Figure 30 battery alert settings - DJI....28

Figure 31 Battery cells levels and settings expressed in Volts. 28
Figure 32 control modes (gitplanet.com) 31
Figure 33 Drone control in Mode 2 (Parrot Anafi manual) 32
Figure 34 rear of Parrot Anafi controller (Parrot) 33
Figure 35 Tactical Mobilicom controller (Mobilicom) 33
Figure 36 DJI smart controller (DJI) 33
Figure 37 GCS professional cinematographer's controller (pinterest.fr) 33
Figure 38 Anafi controller display (Parrot) 34
Figure 39 Examples of flight modes (Stephens - Flickr.com) 35

List of tables

Table 1 Maintenance book 43