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SCHOOL OF ELECTRICAL AND ELECTRONICS

DEPARTMENT OF ELECTRONICS AND COMMUNICATION ENGINEERING

UNIT 1 - DRONE ELECTRONICS – SECA4003

Unit I - INTRODUCTION TO DRONE

- Definition of drones
- History of drones
- Classification of drones based on structure- Fixed wing structure, Lighter than air systems and Rotary-wing aircraft
- Application of drones
- Parts of Drone system
- System design, Mechanical design, hardware design
- software architecture
- Logistic and Operations Management.

INTRODUCTION:

- An unmanned aerial vehicle (UAV) or uncrewed aerial vehicle commonly known as a drone, is an aircraft without any human pilot, crew or passengers on board.
- UAVs are a component of an unmanned aircraft system (UAS), which include additionally a ground-based controller and a system of communications with the UAV.
- The flight of UAVs may operate under remote control by a human operator, as remotely-piloted aircraft (RPA), or with various degrees of autonomy, such as autopilot assistance, up to fully autonomous aircraft that have no provision for human intervention.
- UAVs were originally developed through the twentieth century for military missions

- As control technologies improved and costs fall, their use in the twenty-first century is rapidly finding many more applications including aerial photography, product deliveries, agriculture, policing and surveillance, infrastructure inspections.

PARTS OF A DRONE

KEY PARTS

- From an engineer's view, the key parts of a drone system are the hardware, software, and mechanical elements;
- and a perfect balance between the three provides a flawless system design.

HARDWARE

- Hardware is the electrical part of the drone system, which is eventually a PCBA (printed circuit board assembly).
- Hardware is a multilayer PCB that accommodates the SOC (system on a chip) and different
- components of the subsystems interconnected through copper traces (part of the PCB) or physical wires. Figure shows the PCBA assembled with SOC and subsystems on the top side (primary side).

THE SOC

- The SOC is a miniature computer on a chip of a present generation systems, especially a drone system. It’s a semiconductor device and an integrated circuit that usually integrates digital, analog, mixed signal, and radio frequency devices on a single chip. SOCs are most commonly used in mobile computing and embedded systems.
- In general, there are three distinguishable types of SOCs: SOCs built around a microcontroller, SOCs built around a microprocessor, and specialized SOCs designed for specific applications that do not fit into the above two categories. SOC usually consume less power and have a lower cost than the multichip systems they replace.
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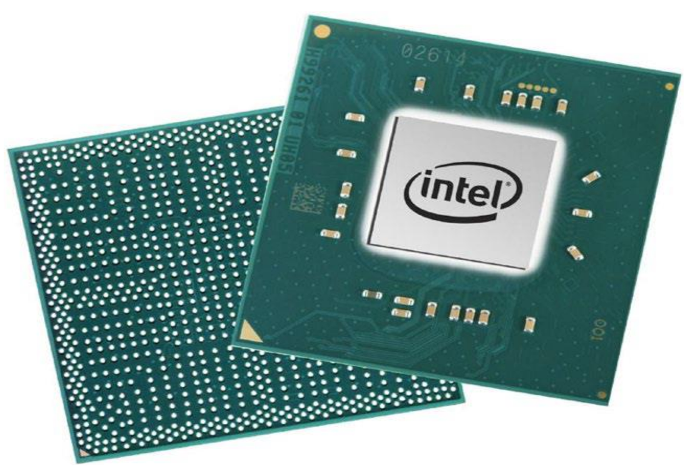


- Figure shows a typical SOC that integrate digital, analog, and mixed signal devices on a single chip. The device at the center of the SOC is the silicon, and some capacitors are distributed on the top side of the SOC. The bottom side of the SOC shows pins (called as balls in a ball grid array), which are soldered on to a PCB to establish the connection with the subsystems through PCB traces.

- **Subsystems**
- Subsystems or electrical subsystems are technologies required in a system to fulfill the intended usage of the system. Broadly speaking, subsystems fall into any one of the following computer architecture parts: input, output, storage, and communication devices.
- Input
- A touch panel, keyboard, mouse, microphone, camera, sensors, and remote control are some examples of input devices of a system.
- Output
- Displays, speakers, motors, fans, and LEDs are some examples of output devices of a system.
- Storage
- Memory, flash, hard disk drive, optical drive, secure digital, and solid-state drive are some examples of the storage devices of a system.
- Communication Devices
- Wired LAN (local area network), wireless LAN, mobile networks (3G, 4G, and LTE), GPS (Global Positioning System), and USB are some examples of the communication devices of a system. All of the subsystems listed above may or may not be a part of a particular drone design. The target application picks the right subsystems to be part of the drone system design.
- For example, if the intended application of a drone is surveillance, it should be equipped with a high-resolution camera and the SOC used in the system should be capable of accepting and processing the high-speed data from that camera. The PCBA should be designed in such a way as to interconnect the high-speed data between SOC and the camera module and then be capable of transmitting the live or recorded data via the wireless communication modules.
- Besides SOC, the camera module, wireless module (WiFi/3G/4G modules), memory, internal storage, sensors, and flight controllers are the basic required subsystems for a surveillance drone.

SOFTWARE

- There are four categories of software that need to use on the drone system:
- *Firmware components*

- *OS and drivers*
- *Sensing, navigation, and control*
- *Application-specific components*

MECHANICAL

- The mechanical system is basically the enclosures, form factor, or simple ID (industrial design) of the drone.
- The ID determines the exterior and appearance of the drone. The ID of the drone will usually have numerous mechanical parts in a complicated assembly with electrical parts interconnected through mechanical or thermal interconnects.
- The most popular drone, has a quadcopter built from an X-frame or H-frame with four servo motor/propeller units on each end with numerous other mechanical parts along with the PCBA enclosed in plastic.
- A drone with frame as a base includes propellers, motors, landing gear, body (usually PCBA, flight controllers, and motor drivers), and a battery.

HISTORY OF DRONES

- With the maturing and miniaturization of applicable technologies in the 1980s and 1990s, interest in UAVs grew U.S. military. In the 1990s, the U.S. DoD gave a contract to AAI Corporation along with Israeli company Malat. The U.S. Navy bought the AAI Pioneer UAV that AAI and Malat developed jointly. Many of these UAVs saw service in the 1991 Gulf War. UAVs demonstrated the possibility of cheaper, more capable fighting machines, deployable without risk to aircrews. Initial generations primarily involved surveillance aircraft, but some carried armaments, such as the General Atomics MQ-1 Predator, that launched AGM-114 Hellfire air-to-ground missiles.
- CAPECON was a European Union project to develop UAVs, running from 1 May 2002 to 31 December 2005.
- As of 2012, the USAF employed 7,494 UAVs – almost one in three USAF aircraft. The Central Intelligence Agency also operated UAVs. By 2013 at least 50 countries used UAVs. China, Iran, Israel, Pakistan, Turkey, and others designed and built their own varieties. The use of drones has continued to increase. Due to their wide proliferation, no comprehensive list of UAV systems exists.
- The development of smart technologies and improved electrical power systems led to a parallel increase in the use of drones for consumer and general aviation activities.
- As of 2021, quadcopter drones exemplify the widespread popularity of hobby radio-controlled aircraft and toys, however the use of UAVs in commercial and general

aviation is limited by a lack of autonomy and new regulatory environments which require line-of-sight contact with the pilot.

CLASSIFICATION

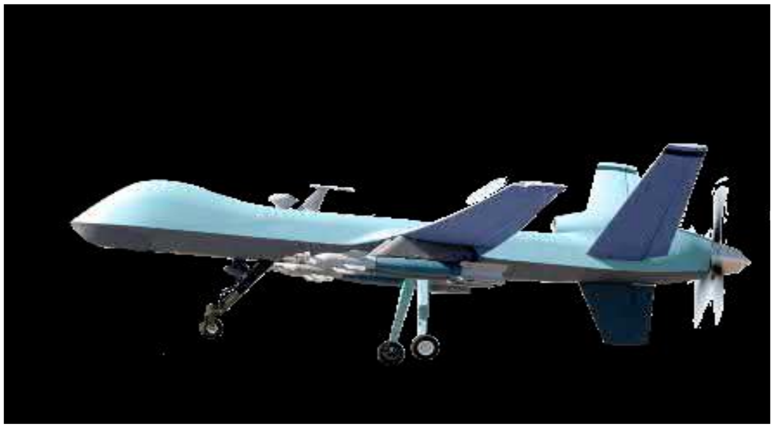
- UAVs may be classified like any other aircraft, according to design configuration such as weight or engine type, maximum flight altitude, degree of operational autonomy, operational role, etc.
- Based on the weight
- Based on their weight, drones can be classified into five categories —
- nano (weighing up to 250 g), Micro air vehicles (MAV) (250 g - 2 kg), Miniature UAV or small (SUAV) (2-25 kg), medium (25-150 kg), and large (over 150 kg).
- Based on the degree of autonomy
- Drones could also be classified based on the degree of autonomy in their flight operations. ICAO classifies uncrewed aircraft as either remotely piloted aircraft or fully autonomous.
- Some UAVs offer intermediate degrees of autonomy. for example, a vehicle that is remotely piloted in most contexts but having an autonomous return-to-base operation.
- Some aircraft types may optionally fly manned or as UAVs, which may include manned aircraft transformed into uncrewed or Optionally Piloted UAVs (OPVs).
- Based on the altitude
- Based on the altitude, the following UAV classifications have been used at industry events such as Unmanned Systems forum:
- Hand-held 2,000 ft (600 m) altitude, about 2 km range
- Close 5,000 ft (1,500 m) altitude, up to 10 km range
- NATO type 10,000 ft (3,000 m) altitude, up to 50 km range
- Tactical 18,000 ft (5,500 m) altitude, about 160 km range
- MALE (medium altitude, long endurance) up to 30,000 ft (9,000 m) and range over 200 km
- HALE (high altitude, long endurance) over 30,000 ft (9,100 m) and indefinite range
- Hypersonic high-speed, supersonic (Mach 1–5) or hypersonic (Mach 5+) 50,000 ft (15,200 m) or suborbital altitude, range over 200 km
- Orbital low earth orbit

- CIS Lunar Earth-Moon transfer
- Computer Assisted Carrier Guidance System (CACGS) for UAVs
- Based on the composite criteria

An example of classification based on the composite criteria is U.S. Military's unmanned aerial systems (UAS) classification of UAVs based on weight, maximum altitude and speed of the UAV component

TYPES OF DRONES

- Drones can be categorized into the following six types based on their mission:
- **Combat:** Combat drones are used for attacking in the high-risk missions. They are also known as Unmanned Combat Aerial Vehicles (UCAV).
- They carry missiles for the missions. Combat drones are much like planes.



Logistics: Logistics drones are used for delivering goods or cargo. There is a number of famous companies, such as Amazon and Domino's, which deliver goods and pizzas via drones. It is easier to ship cargo with drones when there is a lot of traffic on the streets, or the route is not easy to drive.

Civil: Civil drones are for general usage, such as monitoring the agriculture fields, data collection, and aerial photography. The following picture is of an aerial photography drone:

Reconnaissance:

These kinds of drones are also known as mission-control drones. A drone is assigned to do a task and it does automatically, and usually returns to the base by itself, so they are used to get information from the enemy on the battlefield. These kinds of drones are supposed to be small and easy to hide. The following diagram is a reconnaissance drone for your reference, they may vary depending on the usage:

Target and decoy:

These kinds of drones are like combat drones, but the difference is, the combat drone provides the attack capabilities for the high-risk mission and the target and decoy drones provide the ground and aerial gunnery with a target that simulates the missile or enemy aircrafts.

- **Research and development:**
- These types of drones are used for collecting data from the air. For example, some drones are used for collecting weather data or for providing internet.

TYPES BASED ON WING

- Classify drones by their wing types. There are three types of drones depending on their wings or flying mechanism:
- Fixed wing:
- A fixed wing drone has a rigid wing. They look like airplanes. These types of drones have a very good battery life, as they use only one motor (or less than the multi-wing). They can fly at a high altitude.

- They can carry more weight because they can float on air for the wings. There are also some disadvantages of fixed wing drones. They are expensive and require a good knowledge of aerodynamics. They break a lot and training is required to fly them.
- The launching of the drone is hard and the landing of these types of drones is difficult. The most important thing you should know about the fixed wing drones is they can only move forward. To change the directions to left or right, we need to create air pressure from the wing.

FIXED WING UAS

ROTARY WING

- Single rotor: Single rotor drones are simply like helicopter. They are strong and the propeller is designed in a way that it helps to both hover and change directions. Remember, the single rotor drones can only hover vertically in the air.
- They are good with battery power as they consume less power than a multirotor.
- The payload capacity of a single rotor is good. However, they are difficult to fly.
- Their wing or the propeller can be dangerous if it loosens.

ROTARY WING UAS

- Multirotor: Multirotor drones are the most common among the drones. They are classified depending on the number of wings they have, such as tricopter (three propellers or rotors), quadcopter (four rotors), hexacopter (six rotors), and octocopter (eight rotors).
- The most common multirotor is the quadcopter.
- The multirotors are easy to control. They are good with payload delivery. They can take off and land vertically, almost anywhere. The flight is more stable than the single rotor and the fixed wing.
- One of the disadvantages of the multirotor is power consumption. As they have a number of motors, they consume a lot of power.

TYPES OF MULTIROTOR DRONES

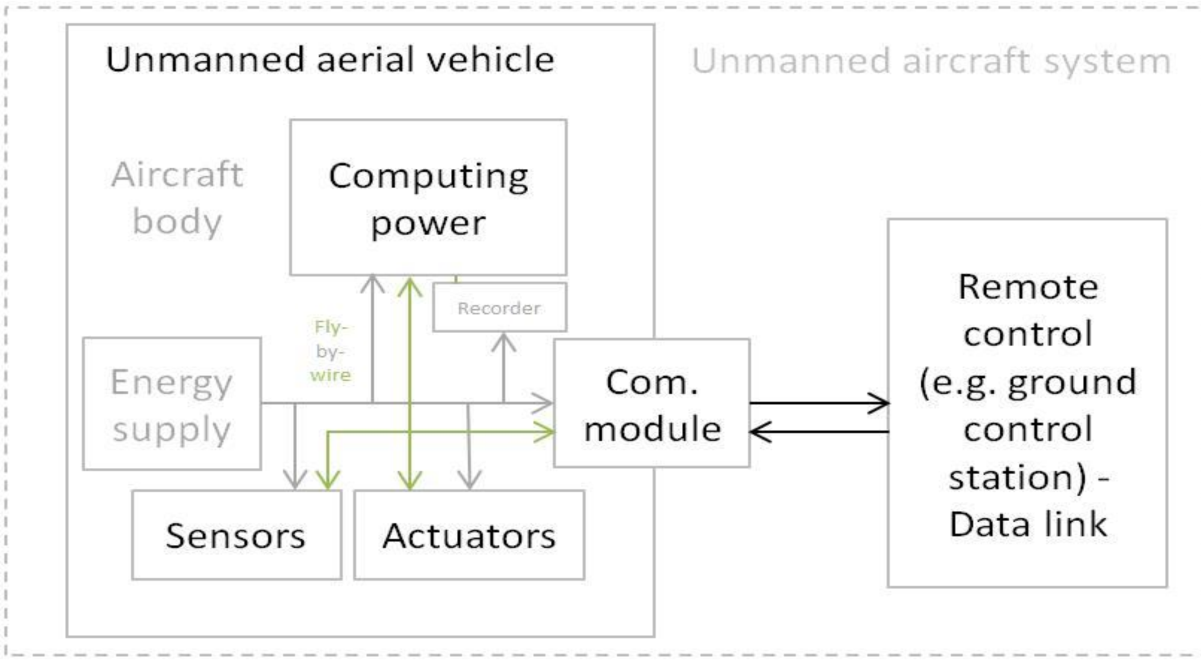
- Classify multirotor drones by their body structure. They can be known by the number of propellers used on them. Some drones have three propellers. They are called tricopters. If there are four propellers or rotors, they are called quadcopters. There are hexacopters and octacopters with six and eight propellers, respectively.
- The gliding drones or fixed wings do not have a structure like copters. They look like the airplane. The shapes and sizes of the drones vary from purpose to purpose.
- The **Ready to Fly (RTF)** drones do not require any assembly of the parts after buying. You can fly them just after buying them. RTF drones are great for the beginners. They require no complex setup or programming knowledge.
- The **Bind N Fly (BNF)** drones do not come with a transmitter. This means, if you have bought a transmitter for your other drone, you can bind it with this type of drone and fly.
- The problem is that an old model of transmitter might not work with them and the BNF drones are for experienced flyers who have already flown drones with safety, and had the transmitter to test with other drones.
- The **Almost Ready to Fly (ARF)** drones come with everything needed to fly, but a few parts might be missing that might keep it from flying properly.
- They come with all the parts, but you have to assemble them together before flying. You might lose one or two things while assembling.
- So be careful if you buy ARF drones. We always lose screws or spare small parts of the drones while we assemble.

- From the name of these types of drones, you can imagine why they are called by this name. The ARF drones require a lot of patience to assemble and bind to fly. Just be calm while assembling.

- **CARBON FIBER AND PLASTIC PROPELLERS**

- A propeller converts rotational motion into thrust in agreement with the Bernoulli's principle. Aircraft propellers are characterized by the size, pitch, number of blades, and type of material. Carbon fiber propellers are more expensive than plastic ones and provide better performance. They are more rigid and produce less vibration when spinning.
- In addition, they are lighter and more durable during small crashes. However, as they are more rigid, the motor bearings support higher impacts during crashes.

PHYSICAL STRUCTURE OF DRONE:



FEATURES

- Crewed and uncrewed aircraft of the same type generally have recognizably similar physical components. The main exceptions are the cockpit and environmental control system or life support systems.
- Some UAVs carry payloads (such as a camera) that weigh considerably less than an adult human, and as a result, can be considerably smaller. Though they carry heavy payloads, weaponized military UAVs are lighter than their crewed counterparts with comparable armaments.
- Control systems for UAVs are often different than crewed craft. For remote human control, a camera and video link almost always replace the cockpit windows; radio-transmitted digital commands replace physical cockpit controls. Autopilot software is used on both crewed and uncrewed aircraft, with varying feature sets.

PARTS OF BLOCK DIAGRAM

- UAV computing capability followed the advances of computing technology, beginning with analog controls and evolving into microcontrollers, then system-on-a-chip (SOC) and single-board computers (SBC).
- System hardware for small UAVs is often called the flight controller (FC), flight controller board (FCB) or autopilot.
- Sensors

- Position and movement sensors give information about the aircraft state. Exteroceptive sensors deal with external information like distance measurements, while Exproprioceptive ones correlate internal and external states.
- Non-cooperative sensors are able to detect targets autonomously so they are used for separation assurance and collision avoidance.
- Degrees of freedom (DOF) refers to both the amount and quality of sensors on board: 6 DOF implies 3-axis gyroscopes and accelerometers (a typical inertial measurement unit – IMU), 9 DOF refers to an IMU plus a compass, 10 DOF adds a barometer and 11 DOF usually adds a GPS receiver.
- Actuators
- UAV actuators include digital electronic speed controllers (which control the RPM of the motors) linked to motors/engines and propellers, servomotors (for planes and helicopters mostly), weapons, payload actuators, LEDs and speakers.
- Software
- UAV software called the flight stack or autopilot. The purpose of the flight stack is to obtain data from sensors, control motors to ensure UAV stability, and facilitate ground control and mission planning communication.
- UAVs are real-time systems that require rapid response to changing sensor data. As a result, UAVs rely on single-board computers for their computational needs. Examples of such single-board computers include Raspberry Pis, Beagleboards, etc. shielded with NavIO, PXFMini, etc. or designed from scratch such as NuttX, preemptive-RT Linux, Xenomai, Orocos-Robot Operating System or DDS-ROS 2.0.

APPLICATION OF DRONES

- An unmanned aerial vehicle (UAV), commonly known as a drone, is an aircraft without a human pilot onboard. UAVs are a component of an unmanned aircraft system, which includes a UAV, a ground-based controller, and a system of communications between the two.
- The flight of UAVs may operate with various degrees of autonomy, either under remote control by a human operator or autonomously by onboard computers.
- Drones are classified into different categories based on the applications. Applications are broad, and from the design perspective, generally fall under three major groups: military, industrial (enterprise), and commercial.

MILITARY

- Drones in military applications are used for anti-aircraft target practice, intelligence gathering and, more controversially, as weapons platforms.

INDUSTRIAL

- The integration of drones and IoT (Internet of Things) technology has created numerous industrial and enterprise use cases: drones working with on-ground IOT sensor networks can help agricultural companies monitor land and crops, energy companies survey power lines and operational equipment, and insurance companies monitor properties for claims and/or policies.

COMMERCIAL

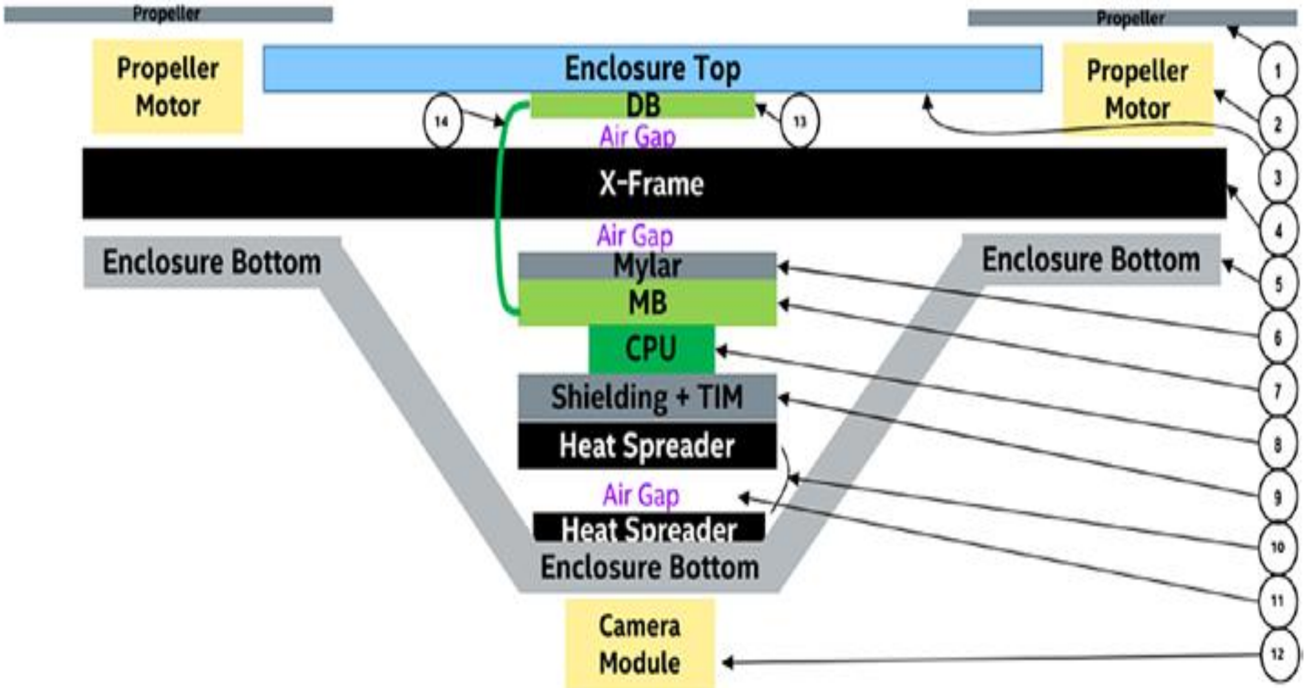
- The commercial field is a growing development, where the largest, strongest, fastest, and most capable drones on the market are targeted toward the professional community. They are the types of machines that the movie industry puts to work and that commercial agencies use to inspect infrastructure.
- Some impressive self-piloted drones survey individual farmer's fields. Commercial drones are the smaller consumer products that make up just a tiny portion of the overall drone market. Look at the picture of commercial drone:

AGRICULTURE DRONES

COMMERCIAL DRONES

MECHANICAL DESIGN

Figure shows the typical stack-up of mechanical parts in a drone ID. This is also the cross-sectional view of the mechanical design of the drone, and the significance of each part is explained below. This stack-up may differ for drones in different applications.



DRONE SYSTEM STACK UP

- *1.Propeller*: Angled blades attached to the revolving shaft of a motor. These blades give thrust and are why the drones can fly high.
- 2. *Propeller motor*: This is a DC motor attached to the four corners of the X-Frame. Power from the drone's electrical system rotates the blades to provide thrust to the drone.
- 3. *Enclosure top*: A plastic or fiber mechanical enclosure of the drone protects the internal electrical and mechanical subsystems from the external disturbances. Enclosures also provide the aesthetic look for the drone as a product.
- 4. *X-frame*: This is the vertebra of the drone. All of the other mechanical parts and subsystems of the drone are attached to the X-frame through different types of fasteners or ties. The X-frame is symmetrical by dimensions and weight on all sides to achieve a balanced flight of the drone. So the cross-sectional view is symmetrical on Y axis.
- *Enclosure bottom*: A plastic or fiber mechanical enclosure of the drone protects the internal electrical and mechanical subsystems from the external disturbances. Enclosures also provide the aesthetic look for the drone as a product.

- 6. *Mylar*: A form of polyester resin used to make heat-resistant plastic films and sheets. It acts as an insulation layer between the conductive layer of the PCBA and the metallic X-frame.
- 7. *MB (motherboard)*: The PCBA of the system hosts all of the electrical parts of the system soldered on to it. By modifying the PCBA shape, the same layer can accommodate the battery on the sides of the PCBA.
- 8. *CPU*: Usually an SOC, it's the processing unit of the system. All other devices soldered on the PCBA are on the same layer adjacent to the CPU.
- 9. *Shielding and TIM*: Digital and RF devices usually need shielding to protect from external disturbances or to protect the external devices through radiation. Radiation from the external world is suppressed by connecting the shield to a system ground.
- The TIM, thermal interface materials such as graphite, is pasted as a thin layer on the shield to radiate the excess heat generated from the components of the system.
- 10. *Heat spreader*: The heat exchanger that moves heat between a heat source and a secondary heat exchange, whose surface area and geometry are more favorable than the source.
- *11.Air gap*: Provided wherever necessary in a system. This air gap acts an insulator and also accommodates material expansion and contraction due to unavoidable reasons in a system.
- 12. *Camera module*: The lower-most part of the drone in this application is the camera module. Attached on the bottom to get a better field of view (FOV) when drone fly high. Most camera modules accommodate ISPs and connect to the SOC through the USB 3.1 interface. If the SOC has integrated ISPs, then the camera sensor can directly connect to the SOC with camera-specific interfaces.
- 13. *DB (daughterboard)*: If all of the ingredients can't be accommodated in the single PCBA, then there can be several daughterboards on the system to accommodate additional ingredients. Motherboards and daughterboards can be connected through board-to-board interconnections or a flex PCB interconnect.
- In this drone, the WiFi+BT module cannot be kept below the X-frame. The metal
- X-frame might obstruct the signal for the module's embedded antenna. Alternatively, the module can be kept in the same PCBA with the external antenna, which may not be good for an ID.
- 14. *FPC (flexible PCB)*: Generally used to connect one or more rigid PCBs in a complex system.

SOFTWARE ARCHITECTURE

- Software is the driver (in a way) of a system. In other words, the hardware provides the capabilities, while the software uses the same, makes it run, and provides the desired functionality.
- Theoretically speaking, there is always a possibility to design purpose-built hardware (with limited or no software) for a particular usage; however, practically speaking, we need to make design decisions in terms of what functionality should be part of hardware and what should be part of software.
- These design decisions are made very early in the requirement phase. And, once done, the hardware and software system designs run in parallel. Of course, there is some dependency of SW development (and testing) on HW availability.
- However, the dependency is mitigated by means of using HW simulators. The simulators are used to provide the functional models of hardware, which can be used to run and validate the software.
- 1.Firmware components: You know that the firmware components are dependent on and tied to the device they are associated with. The device vendor is responsible for providing production-worthy firm-ware for the device.
- 2.OS and drivers: The OS component is supplied by the OSV (OS vendors). There are a number of OS flavors and variations that we can choose from. This decision is guided by the OS properties and characteristics. For our example, we'll use a real-time operating system, since drones are real-time devices.
- The drivers fall into two categories. The drivers for generic devices based on a certain standard can be part of the OS itself, as an inbox component. However, the drivers for devices with differentiated values and characteristics are provided by the device vendor itself.

LOGISTIC AND OPERATIONS MANAGEMENT

- Logistics and operations management is critical to the success of the project, which involves high volume manufacturing. Commercial drones are usually produced in high volumes. Agricultural drones like Crop Squad will be manufactured in lesser volumes, but the process of logistics and operation management will be same when it is built by bigger companies partnering with ODM/OEMs.
- Logistics and operations management is also referred to as supply chain management, and includes all the operations end to end, from the extraction of raw materials to the manufacturing of the end product. Logistics is the key function in meeting market requirements quickly, flexibly, and without incurring inventory cost. There are representatives from the designers, third-party vendors supplying materials, and the factory to manage the logistics and supply chain.

- Operations management tracks the overall project schedule, supply chain, stakeholder management, and coordination of internal teams, third-party vendors, and external customers. Each party or the company participating in the development of the drone benefits from the success of the product; this is common for all types of products, not just drones.

Board and System Assembly

The supply chain management makes sure that the line items of the system BOM and EBOM will be available on the scheduled date for PCB assembly and system assembly.

Demand BOM

The demand BOM generates reservations for components that are in stock and requisitions for components that are not in stock. Each part has a unique part number. This includes the buy items and make items of the board as well as the system. Buy items are the parts that need to be procured from third-party suppliers; they already have unique manufacturer part numbers. Make items will not have a manufacturer or manufacturer part number because they are custom made in the internal design house.

Production BOM

A production BOM is the final BOM. It is hierarchical in nature and includes all board-level and system-level components, subassemblies, and software required for the final product build. Exactly two weeks before the PCBA build and system build, the BOM needs to be frozen, after which no parts can be added. The addition of any new component in this phase will cause a delay in the PCBA or product build, which will affect the overall product schedule.

Two weeks is not a standard practice; it depends on the lead time of the parts used in the BOM. The lead time of some special parts can be in terms of months. Any part added at the last minute with a month-long lead time will hold the PCBA and system build until that part docks in the factory.

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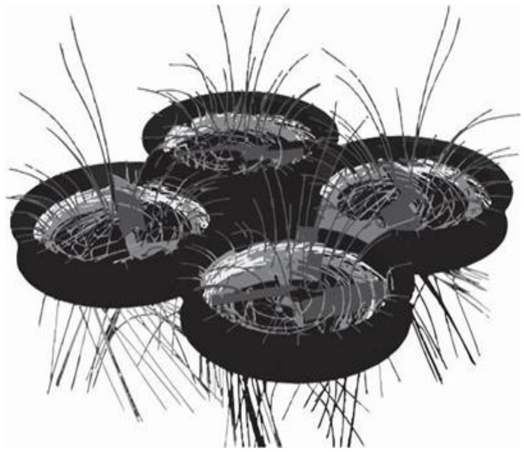
UNIT 2 - DRONE ELECTRONICS – SECA4003

UNIT 2: DYNAMICS AND STABILITY

- Forces of flight
- Principal axes and rotation of aerial systems
- Longitudinal axis, Lateral(transverse) axis and Perpendicular axis
- Equilibrium, Stability - Stable system
- Unstable system and
- Neutrally stable system, Control –Roll, Pitch, Yaw and Throttle

- The physics for flying a drone is really necessary to be known by all the
- drone pilots because, if you cannot master the air, your drone will not fly properly. how air is affected by the propellers of the drone.
- The figure is taken from the NASA website. They simulated the aerodynamics via computers:



INTRODUCTION

- So, basically a drone (specially quadcopters) has two pairs of propellers (two in a clockwise direction and another two in a anticlockwise direction).
- The speed of each motor is individually controlled to control the movement of the drone.
- We need to think about two things for flying a drone, the torque, and the thrust. Well, a torque is nothing but a twisting force that tends to cause rotation.
- Alternatively, we can say, in physics, the capability of rotating an object around a fixed axis is known as torque. It is symbolized as (Tau). Mathematically, torque is the vector product of force (F) and the distance (r) of the axis.

DEFINITION

$$\vec{\tau} = \vec{F} \times \vec{r}$$

(OR)

$$\tau = Fr\sin\theta$$

Where is the angle between the force and the distance from the center of the axis. Thrust is simply pushing something suddenly or with propulsive force.

In physics, thrust is defined as the forward force that impels it to go faster or keeps it going in the intended direction.

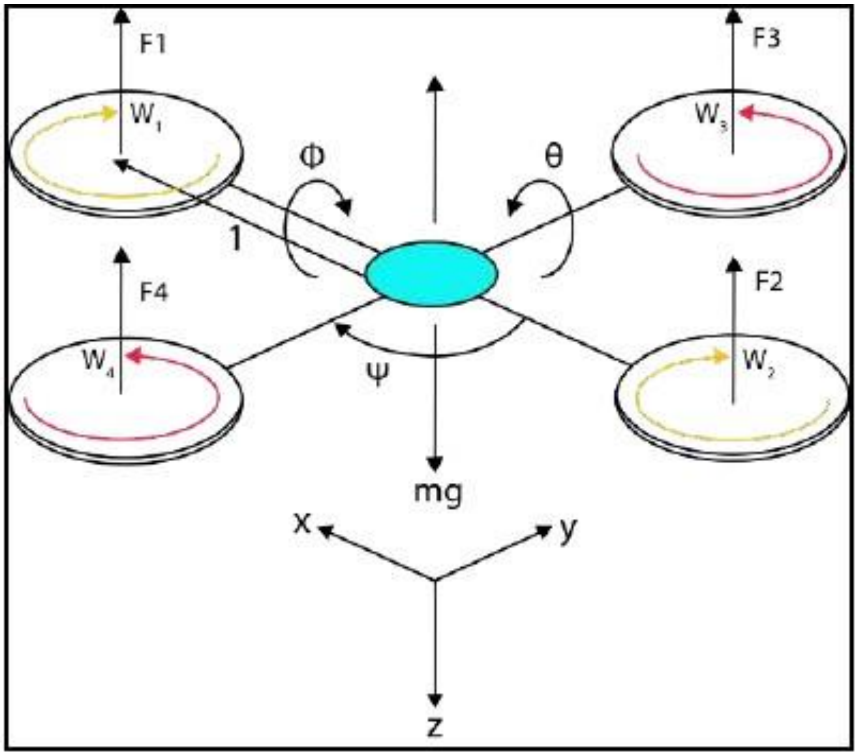
Mathematically, thrust is the product of pressure (P) and area (A). So, we can say,

Thrust = P x A.

FORCES

- We use a small control board to control the drone. The control board has a few sensors that provide the necessary signals to move the propellers at the proper speed, and in the right direction.
- Inside the control board, there is a gyroscope and accelerometer that provide the orientation information of the drone.
- The RC receiver gets a signal from the RC transmitter and sends it to the microcontroller of the control board, and the ESCs connected to the microcontroller are then controlled to provide the necessary speed.
- The following figure shows the forces and movements of the quadcopter:

FORCES AND MOVEMENTS



DEFINITIONS & EQUATIONS

Mathematically, Thrust (T) will be proportional to the square of the angular velocity (w) of the propellers. The thrust is perpendicular to the Z direction of the drone. So, we can write:

$$T \propto \omega^2$$

or

$$T = K_a \times \omega^2$$

Here, K_a is a constant. As the propellers rotate and create a thrust in the Z direction, there must be an opposite force in the drone. Let the movement be M_i, which will also be equal to the right side of the previous equation.

Therefore, $M_i = K_b \times \omega^2$, where K_b is a constant. We used two different constants because the force might be slightly decreased or increased, due to the friction of the air particle or the dust.

The opposite pair of propellers are M_x and M_y. According to the definition of movements, if the distance of the center of the drone and a propeller is l, we can write the following equations:

$$M_x = |F_1 - F_2| \times l$$

RELATIONSHIP BEWEEN FORCES :

$$M_x = |F_1 - F_2| \times l$$

$$M_y = |F_3 - F_4| \times l$$

The weight of the drone $W = mg$. The weight always acts in the direction of the quadcopter. From Newton's second law of motion, we know:

$$force = mass \times acceleration \ (linear)$$

The torque can be defined with the help of inertia as follows:

$$Torque = Inertia \times acceleration \ (angular)$$

HOVER, RISE AND DROP ACTIONS:

Hovering

To hover the quadcopter, the weight of the drone must be equal to all the upward forces of the propellers, where the movement must be equal to zero:

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

For flying, the upward force must be greater than the weight. So, if we subtract the mass of the drone from the upward forces of the propellers, we will get the equation of motion of the drone flying. Let's say it is D_*. So, we can write:

$$D_* = F_1 + F_2 + F_3 + F_4 - mg$$

Rising or climbing or taking off

To fly the drone over the ground, the equations will be changed as follows:

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

$$D_* = F_1 + F_2 + F_3 + F_4 - mg > 0$$

Dropping or descent or falling

The drone will not fly if the weight is more than the upward forces or $D_* < 0$:

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

$$D_* = F_1 + F_2 + F_3 + F_4 - mg < 0$$

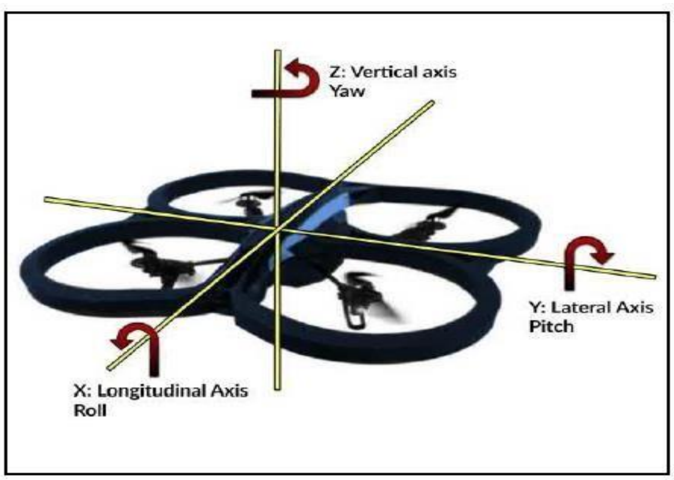
Yaw

Yaw is the motion of the drone in the *xy* plane, or the horizontal plane as shown in the previous figure. The opposite kind of pair of propellers will create reaction movements. If the sum of all the movements of each propeller is equal to each other, then there is no yaw motion. But if there is difference movements between any pair of propellers, there will be yaw motion, and the drone will move, as shown in the following figure:

PROPELLER MOVEMENTS:

Pitch and roll

The pitch is the rotation of the drone in the *Y* direction, while the rotation along the *X* direction is known as roll or vice versa, depending on the front of the drone. This will happen if one pair of opposite propellers provide, thrust more than the other two propellers.



If the drone simply rotates along the *z* direction, it is known as a yaw motion. This will occur, if there is a stable upward force and the propeller forces are as follows:

$$I_{zz} = M_1 + M_2 + M_3 + M_4$$

DRONE FRAMES

- Basically, the drone frame is the most important to build a drone. It helps to mount the motors, battery, and other parts on it. If you want to build a copter or a glide, you first need to decide what frame you will buy or build.
- For example, if you choose a tricopter, your drone will be smaller, the number of motors will be three, the number of propellers will be three, the number of ESC will be three, and so on.
- If you choose a quadcopter, it will require four of each of the earlier specifications. For the gliding drone, the number of parts will vary.

- So, choosing a frame is important as the target of making the drone depends on the body of the drone. And a drone's body skeleton is the frame.
- If you want to buy the drone frame, there are lots of online shops who sell ready- made drone frames. Make sure you read the specification before buying the frames. While buying frames, always double check the motor mount and the other screw mountings.
- If you cannot mount your motors firmly, you will lose the stability of the drone in the air. About the aerodynamics of the drone flying, we will discuss them soon.
- The following figure shows a number of drone frames. All of them are pre-made and do not need any calculation to assemble.

FRAME ACCESSORIES:

• You should also choose a material which light but strong. My personal choice is carbon fiber. But if you want to save some money, you can buy strong plastic frames.

• You can also buy acrylic frames. When you buy the frame, you will get all the parts of the frame unassembled, as mentioned earlier.

• The following picture shows how the frame will be shipped to you, if you buy from the online shop.

SPECIFICATIONS

• The specifications covering additional internal features of the drone system. It must again be noted that the specification here is for an example drone and will vary from one drone system to another.

• As seen earlier, some subsystems from the list may or may not be required for the target application of the system.

• Subsystems Features Specifications

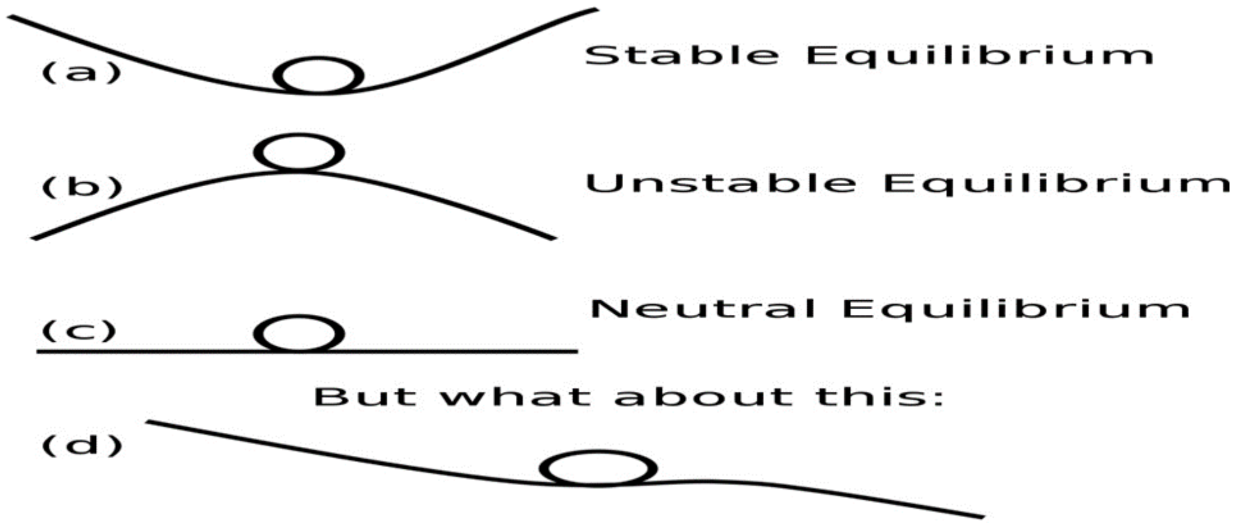
- NETWORK Technology GSM / CDMA / HSPA / EVDO / LTE
- PROCESSING CPU Quad-core 2.34 GHz
- GPU 6-core graphics
- MEMORY Card slot No

FEATURES OF A DRONE

- Internal 32/128/256 GB, 2 GB RAM
- CAMERA Primary 12 MP (f/1.8, 28mm, 1/3"), phase detection auto focus,
- OIS, quad-LED dual-tone flash, check quality
- Features Geo-tagging, simultaneous 4K video and 8MP image
- recording, touch focus, face/smile detection, HDR
- (photo/panorama)
- Video 2160p@30fps, 1080p@30/60/120fps, 720p@240fps,
- check quality
- Secondary 7 MP (f/2.2, 32mm), 1080p@30fps, 720p@240fps,
- face detection, HDR, panorama
- AUDIO Alert types Vibration
- Loudspeaker Yes, with stereo speakers
- 3.5mm jack No
- Equilibrium, Stability - Stable system
- Unstable system and
- Neutrally stable system, Control

EQUILIBRIUM STATES

- If a system in an equilibrium state, returns to equilibrium following a small disturbance, the state is said to be stable equilibrium Figure 1.



• On the other hand, if the system diverges from equilibrium when slightly disturbed, the state is said to be an unstable equilibrium.

• Strictly speaking, Figure 1(d) is also a case of stable equilibrium, because a very small disturbance from equilibrium would result in a force and moment imbalance that would return the ball to its original equilibrium state.

• But a little extra disturbance, towards right could cause the ball to move past the apex, which would produce a force and moment imbalance that would cause the ball to move away from its original equilibrium state.

• This type of stable equilibrium can sometime occur with an aircraft.

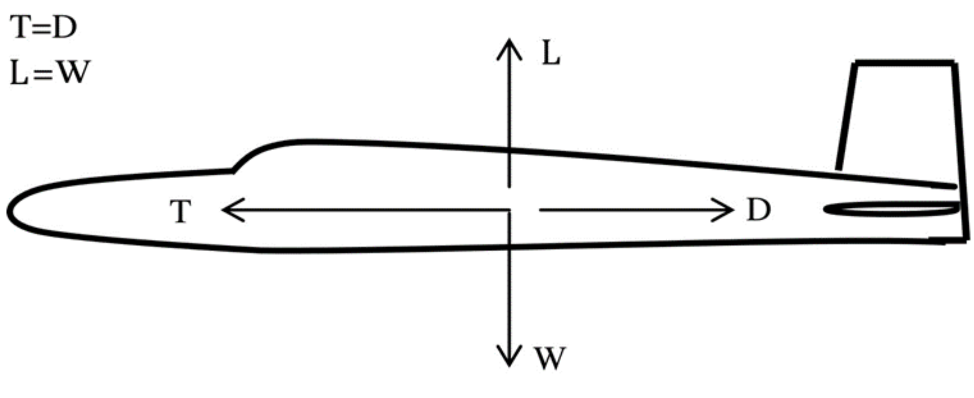
• In general, when aircraft is being referred to be in stable equilibrium, we mean dynamic stability. However, it so happens that for most of the cases, for conventional aircraft, if it is statically stable, it also automatically satisfies dynamic stability criterion {but not all aircraft! Handling qualities may be different.

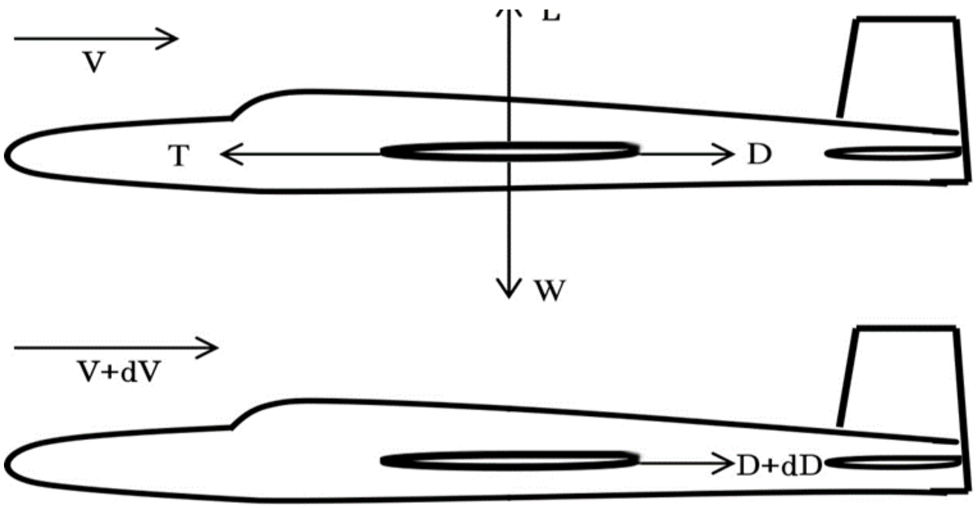
Static equilibrium occurs whenever there is no acceleration (linear or angular) of the aircraft. Un-accelerated flight requires that the summations of forces and moments acting on the aircraft are zero.

- Static equilibrium also requires that the side force acting on the airplane is also zero.
- Additionally, the summation of moments about the centre of gravity (CG) in roll, pitch and yaw must all be zero for equilibrium (Trimmed flight).

Stable Trim - Longitudinal (Axial)

- Small translational disturbances in axial, normal or side slip velocity must all result in a return to the original trimmed equilibrium condition. This is also referred to as pitch stability. An object moving through the air will experience drag that opposes the motion.
- If angle of attack remains fixed, this drag will increase with speed. (Drag opposes increase in speed). Thrust developed by engine is either constant with airspeed or decrease with increasing air speed. (Drag increase in speed).
- In static equilibrium with regard to translational in the direction of motion, the forward component of thrust must balance the drag (T = D)
- At constant angle of attack, a small increase in airspeed will result in (i) Increase in Drag (ii)Either a decrease in Thrust or No change in Thrust
- Therefore, this force imbalance in the axial direction will result in a deceleration, which will tend (initial tendency) to restore the airspeed to the original value.
- Conversely, if airspeed is decreased by a small disturbance with no change in angle of attack, the drag will become less than the thrust and the aircraft will accelerate back (tends to) to the equilibrium airspeed.





dD will oppose dV . If dV is positive; dD will act to reduce/marginalize dV .If dV is negative; dD will tend to increase the speed as in that case T > D.

EQUILIBRIUM AND STABILITY

- The study of stability and control can be viewed as the problem of setting and maintaining equilibrium.
- In steady level flight or steady climb, for example, the net force and moment on an aircraft are zero and the aeroplane advances in unaccelerated motion.
- First, we define equilibrium: a body is in equilibrium when the net force and net moment acting on it are both identically zero.
- An aircraft which is in equilibrium is said to be in trim, or trimmed.
- Stability relates to the tendency of a system to return to equilibrium if it is disturbed in some way.
- Static stability refers to the instantaneous response of a system when perturbed:
- a statically stable system will initially move back towards its equilibrium state.
- A dynamically stable system will eventually recover its equilibrium, though not necessarily immediately.

STABILITY

• Figure 1.1 illustrates the two cases and also that of neutral stability, where the system remains in the state to which it has been perturbed.

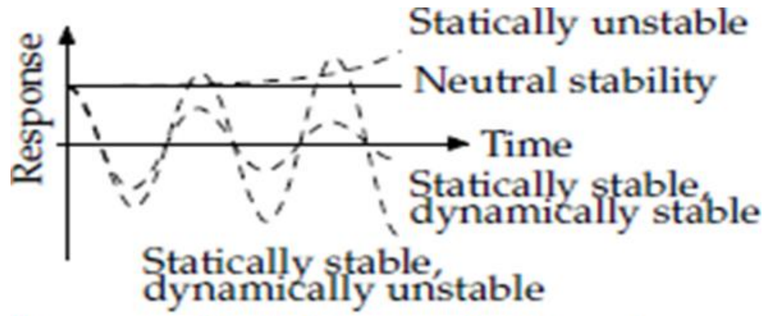


Figure 1.1: Equilibrium and static and dynamic stability

STABILITY

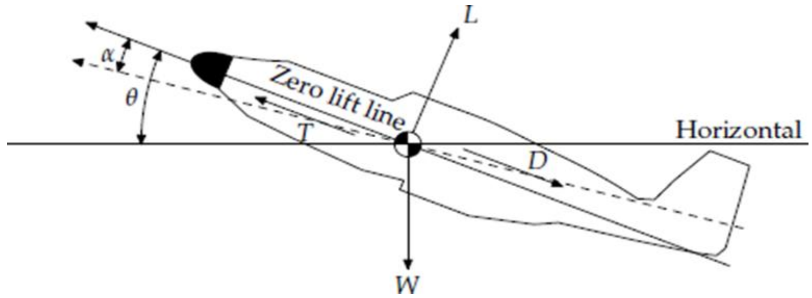
• Figure 1.2 shows the notation for the analysis of aircraft stability. The two angles shown are the incidence a and the inclination q.

• The second of these is the angle between a reference line on the aircraft and the horizontal and in practice is of little interest to us in analyzing stability and control, though it is important to a pilot, to whom it is known as “attitude”.

• The incidence, on the other hand, is of great interest and is the angle between the reference line and the direction of flight. As a reference, we take the zero lift line (ZLL) which is the angle of attack at which the lift is zero.

• This choice makes future analysis a little more compact, because then CL = aa, but be careful in consulting other work since the reference system might be different.

LONGITUDINAL STABILITY



Resolving forces and moments from Figure 1.2,

$$T - D - W \sin\theta = 0; \qquad (1.1a)$$

$$L - W \cos\theta = 0; \qquad (1.1b)$$

$$M_{cg} = 0, \qquad (1.1c)$$

- where c.g. refers to “centre of gravity” and coordinates are taken in a frame of reference attached to the aircraft. By taking moments about the centre of gravity, we remove the effects of the mass distribution of the aircraft and (1.1c) is a statement about the balance of aerodynamic moments only.

- If we are to relate scale-test data to full-size aircraft, this is a very useful thing. A pilot brings an aircraft into, or out of, trim by modifying the aerodynamic moments through use of the control surfaces; without worrying about details of the mass distribution.

CONTROL

- THRUST OF THE MOTOR:

- If P is the payload capacity of your drone (how much your drone can lift., M is the number of motors, W is the weight of the drone itself, and H is the hover throttle % Then, our thrust of the motors T will be as follows:

- The drone's payload capacity can be found with the following equation:

$$T = \frac{\frac{1}{H} \times (P + W)}{M}$$

$$P = T \times M \times H - W$$

TYPES OF MOTORS USED FOR DRONES:

- There are a few types of motors that are used to build drones.
- But as the drone needs to be thrust in the air to float, we should use some powerful motors.
- The cheap, lightweight, small, and powerful motors used in drones are

Brushless DC motors (BLDC).

- For small drones, we do not use BLDC motors, but instead use small DC gear motors.

SPEED CONTROLLERS

- You cannot control the speed of motors of your drone unless you use speed controllers.
- They enable you to control the voltage and current of the motors and hence control the speed, which is the first priority to move the drone one place to another, after floating in the air.
- You need to increase and decrease the speed of motor(s) to move the drone forward, backward, left, or right.
- The connection between the controller board of the drone and ESC and the battery/power distribution board is shown in Figure.

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SCHOOL OF ELECTRICAL AND ELECTRONICS

DEPARTMENT OF ELECTRONICS AND COMMUNICATION ENGINEERING

UNIT 3 - DRONE ELECTRONICS – SECA4003

UNIT III SENSORS IN DRONE

Sensors – Accelerometer, Barometer

Gyro Sensor, Magnetometer

Distance sensors, Time of Flight (ToF) Sensors

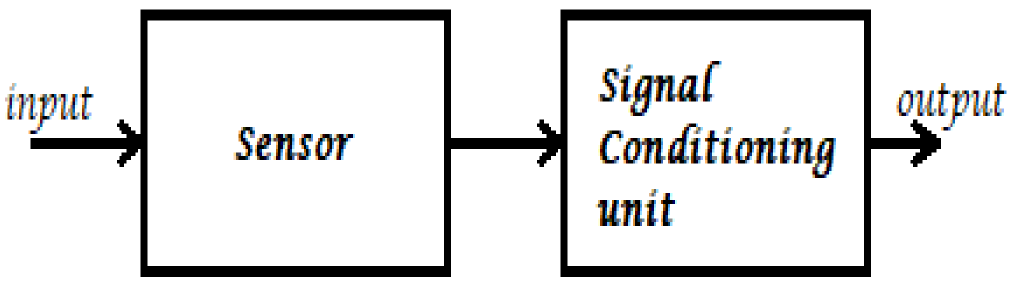
Thermal sensors, Chemical Sensors and

Sensor Testing – Test Philosophies and methodologies

Test equipment, Performance testing of sensors

SENSORS IN DRONE

- The sensor can be defined as a device which can be used to sense/detect the physical quantity like force, pressure, strain, light etc and then convert it into desired output like the electrical signal to measure the applied physical quantity. In few cases, a sensor alone may not be sufficient to analyze the obtained signal. In those cases, a signal conditioning unit is used in order to maintain sensor's output voltage levels in the desired range with respect to the end device that we use.



SIGNAL CONDITIONING UNIT

- In **signal conditioning unit**, the output of the sensor may be amplified, filtered or modified to the desired output voltage. For example, if we consider a microphone, it detects the audio signal and converts to the output voltage (is in terms of millivolts) which becomes hard to drive an output circuit. So, a signal conditioning unit (an amplifier) is used to increase the signal strength. But the signal conditioning may not be necessary for all the sensors like photodiode, LDR etc.

- Most of the sensors can't work independently. So, sufficient input voltage should be applied to it. Various sensors have different operating ranges which should be considered while working with it else the sensor may get damaged permanently.

TYPES OF SENSORS

- The various different types of sensors that are available in the market and discuss their **functionality, working, applications** etc.

- **Light Sensor**
  - IR Sensor (IR Transmitter / IR LED)
  - Photodiode (IR Receiver)
  - Light Dependent Resistor
- **Temperature Sensor**
  - Thermistor
  - Thermocouple

- **Pressure/Force/Weight Sensor**

  Strain Gauge (Pressure Sensor)

  Load Cells (Weight Sensor)

Position Sensor

Potentiometer

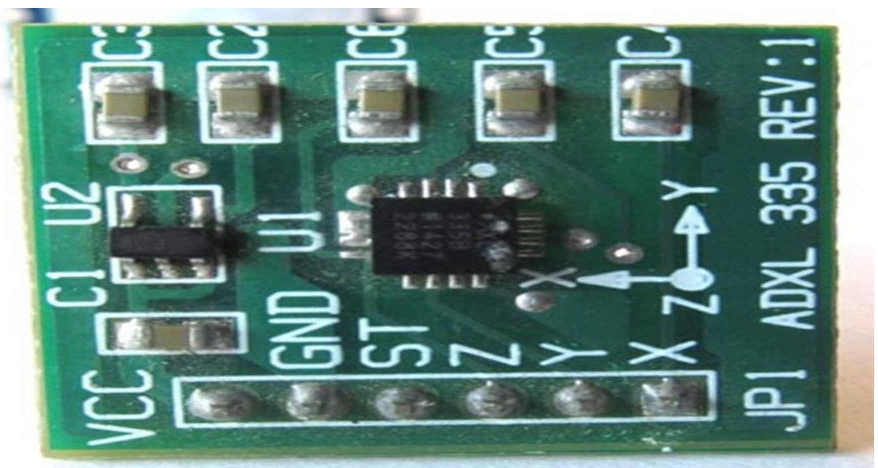
Encoder

- **Hall Sensor (Detect Magnetic Field)**
- **Ultrasonic Sensor**
- **Touch Sensor**
- **PIR Sensor**
- **Tilt Sensor**

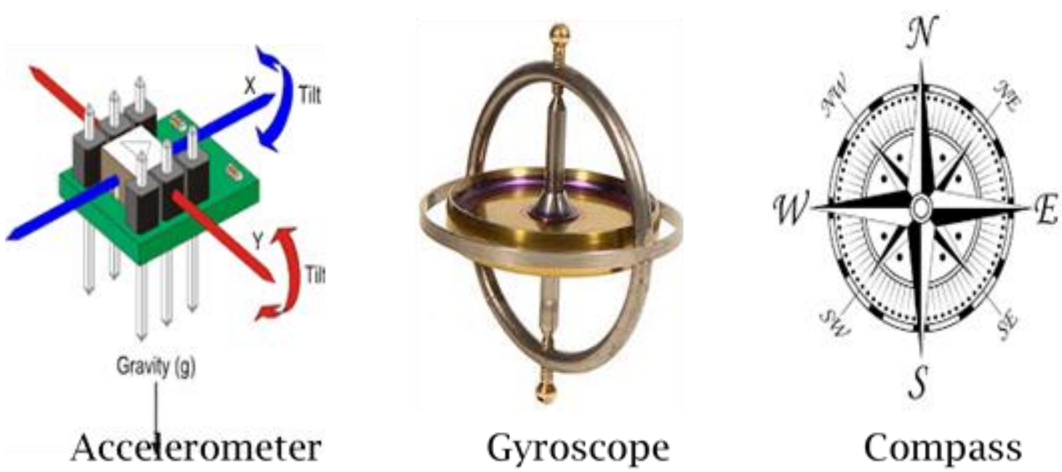
  Accelerometer
- **Gas Sensor**
- We need to select the desired sensor based on our project or application. In order to make them work, proper voltage should be applied based on their specifications.

ACCELEROMETER (TILT SENSOR)

- **An accelerometer sensor *can sense the tilt or movement of it in a particular direction*.** It works based on the acceleration force caused due to the earth's gravity.
- The tiny internal parts of it are such sensitive that those will react to a small external change in position. It has a piezoelectric crystal when tilted causes disturbance in the crystal and generates potential which determines the exact position with respect to X, Y and Z axis.



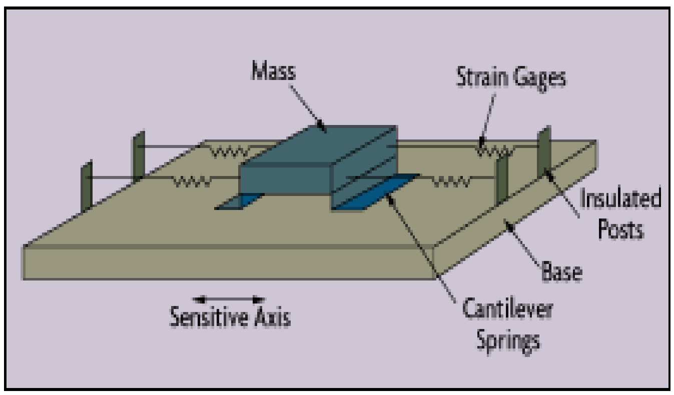
DRONE STABILIZATION



Inertial Measurement Unit (IMU) crucial for tracking 3D orientation → stabilization, control

ACCELEROMETER

An accelerometer is a device that measures the vibration, or acceleration of motion of a structure. The force caused by vibration or a change in motion (acceleration) causes the mass to "squeeze" the piezoelectric material which produces an electrical charge that is proportional to the force exerted upon it. Since the charge is proportional to the force, and the mass is a constant, then the charge is also proportional to the acceleration.



- Accelerometers are available as digital devices and analog devices. Accelerometers are designed using different methods. Piezoelectric, piezoresistive and capacitive components are generally used to convert the mechanical motion caused in accelerometer into an electrical signal.
- Piezoelectric accelerometers are made up of single crystals. These use the piezoelectric effect to measure the acceleration. When applied to stress, these crystals generate a voltage which is interpreted to determine the velocity and orientation.

ACCELEROMETER TYPES

- There are two types of piezoelectric accelerometers (vibration sensors). The first type is a "high impedance" charge output accelerometer. In this type of accelerometer, the piezoelectric crystal produces an electrical charge which is connected directly to the measurement instruments. The charge output requires special accommodations and instrumentation most commonly found in research facilities. This type of accelerometer is also used in high temperature applications (>120C) where low impedance models cannot be used.

- The second type of accelerometer is a low impedance output accelerometer. A low impedance accelerometer has a charge accelerometer as its front end but has a tiny built-in micro-circuit and FET transistor that converts that charge into a low impedance voltage that can easily interface with standard instrumentation. This type of accelerometer is commonly used in industry. An accelerometer power supply like the ACC-PS1, provides the proper power to the microcircuit 18 to 24 V @ 2 mA constant current and removes the DC bias level, they typically produce a zero-based output signal up to +/- 5V depending upon the mV/g rating of the accelerometer. All OMEGA(R) accelerometers are this low impedance type.

BAROMETER

A barometer is a widely used weather instrument that measures atmospheric pressure (also known as air pressure or barometric pressure) -- the weight of the air in the atmosphere. It is one of the basic sensors included in weather stations. While an array of barometer types exist, two main types are used in meteorology: the mercury barometer and the aneroid barometer.

WORKING

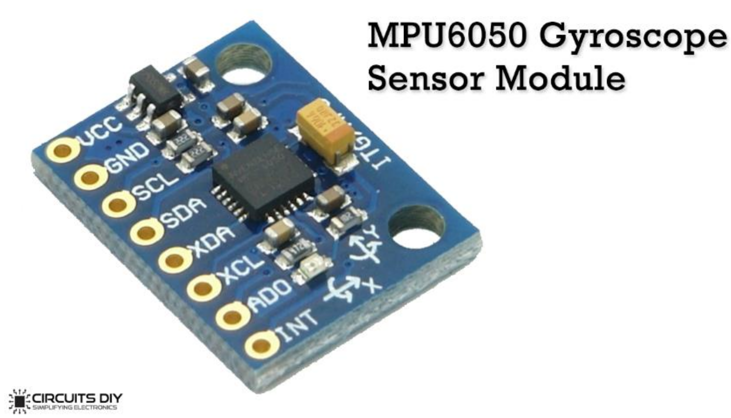
- The classic mercury barometer is designed as a glass tube about 3 feet high with one end open and the other end sealed. The tube is filled with mercury. This glass tube sits upside down in a container, called the reservoir, which also contains mercury. The mercury level in the glass tube falls, creating a vacuum at the top.

- The barometer works by balancing the weight of mercury in the glass tube against the atmospheric pressure, much like a set of scales. Atmospheric pressure is basically the weight of air in the atmosphere above the reservoir, so the level of mercury continues to change until the weight of mercury in the glass tube is exactly equal to the weight of air above the reservoir. Once the two have stopped moving and are balanced, the pressure is recorded by "reading" the value at the mercury's height in the vertical column.
- If the weight of mercury is less than the atmospheric pressure, the mercury level in the glass tube rises (high pressure). In areas of high pressure, air is sinking toward the surface of the earth more quickly than it can flow out to surrounding areas. Since the number of air molecules above the surface increases, there are more molecules to exert a force on that surface. With an increased weight of air above the reservoir, the mercury level rises to a higher level.
- If the weight of mercury is more than the atmospheric pressure, the mercury level falls (low pressure). In areas of low pressure, air is rising away from the surface of the earth more quickly than it can be replaced by air flowing in from surrounding areas. Since the number of air molecules above the area decreases, there are fewer molecules to exert a force on that surface. With a reduced weight of air above the reservoir, the mercury level drops to a lower level.

GYRO SENSOR

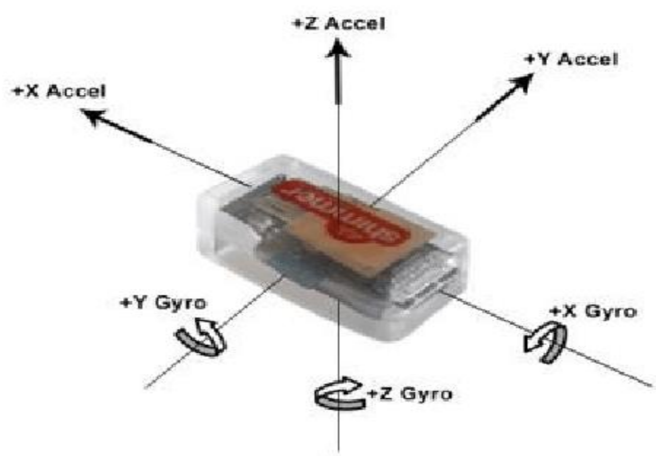
- Gyro sensors, also known as angular rate sensors or angular velocity sensors, are **devices that sense angular velocity**. In simple terms, angular velocity is the change in rotational angle per unit of time. Angular velocity is generally expressed in deg/s (degrees per second).

GYROSCOPE SENSOR



WORKING

- Besides sensing the angular velocity, Gyroscope sensors can also measure the motion of the object. For more robust and accurate motion sensing, in consumer electronics Gyroscope sensors are combined with Accelerometer sensors.
- Depending on the direction there are three types of angular rate measurements. Yaw- the horizontal rotation on a flat surface when seen the object from above, Pitch- Vertical rotation as seen the object from front, Roll- the horizontal rotation when seen the object from front.



PRINCIPLE OF WORKING

- Working principle of Gyroscope sensor can be understood by observing the working of Vibration Gyroscope sensor.
- This sensor consists of an internal vibrating element made up of crystal material in the shape of a double – T- structure. This structure comprises a stationary part in the center with ‘Sensing Arm’ attached to it and ‘Drive Arm’ on both sides.
- This double-T-structure is symmetrical. When an alternating vibration electrical field is applied to the drive arms, continuous lateral vibrations are produced. As Drive arms are symmetrical, when one arm moves to left the other moves to the right, thus canceling out the leaking vibrations. This keeps the stationary part at the center and sensing arm remains static.
- When the external rotational force is applied to the sensor vertical vibrations are caused on Drive arms. This leads to the vibration of the Drive arms in the upward and downward directions due to which a rotational force acts on the stationary part in the center.

- Rotation of the stationary part leads to the vertical vibrations in sensing arms. These vibrations caused in the sensing arm are measured as a change in electrical charge. This change is used to measure the external rotational force applied to the sensor as Angular rotation.

APPLICATIONS

- Gyroscope Sensors are used for versatile applications. Ring laser Gyros are used in Aircraft and Source shuttles whereas Fiber optic Gyros are used in racecars and motorboats.
- Vibration Gyroscope sensors are used in the car navigation systems, electronic stability control systems of vehicles, motion sensing for mobile games, camera-shake detection systems in digital cameras, radio-controlled helicopters, Robotic systems, etc…
- The main functions of the Gyroscope Sensor for all the applications are Angular velocity sensing, angle sensing, and control mechanisms. Image blurring in cameras can be compensated by using Gyroscope Sensor-based optical image stabilization system.
- By understanding their behavior and characteristics developers are designing many efficient and low-cost products such as gesture-based control of the wireless mouse, directional control of wheel-chair, a system to control external devices using gesture commands, etc…

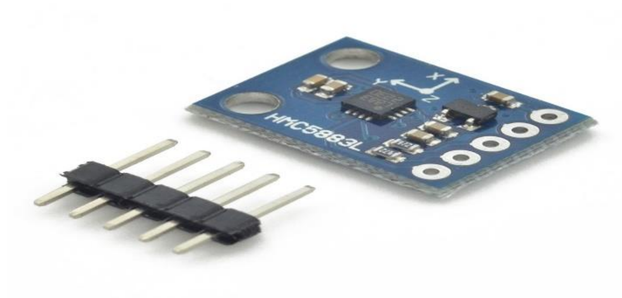
MAGNETOMETER

- A magnetometer is a device used to measure the magnetic field, particularly with respect to its magnetic strength and orientation.
- A popular example of a magnetometer would be the compass, which is used to measure the direction of an ambient magnetic field (i.e. in this case, the earth's magnetic field).
- Other magnetometers measure magnetic dipole moments; a magnetic dipole is the limit of either a closed loop of electric current or a pair of poles, since the size of the source is reduced to zero while keeping the magnetic moment - the magnetic field's magnetic strength and orientation - constant. Think of the ferromagnet, a type of magnetic material that is used to record the effect of this magnetic dipole on the induced current in a coil.
- A magnetometer can work like a compass. The compass's needle aligns itself with the north of the earth's magnetic field when it's at rest. In other words, the sum of the forces acting upon it is zero and the weight of the compass's own gravity cancels out the earth's magnetic force acting upon it.

- Electronic compasses can similarly help indicate which direction is the magnetic north using phenomena such as the Hall effect, magneto induction, or magnetoresistance.

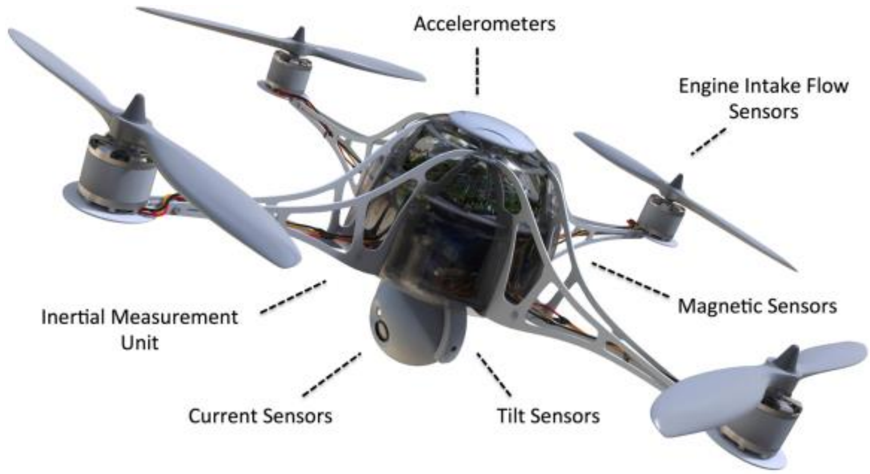
MAGNETOMETER SENSOR MODULE

Magnetometer is used for measurement of magnetic field direction in space. Most navigation systems use electronic compasses to determine heading direction.
A **magnetometer** can sense where the strongest magnetic force is coming from.



ROLE OF SENSORS IN DRONES

With modern drones being made to maximize ease-of-use, it’s also become easy to take for granted just how complex and well-designed these drones are. Aside from the mechanical components that allow a drone to generate lift and maneuver in mid-air, drones also employ an array of sensors that constantly collect information from their surroundings. With this information, drones can maintain their positions, determine how fast they are, and avoid obstacles. What exactly are these sensors and how do they work?



1.GYROSCOPE

- The most basic of drone sensors, gyroscopes are cheap and basic enough to be integrated into even cheap mini-drones. Despite the very simple scientific principles that govern how gyroscopes work, they are still highly essential tools that are used for navigation in high-end aircraft and space shuttles.
- Gyroscopes work on the principle of conservation of angular momentum. Simply put, a gyroscope consists of a spinning disk that is mounted on a frame. While the disk is spinning, the axis of its rotation remains in place, regardless of the tilting or rotation of the frame where it is mounted. By establishing an inertial reference frame, a gyroscope can be used to determine the rate of rotation, degree of tilt, and angular velocity of a moving object.
- Gyroscopes are an all-around tool used for measuring or maintaining orientation. By integrating three accelerometers, each of which is oriented in a different axis, the degree of motion of a drone in any axis can be determined. This helps in collecting information on the drone's roll, pitch, and yaw, and feeding back this information to the drone's proportional-integral-derivative (PID) controller.
- In practically all drones, gyroscope technology is heavily employed to help maintain a stable hover. When there is no input from the pilot, any wayward drifting or wobbling by the drone is detected by the gyroscope. This information is then relayed to the PID controller, which commands the drone's motors to counteract the unwanted movements. Gyroscopes are so essential to the stable operation of a drone that a malfunction in the gyro sensors will very likely result in a crash.

2. BAROMETER

- Barometers are sensors that measure air pressure. In drones, this air pressure information is used to determine the drone's altitude. The principle and technology behind this process are pretty simple, but air pressure readings are prone to drifting due to winds or any rapid changes in the drone's movements. To ensure their best performance, barometers need to be periodically using air pressure readings at the local sea level.

- Barometers are found in almost all drones and are mostly used to aid in maintaining a stable altitude. Autonomous drone missions were changes in altitude are essential also make use of the readings from the onboard barometer. Although GPS technology can also be used to determine the altitude of a drone, barometers produce much more accurate data and provide faster feedback, as long as they have been properly calibrated.

3. ACCELEROMETER

- The accelerometer of a drone works together with its gyroscope to determine changes in its position and movement. Where the gyroscope specializes in reading rotational movements, an accelerometer performs better in reading linear movement along any axis. Accelerometers, in combination with GPS technology, allow your smartphone or fitness device to track your route when you are running or traveling.

- So how do these accelerometers work? There are a couple of accelerometer types that function in different ways, but most accelerometers rely on the piezoelectric effect. A piezoelectric accelerometer uses microscopic crystals that generate a current when they undergo stress. This stress can be brought about by accelerative forces, such as the movement of an object.

- Aside from the work done by gyroscopes, accelerometers also aid in allowing a drone to maintain a stable hover. The principle is essentially identical. Any movement of the drone caused by external forces, such as a strong gust of wind, will be detected by the accelerometer and relayed to the PID controller. The controller then commands the motors to counteract the movement.

- The combination of 3-axis accelerometer and 3-axis gyroscopes is what is commonly referred to as 6-axis gyro stabilization. This setup allows a drone to maintain horizontal, vertical, and rotational stability while hovering. For applications such as professional-grade drone photography and 3D imagery, 6-axis gyro stabilization is a must.

4.GPS

- GPS technology has played a huge role in allowing drones to fly autonomous missions. It's not a feature that can be found in all drones but is a pretty standard inclusion for prosumer-grade models. By comparing the actual position of the drone with its targeted position, the PID controller determines which way the aircraft should move and instructs the drone motors with the appropriate commands.

- The principle behind GPS technology is pretty simple. A drone is outfitted with a GPS receiver that can receive signals from several GPS satellites. Depending on the location of the satellite source, the time it takes for the drone's GPS module to receive the signal will vary. By triangulating the relative position of the drone from the different GPS satellites, the location of the drone in a specified geospatial reference system can be determined. The accuracy of the location will depend on the strength of the signal that the drone's GPS module receives and the number of satellites within its range.

- Despite the prevalence of GPS technology, it is not a foolproof method for determining a drone's location. Since it relies on the reception of signals from satellites located along the Earth's orbit, flying under any canopy cover will drastically reduce the ability of a drone to determine a GPS location.

- Autonomous flight modes using GPS location will also only function if the drone can identify a 'heading' – basically an indication of where the North direction is. Although it's possible to determine the heading based on the drone's movements and relative GPS locations, this can only be done as long as the drone is constantly moving. There's also a bit of latency using this method, so the ability of the drone to follow a pre-programmed route may not be as accurate.

5. MAGNETOMETER

- In cases where determining the drone's heading using only GPS location is not appropriate, a drone needs to have a magnetometer. As its name implies, a magnetometer measures the strength and direction of a magnetic field. Using this principle, a drone can always determine the direction of the magnetic North and adjust its trajectory accordingly.

- Unfortunately, it can be very easy to throw a magnetometer off its course. Anything that emits a magnetic field – such as power lines, motors, and other electrical devices – have the potential of disturbing the magnetometer's ability. This can be avoided from avoiding such disruptive sources and performing a calibration of the magnetometer periodically.

6. RANGEFINDER

- There are different types of rangefinders found in drones but all of them perform a simple task: to determine how far away from the ground the drone is. If it sounds like a rangefinder's function would be redundant with that of the barometer, then you're right: a rangefinder is basically an alternative to a barometer that has a more limited scope but is much more accurate.

- For a rangefinder to function as intended, it needs to be pointed to the ground at all times. The most common rangefinders use sonar technology. By receiving sound waves from the direction of the ground, a sonar rangefinder can deduce the altitude of the drone. A laser rangefinder works in pretty much the same manner except it uses lasers in place of sound waves. Laser rangefinders have a bigger range but are also more expensive.

- The main drawback of using a rangefinder is that it only works when the drone is hovering close to the ground. You may be wondering: given the limited range, why use a rangefinder in the first place? The answer lies in accuracy. The altitude reading of a rangefinder is unaffected by drift or sudden changes in wind strength. It also takes into account minor variations in topography.

7. Inertial Measurement Unit (IMU)

- An IMU is not exactly a separate sensor of the drone but is instead a collaboration of several sensors. In most cases, a drone's IMU consists of accelerometers, gyroscopes, and magnetometers, each set of which works in all three axes of movement. By combining the capabilities of all these sensors, an IMU can detect changes in location and rotational attributes related to an aircraft's roll, pitch, and yaw. By detecting the orientation and strength of magnetic fields, an IMU can even enforce on-the-fly calibration against orientation drift.
- Before drones were even a thing, IMU modules have formed the backbone of the navigation systems of manned aircraft, satellites, space shuttles, and missiles. Nowadays, IMUs are so common that they can be found in almost all smartphones and tablets, some game controllers, and self-balancing hoverboards.
- IMUs allow drones to determine their location via a process called 'dead reckoning.' In this method, the drone's position is determined using a previously determined location and the estimated speeds over the period of time from the previous reading. In simpler terms, an IMU continuously integrates the acceleration of the drone to calculate its velocity and position. This technology allows the drone to determine its approximate location even when GPS signals drop off, such as when flying indoors.
- A disadvantage of the IMU's use of multiple sensors is that the error that the sensors generate tend to accumulate. Since velocity and location are determined by integrating the acceleration of the drone, any error in the acceleration numbers will result in exponentially higher errors in both location and velocity. The 'drift' caused by these errors can also get larger over time.
- For this reason, periodic calibration of a drone's IMU is strongly recommended. Software-assisted IMU calibration has bene the norm for modern drones, so this shouldn't be much of a chore.

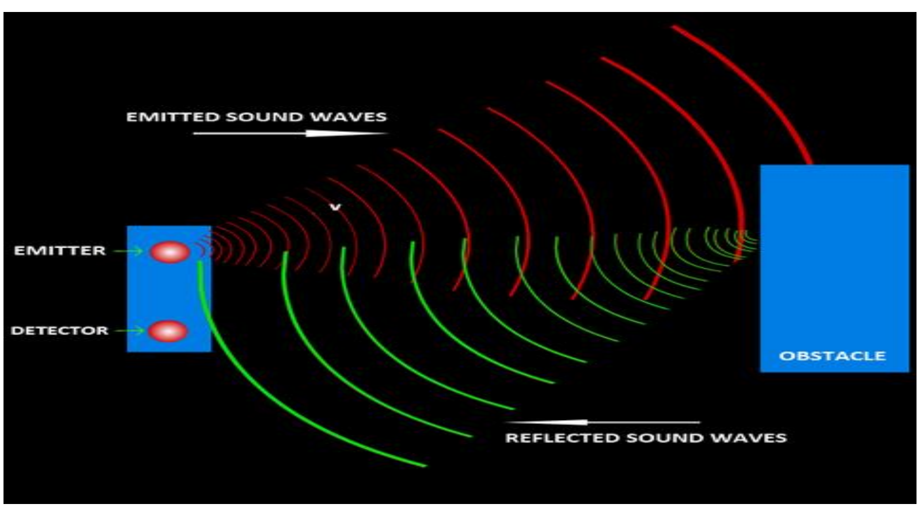
8. OBSTACLE AVOIDANCE

- Obstacle avoidance sensors isn't exactly a standard feature in drones. In fact, you would probably only find these sensors in the more expensive and higher end models. Still, obstacle avoidance features are highly sought by many drone pilots. As drones become even more sophisticated, we can expect drone manufacturers to compete with each other to see who can produce a better, more reliable, and more accurate obstacle avoidance system.

- Different drones take different approaches to obstacle avoidance. Stereoscopic sensors combine images from two different cameras to infer the three-dimensional shapes of the features around it. Ultrasonic sensors both transmit and receive ultrasonic waves, deducing how far away the drone is from potential obstacles using the time difference from signal emission and reception. Infrared sensors work in much the same way, except they use infrared signals that are less prone to interception.
- DJI has been known to combine different obstacle avoidance technologies in their drones. For instance, the omnidirectional obstacle avoidance of the Mavic 2 uses infrared sensors at the upward and downward directions while all the forward, backward, and lateral sensors use stereoscopic technology.
- Yuneec drones have famously used Intel RealSense technology for obstacle avoidance. This technology uses a dedicated camera to construct a 3D model of its surroundings using a stereoscopic technique. RealSense can remember the models it has constructed, enhancing its capability to avoid obstacles should it return to a location that it has already modeled.

DISTANCE SENSORS

- An ultrasonic sensor is an electronic device that measures the distance of a target object by emitting ultrasonic sound waves, and converts the reflected sound into an electrical signal. Ultrasonic waves travel faster than the speed of audible sound (i.e. the sound that humans can hear).



- Ultrasonic distance sensors measure the distance to, or presence of target objects by sending a pulsed ultrasound wave at the object and then measuring the time for the sound echo to return. Knowing the speed of sound, the sensor can determine the distance of the target object.

- As illustrated in Figure 3.10, the ultrasonic distance sensor regularly emits a barely audible click. It does this by briefly supplying a high voltage either to a piezoelectric crystal, or to the magnetic fields of ferromagnetic materials. In the first case, the crystal bends and sends out a sound wave. A timer within the sensor keeps track of exactly how long it takes the sound wave to bounce off a target and return. This delay is then converted into a voltage that corresponds to the distance from the sensed object.

- In the second case, the physical response of a ferromagnetic material in a magnetic field is due to the presence of magnetic moments. Interaction of an external magnetic field with the domains causes a magnetostrictive effect. Controlling the ordering of the domains through alloy selection, thermal annealing, cold working, and magnetic field strength can optimize this effect. The magnetostrictive effects are produced by the use of magnetostrictive bars to control high-frequency oscillators and to produce ultrasonic waves in gases, liquids, and solids.

- Applying converters based on the reversible piezoelectric effect makes one-head systems possible, where the converter serves both as transmitter and as receiver. The transceivers work by transmitting a short-burst ultrasonic packet. An internal clock starts simultaneously, measuring propagation time. The clock stops when the sound packet is received back at the sensor. The time elapsed between transmitting the packet and receiving the echo forms the basis for calculating distance. Complete control of the process is realized by an integrated microcontroller, which allows excellent output linearity.

- The ultrasonic distance sensor can be operated in two different modes. The first mode, referred to as continuous (or analog) mode, involves the sensor continuously sending out sound waves at a rate determined by the manufacturer. The second mode, called clock (or digital) mode, involves the sensor sending out signals at a rate determined by the user. This rate can be several signals per second with the use of a timing device, or it can be triggered intermittently by an event such as the press of a button.

- The major benefit of ultrasonic distance sensors is their ability to measure difficult targets; solids, liquids, powders, and even transparent and highly reflective materials that would cause problems for optical sensors. In addition, analog output ultrasonic sensors offer comparatively long ranges, in many cases > 3 m. They can also be very small – some tubular models are only 12 mm in diameter, and 15 mm × 20 mm × 49 mm square-bodied versions are available for limited-space applications.

-

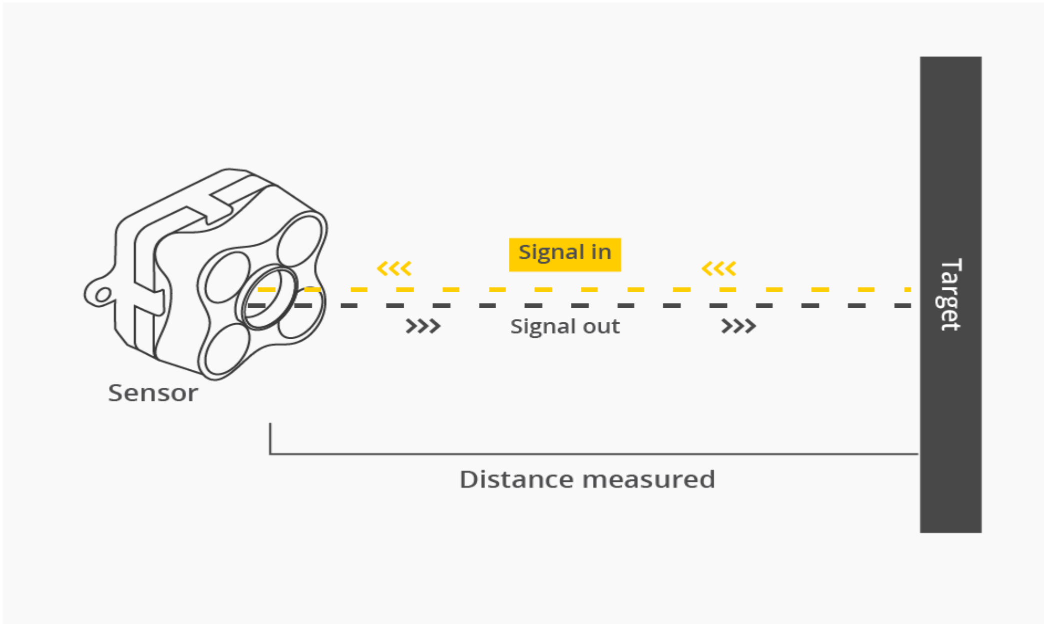
TIME OF FLIGHT SENSORS

- A ToF camera sensor can be used to measure distance and volume, as well as for object scanning, indoor navigation, obstacle avoidance, gesture recognition, object tracking, and reactive altimeters. Data from the sensor can also help with 3D imaging and improving augmented reality (AR) experiences.
- The Time-of-Flight principle (ToF) is a method for measuring the distance between a sensor and an object, based on the time difference between the emission of a signal and its return to the sensor, after being reflected by an object. Various types of signals (also called carriers) can be used with the Time-of-Flight principle, the most common being sound and light.

- Tera Ranger sensors use light as their carrier because it is uniquely able to combine higher speed, longer range, lower weight, and eye-safety. By using infrared light, we can ensure less signal disturbance and easier distinction from natural ambient light, resulting in the highest performing distance sensors for their given size and weight.

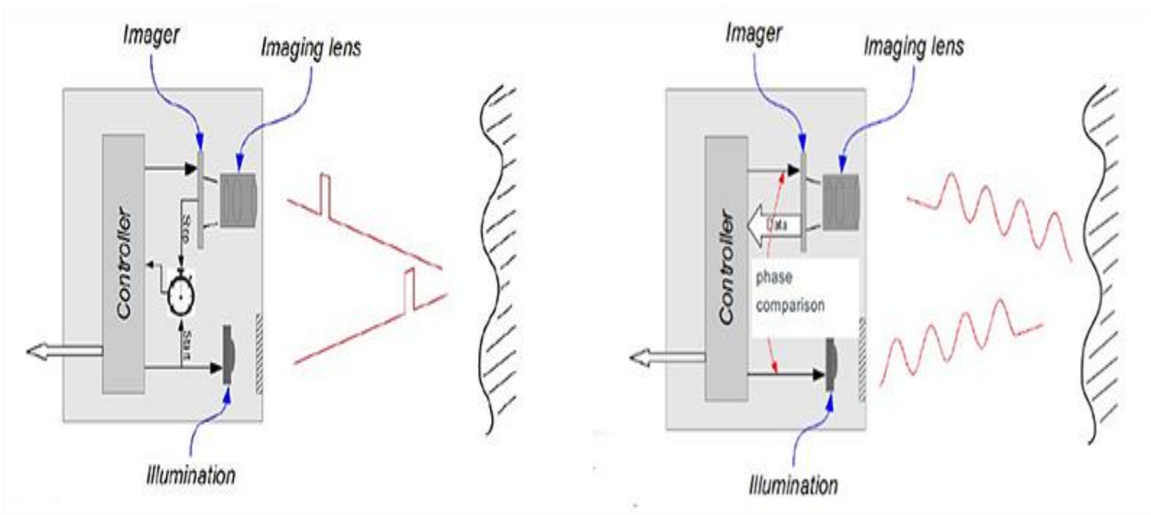
OPTICAL TOF

For range-finding, ToF is very powerful when emitting light rather than sound. Compared to ultrasound, it provides far greater range, faster readings, and greater accuracy whilst still maintaining small size, low weight and low power consumption characteristics.



PRINCIPLE

- All-Time-of-Flight (ToF) sensors measure distances using the time that it takes for photons to travel between two points, from the sensor's emitter to a target and then back to the sensor's receiver. Indirect and direct ToF both offer specific advantages in specific contexts. Both can simultaneously measure intensity and distance for each pixel in a scene. Direct ToF sensors send out short pulses of light that last just a few nanoseconds and then measure the time it takes for some of the emitted light to come back. Indirect ToF sensors send out continuous, modulated light and measure the phase of the reflected light to calculate the distance to an object.



THERMAL SENSORS

- Temperature sensors detect a change in a physical parameter such as resistance or output voltage that corresponds to a temperature change. There are two basic types of temperature sensing: Contact temperature sensing requires the sensor to be in direct physical contact with the media or object being sensed.
- They are devices to measure temperature readings through electrical signals. The sensor is made up of two metals, which generate electrical voltage or resistance once it notices a change in temperature. ... Temperature is the most common physical measurement type in industrial applications.
- Temperature_sensors are employed for a broad variety of practical purposes across many industries throughout the world. Essentially, these sensors provide input to a system in order to either approximately or accurately determine the temperature of a particular object or environment.
- There are two primary types of temperature sensors in use today:

CONTACT TEMPERATURE SENSORS

- These types need to touch the object that they're measuring the temperature of, whether it's a solid, liquid, or gas. They actually just measure their own temperature, but we infer that the temperature of whatever it's in contact with is in thermal equilibrium (i.e. are the same temperature).
- Common types of contact temperatures sensors include thermocouples, RTD's, thermistors, thermostats, and semiconductor temperature sensors. They should be used when you are able to make good thermal contact between the device and what you're measuring. It's also easier to attain continuous monitoring and data collection with contact thermometers.

NON-CONTACT TEMPERATURE SENSORS

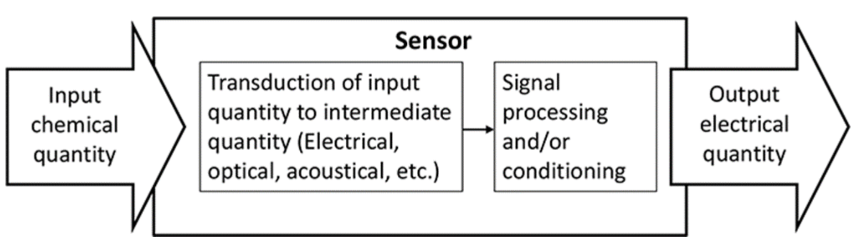
- These determine temperatures from a distance, by measuring the thermal radiation emitted by an object or heat source. The applications for these are often in high temperatures or hazardous environments where you need to maintain a safe distance away from a particular body.
- Thermal_imaging and infrared_sensors are the most common type of non-contact temperature sensors, and are used in the following circumstances: when the target object is moving (such as on a conveyor belt or within moving machinery), if it's a great distance away if there's a dangerous surrounding environment (such as high voltages) or at extremely high temperatures where a contact sensor would not function appropriately.

- Thermal, or infrared, sensors enable drone operators to see invisible temperature data. Deployed on drones, thermographic sensors make it possible to collect radiometric data over wide areas and hard-to-reach places. Recent advances, such as built-in visual imaging, heat analytics, and infrared intelligence, have made thermal analysis accessible and cost-effective for a wide range of applications, such as:
- Scanning building electrical equipment, such as breaker panels, fuses, bolted connections, and switchgear
- Identifying overheating equipment in electrical plants, substations, and towers
- Pinpointing the source of water leaks and energy inefficiencies in building roofs and facades
- Investigating the impact, a fire is having a building's structural integrity
- Measuring crop foliage temperature to identify heat stress, water use, and plant metabolism
- Surveillance and security
- Search and rescue (SAR)

CHEMICAL SENSORS

- Chemical sensors are measurement devices that convert a chemical or physical property of a specific analyte into a measurable signal, whose magnitude is normally proportional to the concentration of the analyte.

The chemical sensor is an analyzer that responds to a particular analyte in a selective and reversible way and transforms input chemical quantity, ranging from the concentration of a specific sample component to a total composition analysis, into an analytically electrical signal, as depicted in Figure 1. The chemical information may originate from a chemical reaction by a biomaterial, chemical compound, or a combination of both attached onto the surface of a physical transducer toward the analyte. The chemical sensor subject is an emerging discipline formed by the multidisciplinary study among chemistry, biology, electricity, optics, mechanics, acoustics, thermology, semiconductor technology, microelectronics technology, and membrane technology.



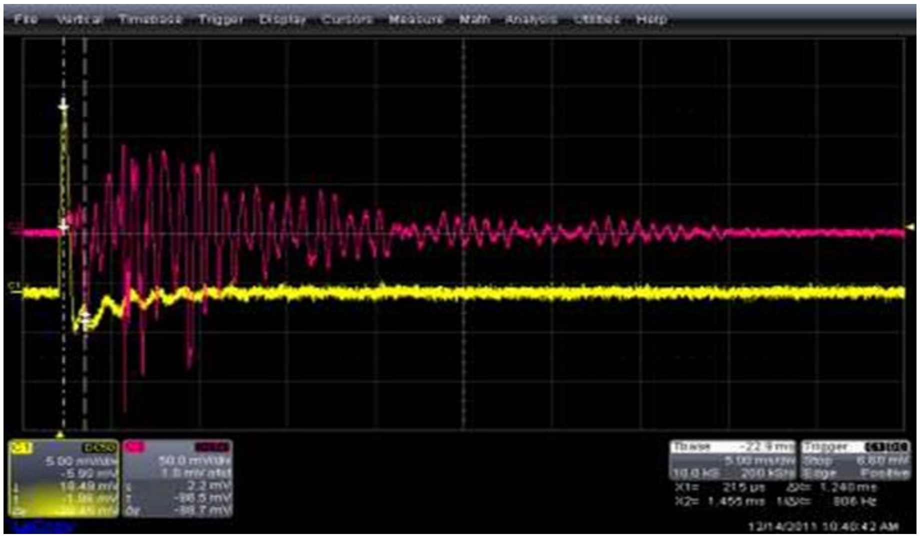
According to the working principle, the chemical sensor can be classified into many types such as optical, electrochemical, mass, magnetic, and thermal. The optical chemical sensor is based on the changes in optical phenomena analysis arising from the interaction between the analyte and the receiver. The electrochemical sensor utilizes electrochemical effect among the analytes and featured electrodes. The working principle of the mass sensor depends on the quality change induced by the mass loading from the adsorption toward the analyte by the special modification of sensor surface. The magnetic device is based on the magnetic properties in analyte adsorption, whereas the thermal sensor utilizes the thermal effect generated by the specific chemical reaction or adsorption process.

A chemical sensor, in form is a self-contained device, can be attached to a drone in order to provide information about the chemical composition of any environment. With the change in the chemical composition of the environment, analyte molecules inside the device interact selectively with the molecules present on the environment. A transducer can be connected to this device which would send signals when a change occurs.

Fig. CHEMICAL AND THERMAL SENSORS

SENSOR TESTING:

In Figure 1 channel 1 of a digital oscilloscope captures the output of a sensor (a force transducer) which detects an impulse from a short (about 1 msec) sharp impact. Channel 2 shows the output of another sensor (an accelerometer) located about 1 meter from the original point of impact. At this point, the original short, sharp impulse has been converted to a lower amplitude but much longer lasting ringing. Using just visual tools, an engineer can place cursors on the two waveforms to measure the time latency between the original impact and the first substantial peak of the transmitted ringing.



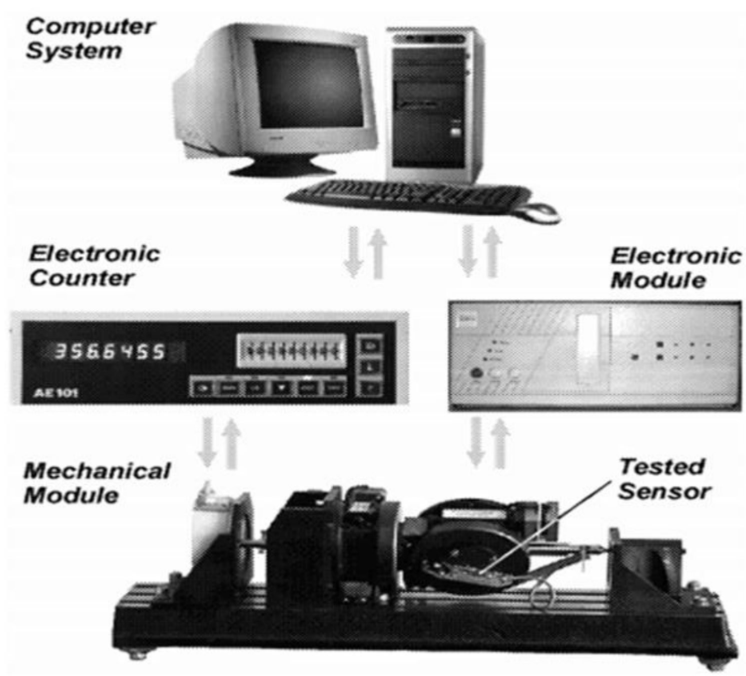
Typically, the first thing an engineer wants to do when testing a sensor or actor is to look at the electrical signal to see if its shape is correct and that it meets some basic criteria. The fundamental oscilloscope properties that come into play are the bandwidth, sampling rate, memory length and display.

Test equipment, Performance testing of sensors:

The test rig consists of four modules – two universal and two custom-designed. The universal modules are: – a PC with an analog-digital data acquisition card (e.g. Advantech PCL 818L), operating under Windows system, and running a driver software that controls the test rig (developed in Visual Basic environment), – an electronic counter AE 101 coupled with an incremental angle transducer IDW 2/16384 manufactured by Jenoptik Carl Zeiss JENA, attached to the mechanical module. The custom modules are: – a mechanical structure consisting of two rotary tables powered by stepper motors, a bed made of cast iron, mechanical elements integrating the rotary tables, a special aligning holder of the tested sensor, a supporting footstock, and spirit levels (for leveling the bed), – an electronic module containing drivers of the stepper motors, a logic circuit controlling the drivers, and transducers coupled with position sensors in the rotary tables.

The test rig operates in the following way. The driver software communicates with the electronic module via the analog-digital data acquisition card. Next, the electronic module actuates the mechanical structure (along with the tested sensor), applying a desired angular position of the rotary tables. Then, the analog output signals from the tested sensor are collected by the analog-digital data acquisition card and recorded in a file against the corresponding real angular positions of the rotary tables (resulting from calculated positions of the tables and additionally indicated by the incremental angle transducer). Comparison of these two sets of data in a further processing is one of the ways of evaluating accuracy of the tested sensor.

The above sequence of operations may be repeated automatically within a chosen angular range with a desired step; thus, the full measurement range of pitch and roll can be covered. The mechanical module of the test rig has been designed in such a way that its geometrical configuration allows the tilt to be applied as its two components: pitch and roll, as discussed in section 2. It also makes it possible to apply any angular position of the tested sensor over the steregon with a satisfactory accuracy.



The main members of this module, presented in Fig. 5, are two rotary tables 1 and 2 powered by stepper motors driving their top through a worm gear. Resolution of the tables is of 1.2 (0.02◦). They are equipped with special optical sensors indicating initial position of the top. The stationary table 1 applies the pitch angle α while the moveable table 2 applies the roll angle γ. The tested sensor 3 is fixed to the moveable table by means of an aligning holder. The stationary table 1 is additionally connected with the incremental angle transducer, thus inaccuracies of its components do not influence accuracy of determining value of the applied angular position, since it is dependent only on the accuracy of the transducer and the employed coupling. The resultant higher accuracy is necessary in some cases, especially while testing precise tilt sensors, usually with a small measuring range (operating as leveling devices), and thus featuring high absolute accuracy.

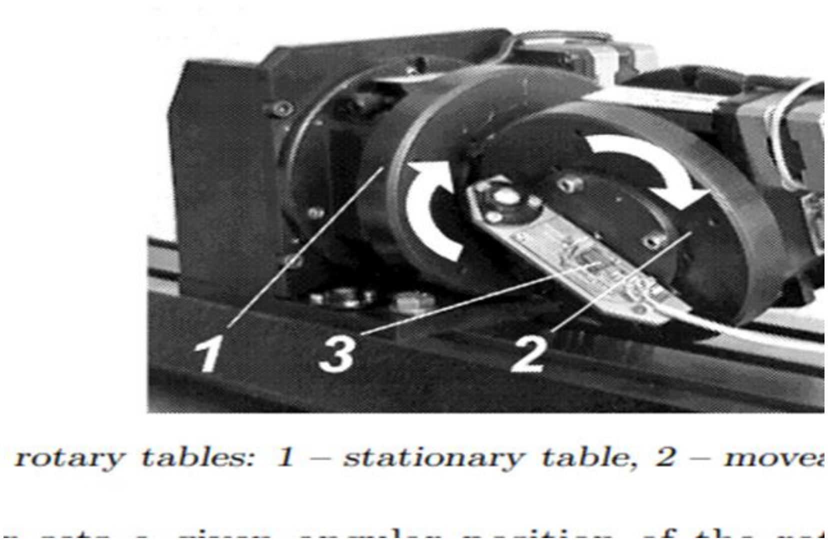


Fig.5: The rotary tables: 1 – stationary table, 2 – moveable table, 3 – tested sensor

The computer sets a given angular position of the rotary tables in two steps. First, the stationary table is activated, and it rotates along with the movable table, which is not powered. Then, the movable table is activated, while the angular position of the stationary table is kept. As the stationary table is connected with the angle transducer (see Fig. 4) by means of a precise coupling, it is possible to determine position of the table with a high accuracy of ca. 1.5 seconds' arc. The pitch angle is applied by means of the stationary table (its rotation axis is always horizontal), while the roll angle is applied by means of the movable table (fixed to the first table; its rotation axis gets tilted as pitch is applied). Because deflection of the rotary shaft of the stationary table caused by the weight of the moveable table and the integrating elements was of few minutes arc, the test rig has been equipped with a special footstock (see Fig. 4) supporting the rotation axis of the stationary table.

The accuracy of the test rig refers to two issues: – accuracy of applying angular position (pitch and roll) of the tested sensor, – accuracy of reading the output analog voltages of the tested sensor.

SENSOR TESTING – TEST PHILOSOPHIES AND METHODOLOGIES:

 Inertial sensors measure object’s orientation and position in space

 Gyroscopes (gyros), accelerometers and magnetometers are considered inertial sensors

 Typically, inertial sensor parameters can be divided into two groups: dynamic
and static.

 Static measurements include:

 Noise and zero input offset information

 Dynamic tests include

 Scale factor error and linearity, cross-axis sensitivity, misalignment, full
scale range and bandwidth testing

 Most of these parameters can be tested over temperature to identify any
temperature sensitivity.

So which tests are appropriate for your sensor:

– It all depends on the application!

 In AHRS systems at least zero rate bias (over temperature) and sensitivity/nonlinearity
should be tested → they are the biggest error contributors to the final orientation angles

 Noise and Allan variance measurements should be performed to identify “goodness” of the sensors, impact of noise on error budget, and long-term tendency of the sensor.

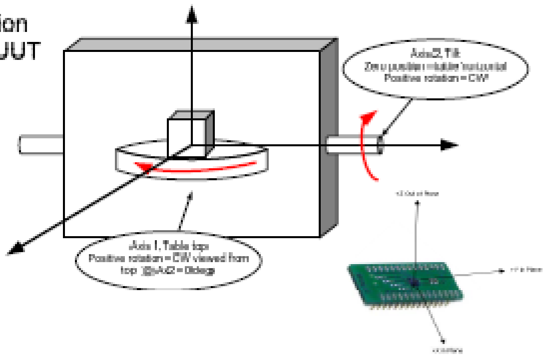
 For high-speed rotation/high dynamic applications, bandwidth and full-scale range are important sensor’s ability to track the motion and identify the point at which the saturation of the output occurs.

TEST METHODOLOGY:

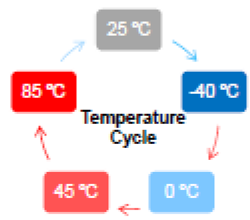
- Several hardware platforms that can be used to test both the dynamic and static properties of MEMs sensors. It is possible to use 1-, 2- or 3-axis rate table test systems. Since the market trend is towards full 6 (9) degrees of freedom IMU, a 2-axis rate table provides enough flexibility to perform almost all test groups on all axes in a reasonable time frame. This section discusses test principles applied to such IMUs.

2-AXIS RATE TABLE
ACUTRONIC AC216

Rate table motion orientation and UUT positioning



Test Methodology Static Tests



- Zero Input Bias
  - For gyros, the zero input offset tests can be done with sensitive axis in any orientation and no rotational motion of the rate table. The data can be collected over a 3 minute period at each chosen temperature. At least 5 temperature points should be used, both extremes, ambient and two more temperature in between the 3 others.
  - For accelerometers, the sensitive axis has to be placed parallel to Earth's gravity thus providing a zero G input. As such, the motion platform would have to be repositioned at least once to align the 3rd IMU axis parallel to the Earth's gravity. The same temperature profile can be used as for gyros.
  - Both accelerometers and gyros can be tested at the same time during the static tests with the exception being one axis of an accelerometer that would need additional sampling time after proper alignment.

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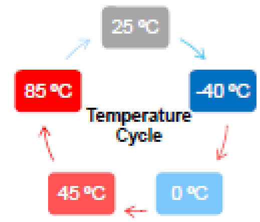
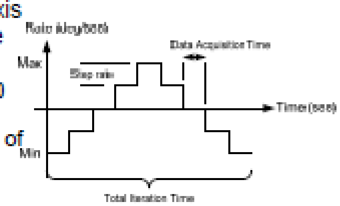
Test Methodology Dynamic Tests



- The dynamic tests typically consist of non-linearity, sensitivity, full scale range and bandwidth of a sensitive axis. In an IMU, it is also common to find factors such as cross axis sensitivity between sensitive axes which shows mechanical misalignment.
- All of the above mentioned tests should also be performed over temperature to expose any temperature sensitivity.
- Conveniently, the results for each test parameter can be obtained from a common motion profile performed on a 2 axis rate and positing table as long as all axis are sampled in the IMU.
  - For gyroscopes, the motion profile involves performing 5 to 10 rotation at a given rate going from negative maximum rate to positive maximum rate with a preset increment of some value of deg/s.
  - For accelerometers, the motion profile is even simpler and consists of a series of position indexes in the field of Earth's gravity for each sensitive axis. As little as 4 index positions can be used per sensitive axis to adequately characterize the test parameters for that axis.



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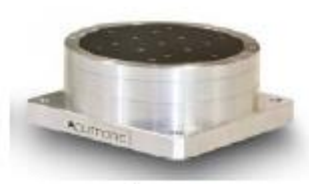
Test Methodology Dynamic Tests

- Another parameter that usually takes an exception to using a rate table as a test platform all together is bandwidth
- Since most accelerometers and gyros have higher bandwidth (in 100s of Hz) specification, the best tool for this job would be a linear and an angular vibration platform for accelerometers and gyroscopes respectively



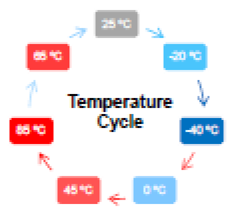
Test Methodology Dynamic Tests

- Bandwidth
  - The test profile for each type of inertial sensor consists of a logarithmic or linear frequency sweep from 5 to 2000 Hz on each motion platform while recording the IMU output at maximum sampling rate possible (as close to sensor ODR as possible).

Test Procedure

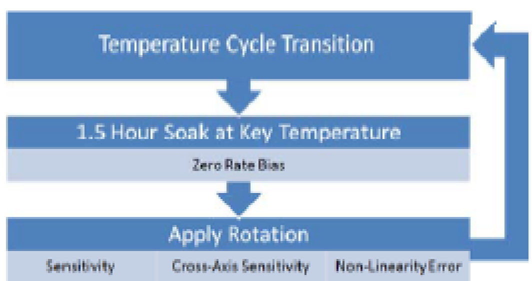
- The testing is divided into three sessions:
  - First Session:

1. Data is recorded during all stages of the test at 50 Hz via I2C.
   a) All devices are mounted on a rate table inside a temperature chamber. Starting at 25 degrees C, the temperature is controlled at +/-1 °C/min. Data is recorded during the transition periods.



   b) The temperature cycles negative and then positive stopping at the following key temperatures in Celsius: 25, -20, -40, 0, 45, 85, 65, 25. At each stable temperature, a soak of 1.5 hours with no rotational input is recorded.

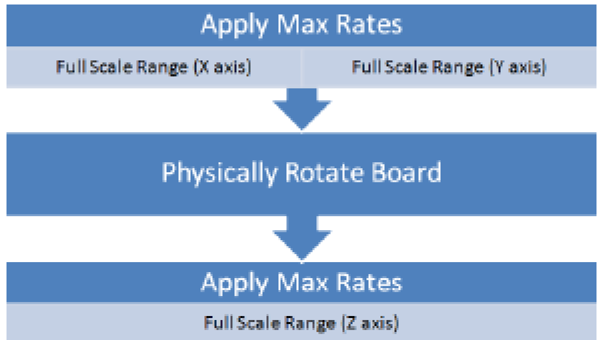
   b) After each soak, before progressing to the next temperature step, the following input rates are applied to the devices for 5 revolutions per rate: -2000 to 2000 deg/s (at +/-100 deg/s intervals) for Z axis. -500 to 500 deg/s (at +/- 100 deg/s intervals) for X and Y axes.



Test Procedure

- Second session:

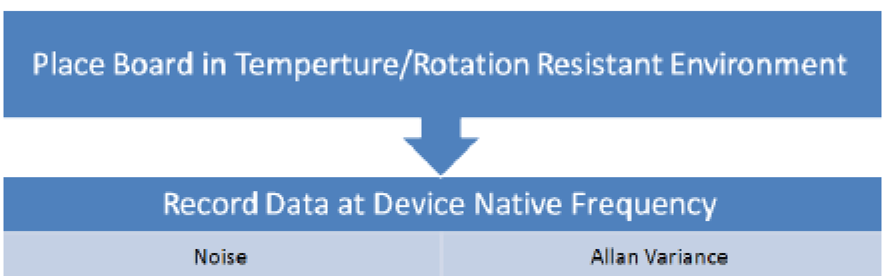
2. Data is recorded during each segment of the test at 50 Hz via I2C.
   a) The devices are physically rotated to test each device axis at the full sc +/-2000 deg/s. Data is recorded for 2.5 minutes at each extreme.



Test Procedure

- Third session:

3. Data is recorded at device native frequencies of 1 kHz via I2C.
   a) Devices are placed in a temperature and rotational resistant environment. Data is recorded for 90 minutes with no input rotation.



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3. Neeraj Kumar Singh, Porselvan Muthukrishnan, Satyanarayana Sanpini, "Industrial System Engineering for Drones: A Guide with Best Practices for Designing", Apress, 2019
4. Felipe Gonzalez Toro, Antonios Tsourdos, "UAV or Drones for Remote Sensing Applications"2018.
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SCHOOL OF ELECTRICAL AND ELECTRONICS

DEPARTMENT OF ELECTRONICS AND COMMUNICATION ENGINEERING

UNIT – 4 – DRONE ELECTRONICS – SECA4003

UNIT 4   GLIDING DRONES

- Glider, Lift, Drag, Airfoil and its type
- Incident and decalage angle
- Three axis motions (roll, pitch, and yaw)
- Thrust, Aspect ratio and glide ratio
- Glide or dive and descent, gliding angle
- Climb, Center of pressure, Pitching moment
- Load factor, Angle of attack, Build our own glider drone.

GLIDER:

A **glider** is a fixed-wing aircraft that is supported in flight by the dynamic reaction of the air against its lifting surfaces, and whose free flight does not depend on an engine.[1] Most gliders do not have an engine, although motor-gliders have small engines for extending their flight when necessary by sustaining the altitude (normally a sailplane relies on rising air to maintain altitude) with some being powerful enough to take off self-launch.

There are a wide variety of types differing in the construction of their wings, aerodynamic efficiency, location of the pilot, controls and intended purpose. Most exploit meteorological phenomena to maintain or gain height. Gliders are principally used for the air sports of gliding, hang gliding and paragliding. However, some spacecrafts have been designed to descend as gliders and in the past military gliders have been used in warfare. Some simple and familiar types of gliders are toys such as paper planes and balsa wood gliders.

Military Glider

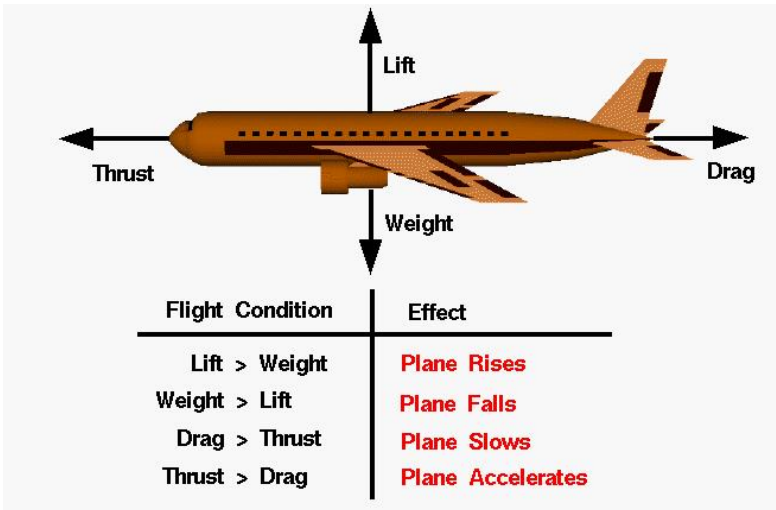
Rocket Glider

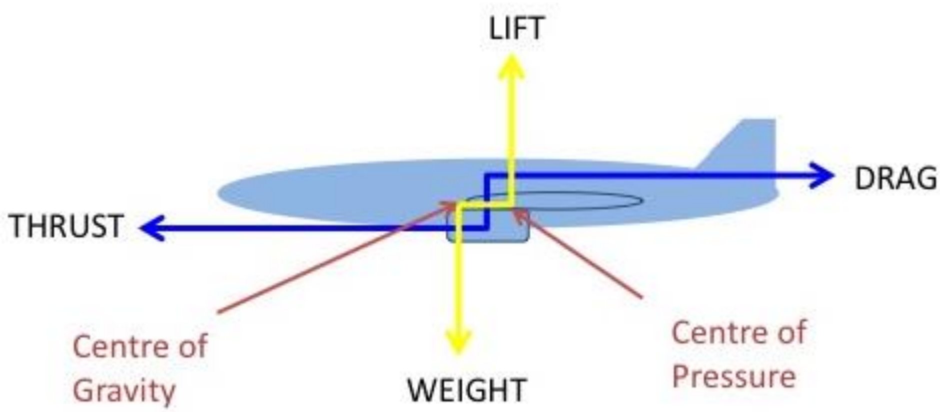
LIFT AND DRAG:

Lift is defined as the component of the aerodynamic force that is perpendicular to the flow direction, and **drag is the component that is parallel to the flow direction**.

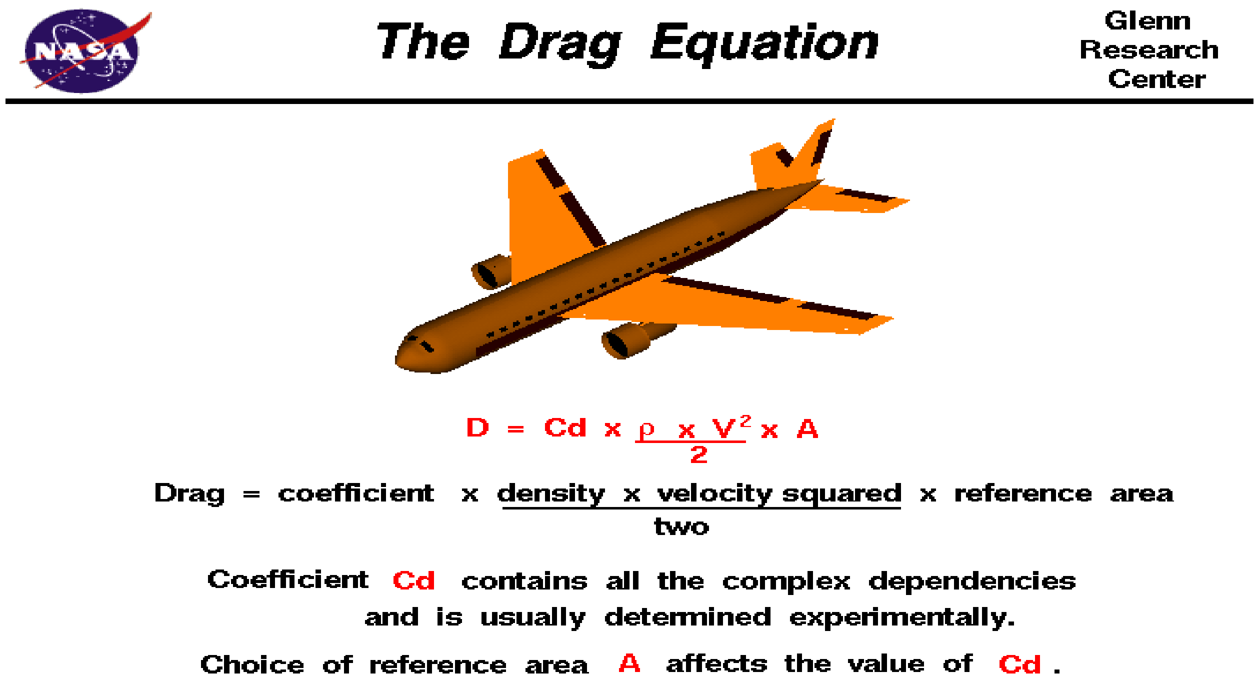
But lift and drag can only arise as air moves past an object. **Lift pushes the object upward**, and drag, a type of air resistance, slows it down. ... An airfoil also creates lift by "bending" or redirecting airflow. Oncoming air follows the curved shape of the foil, shifting downward as it moves past.

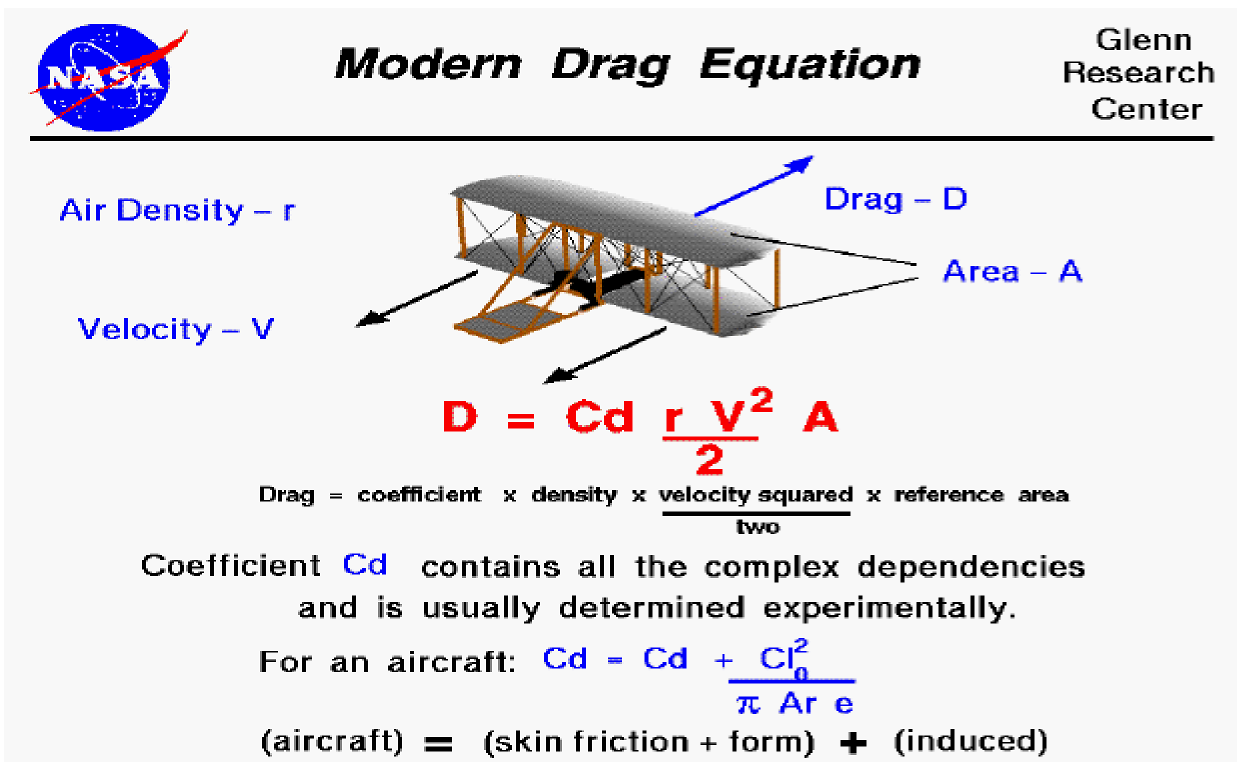
The lift to drag ratio (L/D) is the amount of lift generated by a wing or airfoil compared to its drag. The lift/drag ratio is used to express the relation between lift and drag and is determined by **dividing the lift coefficient by the drag coefficient, CL/CD**.





The drag equation states that drag D is **equal to the drag coefficient Cd times the density r times half of the velocity V squared times the reference area A**. For given air conditions, shape, and inclination of the object, we must determine a value for Cd to determine drag.

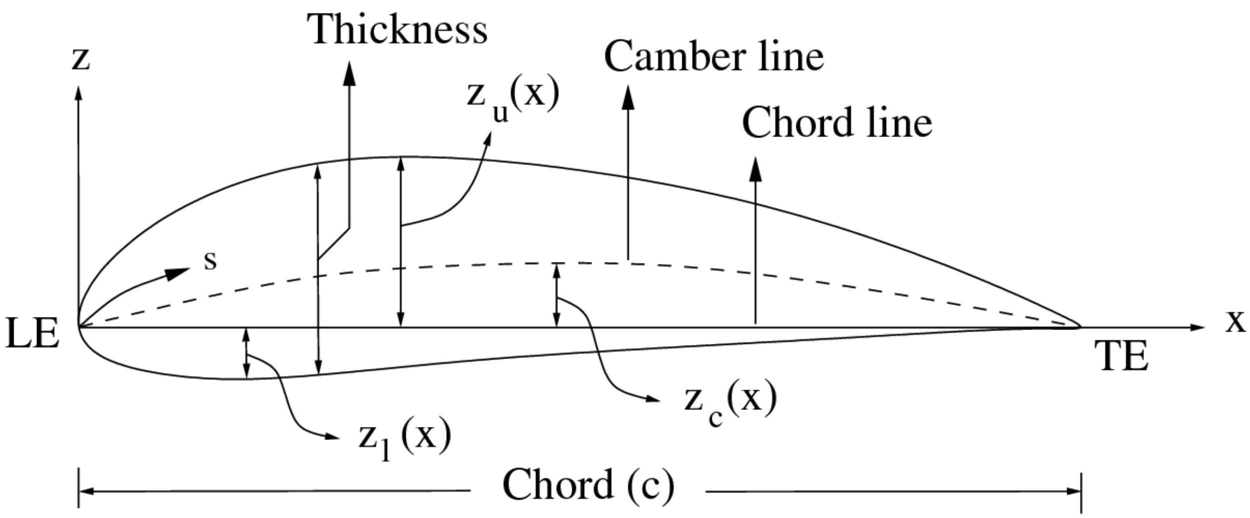




Airfoil and its Type:

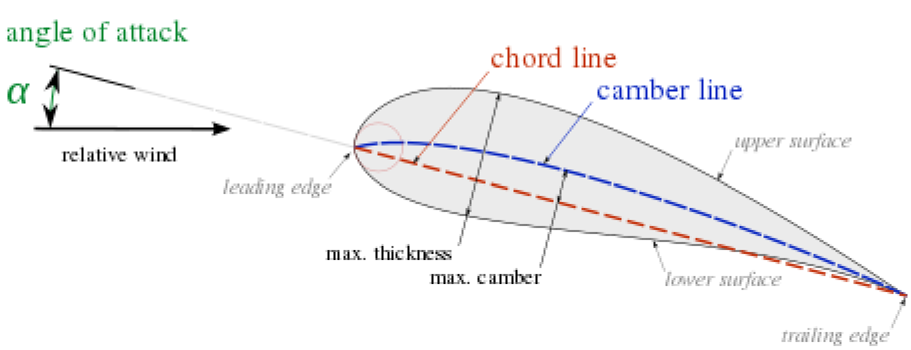
Airfoil, also spelled Aerofoil, shaped surface, such as an airplane wing, tail, or propeller blade, that **produces lift and drag when moved through the air**. An airfoil produces a lifting force that acts at right angles to the airstream and a dragging force that acts in the same direction as the airstream.

Thin airfoil theory is **a straightforward hypothesis of airfoils that relates angle of attack to lift for an incompressible and inviscid flow past an airfoil**. ... Thin airfoil theory is a straightforward hypothesis of airfoils that relates angle of attack to lift for an incompressible and inviscid flow past an airfoil.



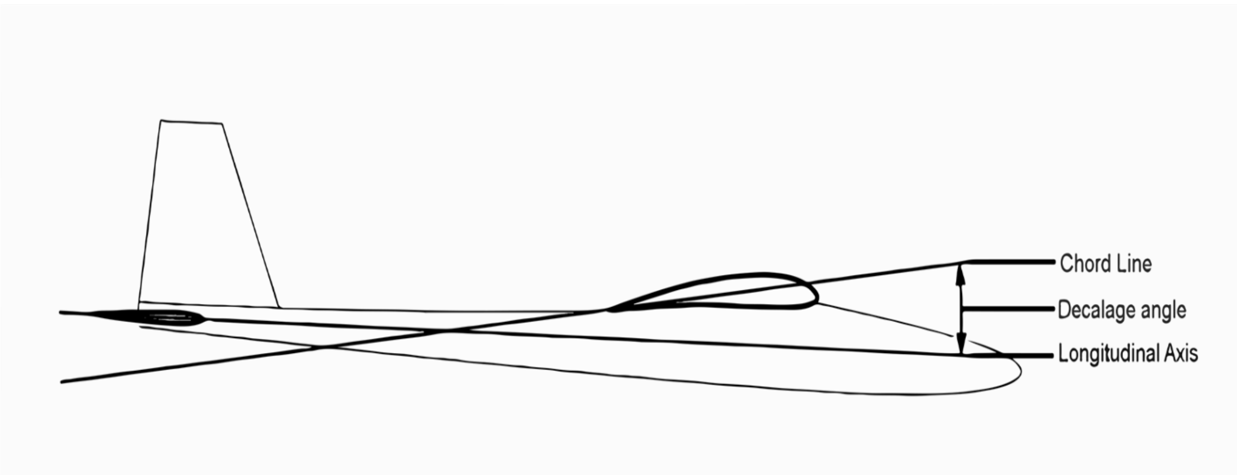
- TYPES OF AIRFOIL:

- Symmetrical aerofoil: This has identical upper and lower surfaces such that the chord line and mean camber line are the same producing no life at zero AOA. ...
- Non-symmetrical aerofoil: It is also known as a cambered aerofoil.



- INCIDENT AND DECALAGE ANGLE:

The incident angle is **the angle between the chord line and the longitudinal axis**. The decalage angle is the angle difference between the upper and lower wings of the glider.

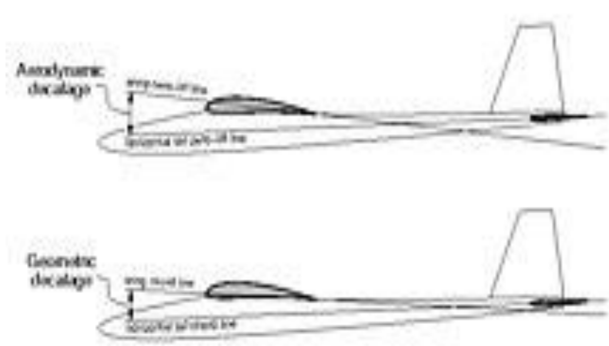


Decalage on a fixed-wing aircraft is the angle difference between the upper and lower wings of a biplane, i.e. the acute angle contained between the chords of the wings in question.

Decalage is said to be positive when the upper wing has a higher angle of incidence than the lower wing, and negative when the lower wing's incidence is greater than that of the upper wing. Positive decalage results in greater lift from the upper wing than the lower wing, the difference increasing with the amount of decalage.[1]

In a survey of representative biplanes, real-life design decalage is typically zero, with both wings having equal incidence. A notable exception is the Stearman PT-17, which has 4° of incidence in the lower wing, and 3° in the upper wing. Considered from an aerodynamic perspective, it is desirable to have the forward-most wing stall first, which will induce a pitch-down moment, aiding in stall recovery.[2] Biplane designers may use incidence to control stalling behavior, but may also use airfoil selection or other means to accomplish correct behavior.

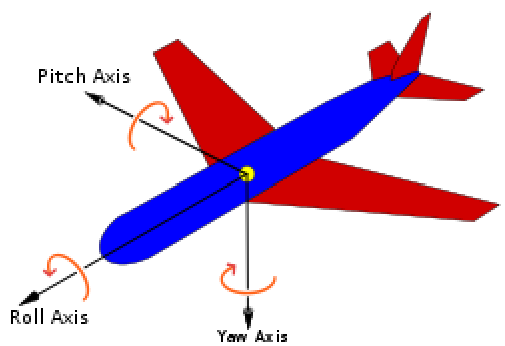
Decalage angle can also refer to the difference in angle of the chord line of the wing and the chord line of the horizontal stabilizer. This is different from the angle of incidence, which refers to the angle of the wing chord to the longitudinal axis of the fuselage, without reference to the horizontal stabilizer.



- Three axis motions (roll, pitch, and yaw)

An aircraft in flight is free to rotate in three dimensions: *yaw*, nose left or right about an axis running up and down; *pitch*, nose up or down about an axis running from wing to wing; and *roll*, rotation about an axis running from nose to tail. The axes are alternatively designated as *vertical*, *transverse*, and *longitudinal* respectively. These axes move with the vehicle and rotate relative to the Earth along with the craft. These definitions were analogously applied to spacecraft when the first manned spacecraft were designed in the late 1950s.

These rotations are produced by torques (or moments) about the principal axes. On an aircraft, these are intentionally produced by means of moving control surfaces, which vary the distribution of the net aerodynamic force about the vehicle's center of gravity. Elevators (moving flaps on the horizontal tail) produce pitch, a rudder on the vertical tail produces yaw, and ailerons (flaps on the wings that move in opposing directions) produce roll. On a spacecraft, the moments are usually produced by a reaction control system consisting of small rocket thrusters used to apply asymmetrical thrust on the vehicle.



- Normal axis, or yaw axis — an axis drawn from top to bottom, and perpendicular to the other two axes, parallel to the fuselage station.
- Transverse axis, lateral axis, or pitch axis — an axis running from the pilot's left to right in piloted aircraft, and parallel to the wings of a winged aircraft, parallel to the buttock line.
- Longitudinal axis, or roll axis — an axis drawn through the body of the vehicle from tail to nose in the normal direction of flight, or the direction the pilot faces, similar to a ship's waterline.

Normally, these axes are represented by the letters X, Y and Z in order to compare them with some reference frame, usually named x, y, z. Normally, this is made in such a way that the X is used for the longitudinal axis, but there are other possibilities to do it.

Vertical axis (yaw)

The **yaw axis** has its origin at the center of gravity and is directed towards the bottom of the aircraft, perpendicular to the wings and to the fuselage reference line. Motion about this axis is called **yaw**. A positive yawing motion moves the nose of the aircraft to the right. The rudder is the primary control of yaw.

The term *yaw* was originally applied in sailing, and referred to the motion of an unsteady ship rotating about its vertical axis. Its etymology is uncertain.

Transverse axis (pitch)

The **pitch axis** (also called **transverse** or **lateral axis** has its origin at the center of gravity and is directed to the right, parallel to a line drawn from wingtip to wingtip. Motion about this axis is called **pitch**. A positive pitching motion raises the nose of the aircraft and lowers the tail. The elevators are the primary control of pitch.

Longitudinal axis (roll)

The **roll axis** (or **longitudinal axis**) has its origin at the center of gravity and is directed forward, parallel to the fuselage reference line. Motion about this axis is called **roll**. An angular displacement about this axis is called **bank**. A positive rolling motion lifts the left wing and lowers the right wing. The pilot rolls by increasing the lift on one wing and decreasing it on the other. This changes the bank angle. The ailerons are the primary control of bank. The rudder also has a secondary effect on bank.

- THRUST, ASPECT RATIO AND GLIDE RATIO :

Glide ratio is equal to lift-to-drag one; Lift-to-drag ratio only depends on angle of attack (and aircraft/wing shape or environment properties – which are fixed); Hence, the best glide ratio is achieved only at the given optimal angle of attack, independent of weight.

A high aspect ratio indicates long, narrow wings. A low aspect ratio indicates short, wide wings. Generally, high aspect ratio wings **give slightly more lift and enable sustained, endurance flight**, while low aspect ratio wings are best for swift manoeuvrability.

In aerodynamics, the **lift-to-drag ratio** (or **L/D ratio**) is the amount of lift generated by a wing or vehicle, divided by the aerodynamic drag it creates by moving through air. A greater or more favorable L/D ratio is typically one of the major goals of aircraft design; since a particular aircraft's required lift is set by its weight, delivering that lift with lower drag results directly in better fuel economy in aircraft, climb performance, and glide ratio.

The term is calculated for any particular airspeed by measuring the lift generated, then dividing by the drag at that speed. These vary with speed, so the results are typically plotted on a 2-dimensional graph. In almost all cases the graph forms a U-shape, due to the two main components of drag.

Lift-to-drag ratios can be determined by flight test, by calculation or by testing in a wind tunnel

As the aircraft fuselage and control surfaces will also add drag and possibly some lift, it is fair to consider the L/D of the aircraft as a whole. As it turns out, the glide ratio, which is the ratio of an (unpowered) aircraft's forward motion to its descent, is (when flown at constant speed) numerically equal to the aircraft's L/D. This is especially of interest in the design and operation of high performance sailplanes, which can have glide ratios almost 60 to 1 (60 units of distance forward for each unit of descent) in the best cases, but with 30:1 being considered good performance for general recreational use. Achieving a glider's best L/D in practice requires precise control of airspeed and smooth and restrained operation of the controls to reduce drag from deflected control surfaces. In zero wind conditions, L/D will equal distance traveled divided by altitude lost. Achieving the maximum distance for altitude lost in wind conditions requires further modification of the best airspeed, as does alternating cruising and thermaling. To achieve high speed across country, glider pilots anticipating strong thermals often load their gliders (sailplanes) with water ballast: the increased wing loading means optimum glide ratio at greater airspeed, but at the cost of climbing more slowly in thermals. As noted below, the maximum L/D is not dependent on weight or wing loading, but with greater wing loading the maximum L/D occurs at a faster airspeed. Also, the faster airspeed means the aircraft will fly at greater Reynolds number and this will usually bring about a lower zero-lift drag coefficient.

Mathematically, the maximum lift-to-drag ratio can be estimated as:

$$(L/D)_{\max} = \frac{1}{2}\sqrt{\frac{\pi\varepsilon AR}{C_{D,0}}},$$

[3]

where *AR* is the aspect ratio, the span efficiency factor, a number less than but close to unity for long, straight edged wings, and the zero-lift drag coefficient.

Most importantly, the maximum lift-to-drag ratio is independent of the weight of the aircraft, the area of the wing, or the wing loading.

It can be shown that two main drivers of maximum lift-to-drag ratio for a fixed wing aircraft are wingspan and total wetted area. One method for estimating the zero-lift drag coefficient of an aircraft is the equivalent skin-friction method. For a well designed aircraft, zero-lift drag (or parasite drag) is mostly made up of skin friction drag plus a small percentage of pressure drag caused by flow separation. The method uses the equation:

$$C_{D,0} = C_{\text{fe}} \frac{S_{\text{wet}}}{S_{\text{ref}}},$$
[4]

where is the equivalent skin friction coefficient, is the wetted area and is the wing reference area. The equivalent skin friction coefficient accounts for both separation drag and skin friction drag and is a fairly consistent value for aircraft types of the same class. Substituting this into the equation for maximum lift-to-drag ratio, along

with the equation for aspect ratio ( ), yields the equation:

$$(L/D)_{\max} = \frac{1}{2}\sqrt{\frac{\pi\varepsilon}{C_{\text{fe}}}\frac{b^2}{S_{\text{wet}}}}$$

where *b* is wingspan. The term is known as the wetted aspect ratio. The equation demonstrates the importance of wetted aspect ratio in achieving an aerodynamically efficient design.

Thrust Thrust is the forward force that propels a self-launching glider through the air. Self-launching gliders have engine-driven propellers that provide this thrust. Unpowered gliders have an outside force, such as a towplane, winch, or automobile, to launch the glider. Airborne gliders obtain thrust from conversion of potential energy to kinetic energy.

Thrust-to-weight ratio is a dimensionless ratio of thrust to weight of a rocket, jet engine, propeller engine, or a vehicle propelled by such an engine that is an indicator of the performance of the engine or vehicle.

The instantaneous thrust-to-weight ratio of a vehicle varies continually during operation due to progressive consumption of fuel or propellant and in some cases a gravity gradient. The thrust-to-weight ratio based on initial thrust and weight is often published and used as a figure of merit for quantitative comparison of a vehicle's initial performance.

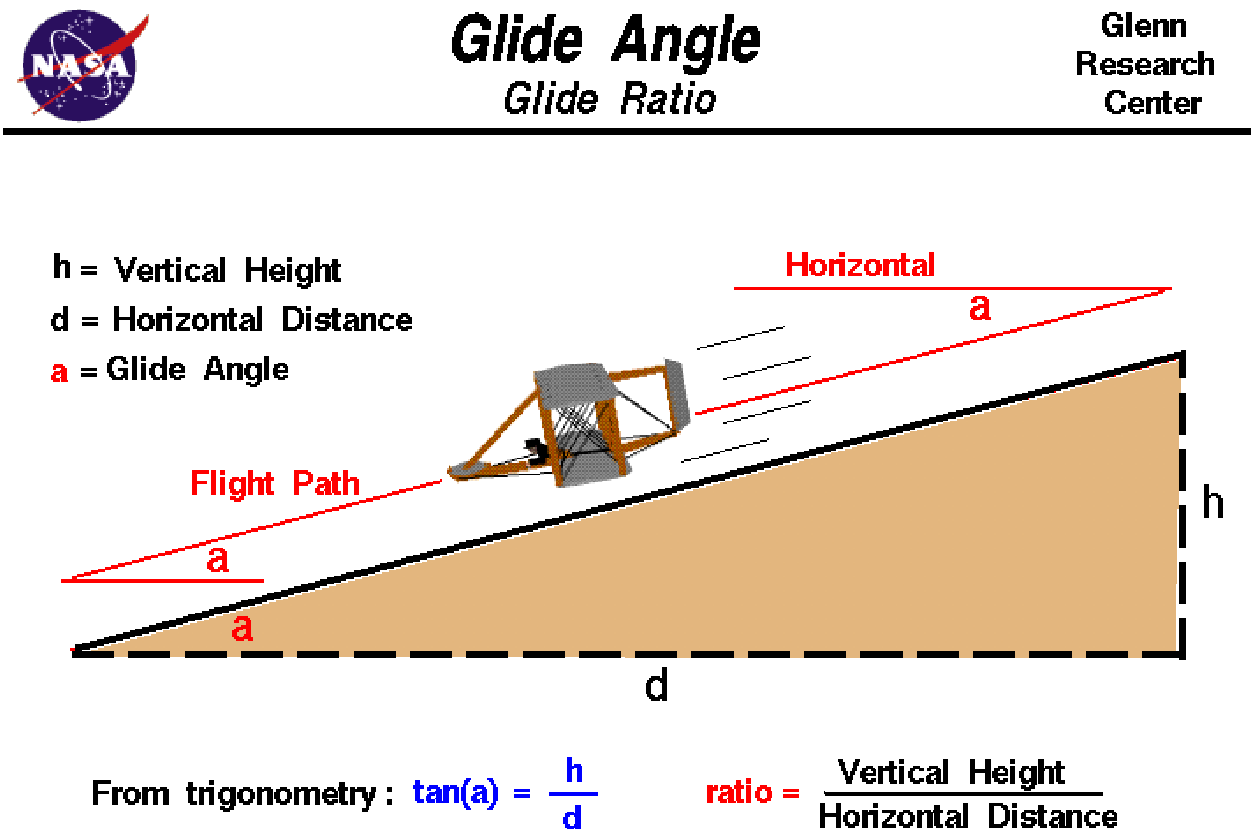
The thrust-to-weight ratio and wing loading are the two most important parameters in determining the performance of an aircraft.[1] For example, the thrust-to-weight ratio of a combat aircraft is a good indicator of the maneuverability of the aircraft.[2]

The thrust-to-weight ratio varies continually during a flight. Thrust varies with throttle setting, airspeed, altitude and air temperature. Weight varies with fuel burn and payload changes. For aircraft, the quoted thrust-to-weight ratio is often the maximum static thrust at sea level divided by the maximum takeoff weight.[3] Aircraft with thrust-to-weight ratio greater than 1:1 can pitch straight up and maintain airspeed until performance decreases at higher altitude.[4]

In cruising flight, the thrust-to-weight ratio of an aircraft is the inverse of the lift-to-drag ratio because thrust is the opposite of drag, and weight is the opposite of lift.[5] A plane can take off even if the thrust is less than its weight: if the lift to drag ratio is greater than 1, the thrust to weight ratio can be less than 1, i.e. less thrust is needed to lift the plane off the ground than the weight of the plane.

$$\left(\frac{T}{W}\right)_{\text{cruise}} = \left(\frac{D}{L}\right)_{\text{cruise}} = \frac{1}{\left(\frac{L}{D}\right)_{\text{cruise}}}$$

- Glide or dive and descent, gliding angle



A glider is a special kind of aircraft that has no engine. Paper airplanes are the simplest aircraft to build and fly, and students can learn the basics of aircraft motion by flying paper airplanes. Toy gliders, made of balsa wood or styrofoam, are an inexpensive way for students to study the basics of aerodynamics, while having fun building and flying the aircraft. **Hang-gliders** are piloted aircraft that are launched by leaping off the side of a hill or by being towed aloft. **Piloted gliders** are launched by ground based catapults, or are towed aloft by a powered aircraft then cut free to glide for hours over many miles. The Wright Brothers perfected the design of the first airplane and gained piloting experience through a series of glider flights from 1900 to 1903. The Space Shuttle flies as a glider during reentry and landing; the rocket engines are used only during liftoff.

If a glider is in a **steady** (constant velocity and no acceleration) descent, it loses altitude as it travels. The glider's flight path is a simple straight line, shown as the inclined red line in the figure. The flight path intersects the ground at an angle **a** called the **glide angle**. If we know the distance flown **d** and the altitude change **h**, we can calculate the glide angle using trigonometry:

$$\tan(a) = h / d$$

where **tan** is the trigonometric tangent function. The ratio of the change in altitude **h** to the change in distance **d** is often called the **glide ratio**.

If the glider is flown at a specified glide angle, the trigonometric equation can be solved to determine how far the glider can fly for a given change in altitude.

$$d = h / \tan(a)$$

Notice that if the glide angle is small, the **tan(a)** is a small number, and the aircraft can fly a long distance for a small change in altitude. Conversely, if the glide is large, the **tan(a)** is a large number, and the aircraft can travel only a short distance for a given change in altitude. We can think of the **glide angle** as a measure of the flying efficiency of the glider. On another page, we will show that the glide angle is inversely related to the lift to drag ratio. The higher the lift to drag ratio, the smaller the glide angle, and the farther an aircraft can fly.

Climbing

To maintain a constant speed and direction, the aeroplane must be in equilibrium, as discussed in the straight and level lesson. We demonstrate the relationships between the four forces in the climb to show that the aeroplane is still in a state of equilibrium when climbing.

There is no requirement to prove anything in a preflight briefing. Statements illustrated with diagrams are sufficient to support the air exercise.

There is a common misconception that in the climb the lift is increased, since if lift must equal weight in level flight, it might appear logical that lift should be increased to climb, but it is not so. Drawing the forces to show that lift is not increased in the climb – but is slightly reduced – should illustrate that the aeroplane is in equilibrium during the climb.

The most important concept the student should grasp, in simple terms, is that in order for an aeroplane to climb, thrust must be equal to drag plus the rearward component of weight (T = D +

RCW). The rate at which the aeroplane will climb depends on how much more power is available. Lots of additional power available will mean a high rate of climb.

Descending

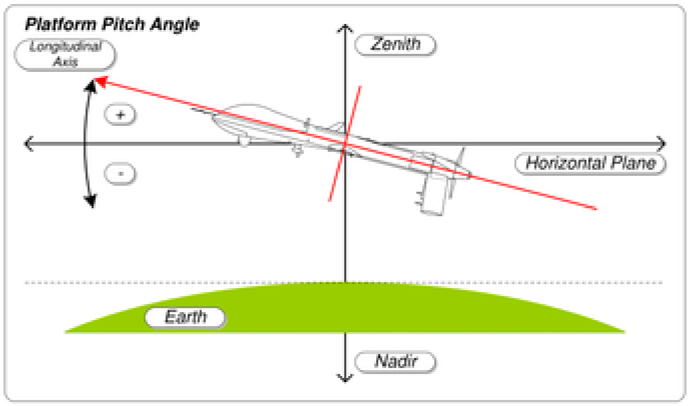
Equilibrium is required for a steady descent. If, while in level flight, the power is removed there will be no force balancing the drag. In order to maintain flying speed the nose must be lowered.

With the nose lowered and weight still acting down towards the centre of the earth, there is now a forward component of weight (FCW) that balances drag. State that for equilibrium there must be a force equal and opposite to weight. This force R is made up of lift and drag. Therefore, the aeroplane is in equilibrium (see Figure 4).

- Climb, Center of pressure, Pitching moment

In aerodynamics, the **pitching moment** on an airfoil is the moment (or torque) produced by the aerodynamic force on the airfoil if that aerodynamic force is considered to be applied, not at the center of pressure, but at the aerodynamic center of the airfoil. The pitching moment on the wing of an airplane is part of the total moment that must be balanced using the lift on the horizontal stabilizer.[1] More generally, a pitching moment is any moment acting on the pitch axis of a moving body.

The lift on an airfoil is a distributed force that can be said to act at a point called the center of pressure. However, as angle of attack changes on a cambered airfoil, there is movement of the center of pressure forward and aft. This makes analysis difficult when attempting to use the concept of the center of pressure. One of the remarkable properties of a cambered airfoil is that, even though the center of pressure moves forward and aft, if the lift is imagined to act at a point called the aerodynamic center, the moment of the lift force changes in proportion to the square of the airspeed. If the moment is divided by the dynamic pressure, the area and chord of the airfoil, the result is known as the pitching moment coefficient. This coefficient changes only a little over the operating range of angle of attack of the airfoil but the change in moment slope against the AOA shown in figure below seems very steep so this should be of change in pitching moment of wing about CG rather than about AC. The combination of the two concepts of *aerodynamic center* and *pitching moment coefficient* make it relatively simple to analyse some of the flight characteristics of an aircraft.[2]



- Load factor, Angle of attack, Build our own glider drone.

Load factor is defined as **the ratio of the average load over a given period to the maximum demand (peak load) occurring in that period**. In other words, the load factor is the ratio of energy consumed in a given period of the times of hours to the peak load which has occurred during that particular period.

The load factor percentage is **derived by dividing the total kilowatt-hours (kWh) consumed in a designated period by the product of the maximum demand in kilowatts (kW) and the number of hours in the period**. In the example below, the monthly kWh consumption is 36,000 and the peak demand is 100 kW.

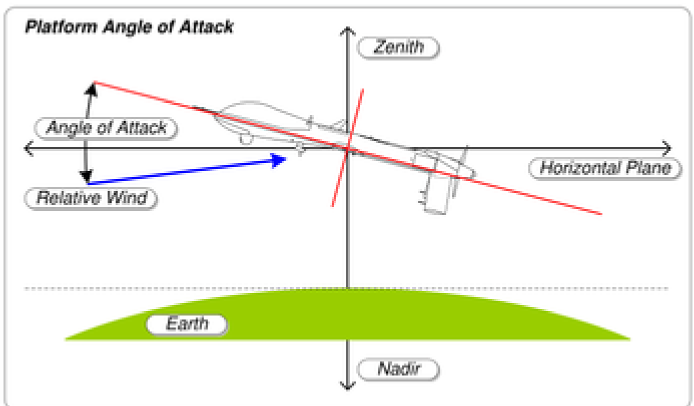
The Load Factor is used **to measure the utilization rate** (means the efficiency of usage of electrical energy). The value of the Load Factor is always less than one. Because the average load will always less than the maximum demand. The high value of Load Factor means the load is using electrical energy more efficiently.

The critical angle of attack is the angle of attack which produces the maximum lift coefficient. This is also called the "stall angle of attack". ... The airspeed at which the aircraft stalls varies with the weight of the aircraft, the load factor, the center of gravity of the aircraft and other factors.

In fluid dynamics, **angle of attack** (**AOA**, **α**, or) is the angle between a reference line on a body (often the chord line of an airfoil) and the vector representing the relative motion between the body and the fluid through which it is moving.[1] Angle of attack is the angle between the body's reference line and the oncoming flow. This article focuses on the most common application, the angle of attack of a wing or airfoil moving through air.

In aerodynamics, angle of attack specifies the angle between the chord line of the wing of a fixed-wing aircraft and the vector representing the relative motion between the aircraft and the atmosphere. Since a wing can have twist, a chord line of the whole wing may not be definable, so an alternate reference line is simply defined. Often, the chord line of the root of the wing is chosen as the reference line. Another choice is to use a horizontal line on the fuselage as the reference line (and also as the longitudinal axis).[2] Some authors[3][4] do not use an arbitrary chord line but use the zero lift axis where, by definition, zero angle of attack corresponds to zero coefficient of lift.

Some British authors have used the term angle of incidence instead of angle of attack.[5] However, this can lead to confusion with the term *riggers' angle of incidence* meaning the angle between the chord of an airfoil and some fixed datum in the airplane.[6]



Build our own glider drone.

Firstly, we need to select a design for the glider. There are a number of designs you can choose. Depending on the wing shape, there are four types of gliders:

- Elliptical wing
- Rectangular wing
- Tapered wing
- Swept-forward wing

In this chapter, we are going to choose the rectangle-shaped wing. The other necessary equipment is as follows:

- Propellers
- ESCs
- Motors
- Battery
- ArduPilot
- Servos
- RC receiver and transmitter
- Some carbon fiber tubes
- Some steel wires
- Some nylon pushrods

TEXT / REFERENCE BOOKS

1. Syed Omar Faruk Towaha, "Building Smart Drones with ESP8266 and Arduino: Build exciting drones by leveraging the capabilities of Arduino and ESP8266" Packt Publishing, 2018

2. Aaron Asadi, "Drones The Complete Manual. The essential handbook for drone enthusiasts", Imagine Publishing Limited, 2016

3. Neeraj Kumar Singh, Porselvan Muthukrishnan, Satyanarayana Sanpini, "Industrial System Engineering for Drones: A Guide with Best Practices for Designing", Apress, 2019

4. Felipe Gonzalez Toro, Antonios Tsourdos, "UAV or Drones for Remote Sensing Applications"2018.

5. K R Krishna, "Agricultural Drones: A Peaceful Pursuit", Apple Academic Press; CRC Press, 2018

SCHOOL OF ELECTRICAL AND ELECTRONICS

DEPARTMENT OF ELECTRONICS AND COMMUNICATION ENGINEERING

UNIT – 5 – DRONE ELECTRONICS – SECA4003

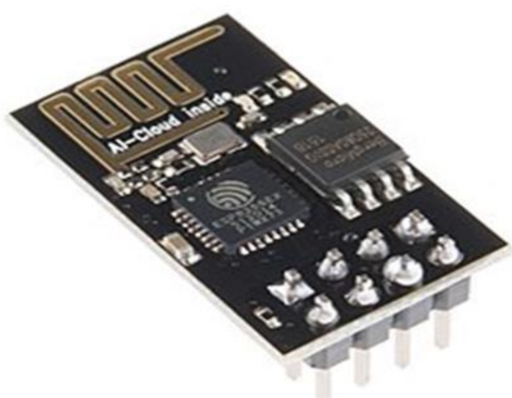
UNIT 5

DRONES FOR MISSION CONTROL APPLICATION

ESP8266, Downloading and installing APM Planner or Mission Planner, Configuring the quadcopter - Frame type selection, Compass calibration, Access calibration, Radio calibration, Flight mode calibration and Failsafe calibration, Surveying with a drone, tweaks with the Flight Plan screen. Future of Drone Systems

ESP8266:

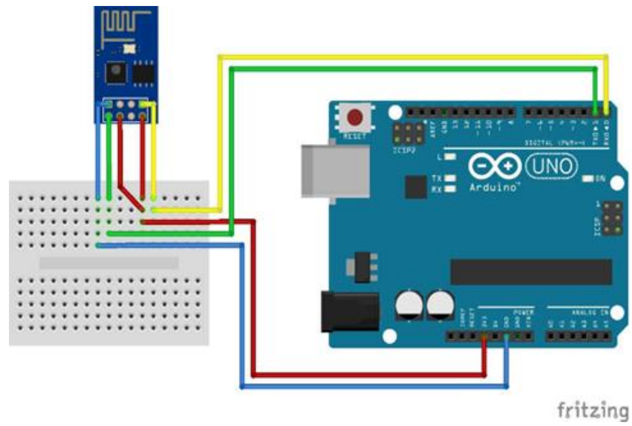
The ESP8285 is an ESP8266 with 1 MiB of built-in flash, allowing the building of single-chip devices capable of connecting to Wi-Fi. These microcontroller chips have been succeeded by the ESP32 family of devices, including the ESP32-C3. The ESP8266 is a low-cost Wi-Fi microchip, with a full TCP/IP stack and microcontroller capability.



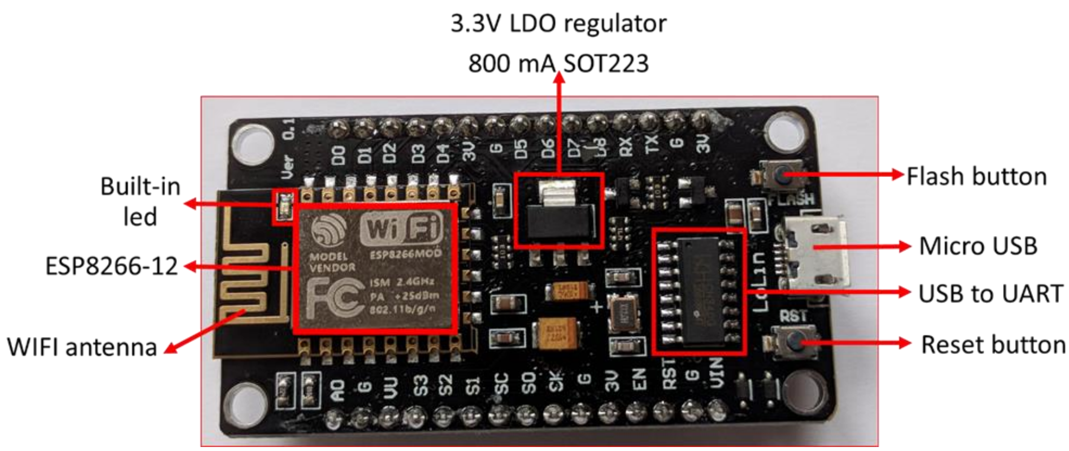
The ESP8266 module enables microcontrollers to connect to 2.4 GHz Wi-Fi, using IEEE 802.11 bgn. It can be used with ESP-AT firmware to provide Wi-Fi connectivity to external host MCUs, or it can be used as a self-sufficient MCU by running an RTOS-based SDK.

The ESP8266 Arduino compatible module is a low-cost Wi-Fi chip with full TCP/IP capability, and the amazing thing is that this little board has a MCU (Micro Controller Unit) integrated which gives the possibility to control I/O digital pins via simple and almost pseudo-code like programming language.

An ESP8266 is a microcontroller: Low-power, highly-integrated Wi-Fi solution. A minimum of 7 external components. Temperature range: -40°C to +125°C.



The ESP8266 WiFi Module is a self-contained SOC with integrated TCP/IP protocol stack that can give any microcontroller access to your WiFi network. The ESP8266 is capable of either hosting an application or offloading all WiFi networking functions from another application processor.



DOWNLOADING AND INSTALLING APM PLANNER OR MISSION PLANNER:

APM Planner is a merge between the Mission Planner functionality and look and feel (Windows only) with the Q Ground Control cross-platform (Mac/Windows/Linux) QT-based architecture, which has better support for multi-vehicle (swarming) control and a plug-in model that is easier to extend.

Downloading:

Just open your browser, find the APK file you want to download, and tap it – you should then be able to see it downloading on the top bar of your device. Once it's downloaded, open Downloads, tap on the APK file, and tap Yes when prompted. The app will begin installing on your device.

Installing APM Planner for Windows:

1.Run .exe file. Open the .exe file to run the installation wizard. Read the open-source license agreement, and select Accept. ...

2.Select options. Choose your installation options. ...

3.Close wizard to complete installation. Select Close to exist the wizard.

SYSTEM REQUIREMENTS:
Windows 7 or later

.NET

300 MB free space

Internet connection to use maps

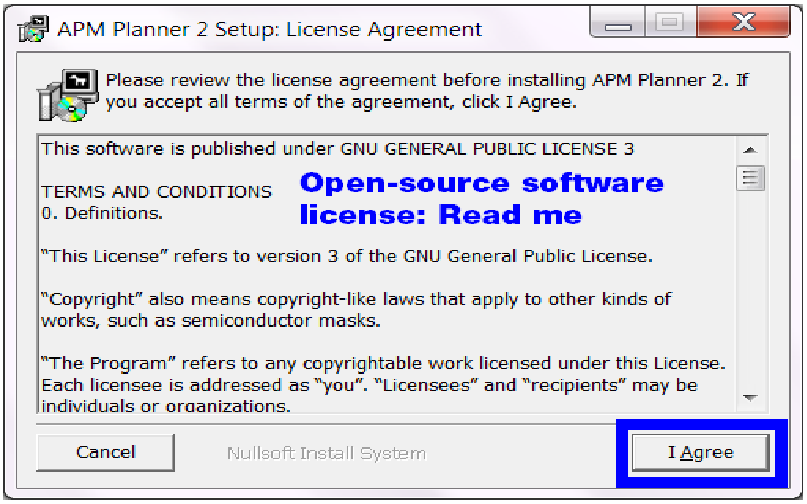
Download
Download the insatller (XXX_win.exe) file for your machine from

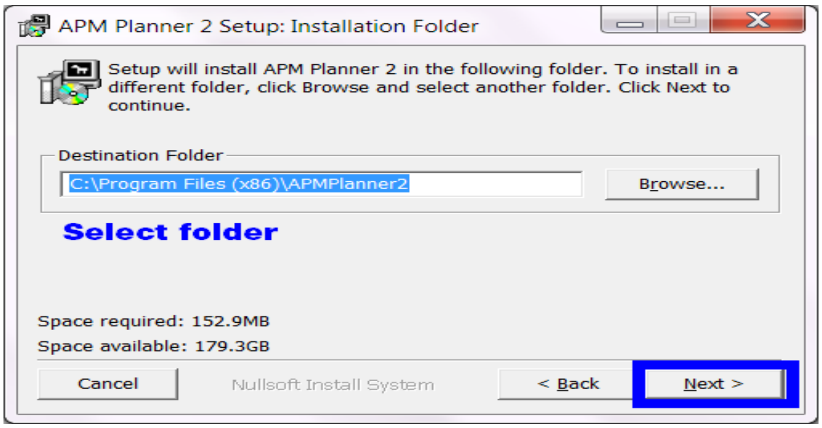
firmware.ardupilot.org/Tools/APMPlanner

And also check the discussion forum for lastest info

https://discuss.ardupilot.org/c/ground-control-software/apm-planner-2-0

Run .exe file
Open the .exe file to run the installation wizard. Read the open-source license agreement, and select Accept. Select a destination folder for the installation (the default option is fine if you aren’t sure).



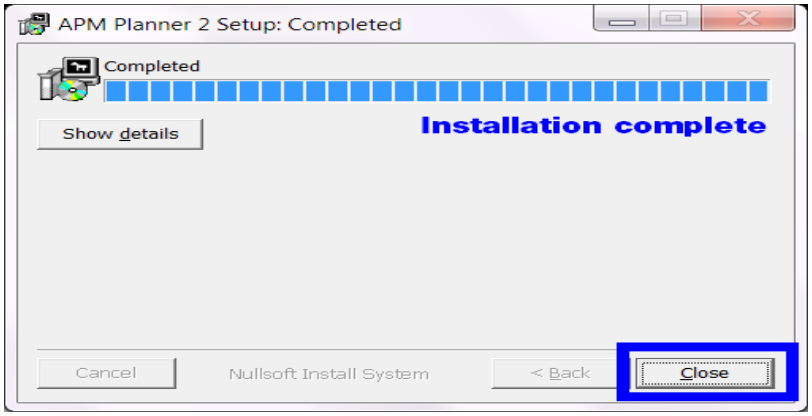


Select options

Choose your installation options. Select APM Planner 2 files and Qt components. Select Create Start Menu Shortcuts to make APM Planner easy to access from the start menu. Select Install.

Close wizard to complete installation:

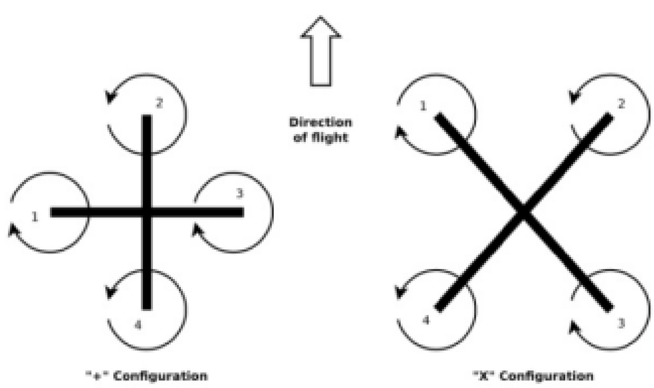
Select Close to exist the wizard. Your installation is now complete. Open APM Planner to run the application.



CONFIGURING THE QUADCOPTER:

A quadcopter is an under actuated aircraft with fixed pitch angle four rotors as shown in Figure 1. Modeling a vehicle such as a quadcopter is not an easy task because of its complex structure. The aim is to develop a model of the vehicle as realistically as possible.

A typical quadcopter have four rotors with fixed angles and they make quadcopter has four input forces, which are basically the thrust provided by each propellers as shown in Figure 1. There are two possible configurations for most of quadcopter designs "+" and "×". An X-configuration quadcopter is considered to be more stable compared to + configuration, which is a more acrobatic configuration. Propellers 1 and 3 rotates counter clockwise (CW) , 2 and 4 rotates counter-counter clockwise (CCW). So that, the quadcopter can maintain forward (backward) motion by increasing (decreasing) speed of front (rear) rotors speed while decreasing (increasing) rear (front) rotor speed simultaneously, which means changing the pitch angle. This process is required to compensate the action/reaction effect (Third Newton's Law). Propellers 1 and 3 have opposite pitch with respect to 2 and 4, so all thrusts have the same direction[7].



There are two reference systems that have to be defined as a reference which are Inertial reference system (Earth frame- XE, YE, ZE) and quadrotor reference system (Body frame- XB, YB, ZB). The reference system frames are shown in Figure 2. The dynamics of quadcopter can be describe in many different ways such as quaternion, Euler angle and direction matrix. However, in designing attitude stabilization control reference in axis angle is needed, so the designed controller can achieve a stable flight. In attitude stabilization control, all angle references in each axis must be approximately zero especially when take-off, landing or hover. It ensures that, the quadcopter body always is in horizontal state, when external forces are applied on it[8]. The quadcopter orientation can be defined by three Euler angles which are roll angle (Φ), pitch angle (θ) and yaw angle (φ). On figure 2 $\omega_1, \omega_2, \omega_3, \omega_4$ - rotation speeds (angular velocity) of the propellers; T_1, T_2, T_3, T_4 : forces generated by the propellers; $F_i \propto \omega_i^2$: on the basis of propeller shape, air density, etc.; m: mass of the quadcopter; mg: weight of the quadcopter; ϕ, θ, ψ : roll, pitch and yaw angels.

FRAME TYPE SELECTION:

1 Prerequisites

The vehicle is completely built to flight condition.

Firmware has been loaded onto the autopilot.

Autopilot is connected to APM Planner and connected to Mavlink.

2 Select frame

Select Mandatory Hardware, Frame Type and choose the correct diagram to select your vehicle configuration.

3. X and Plus

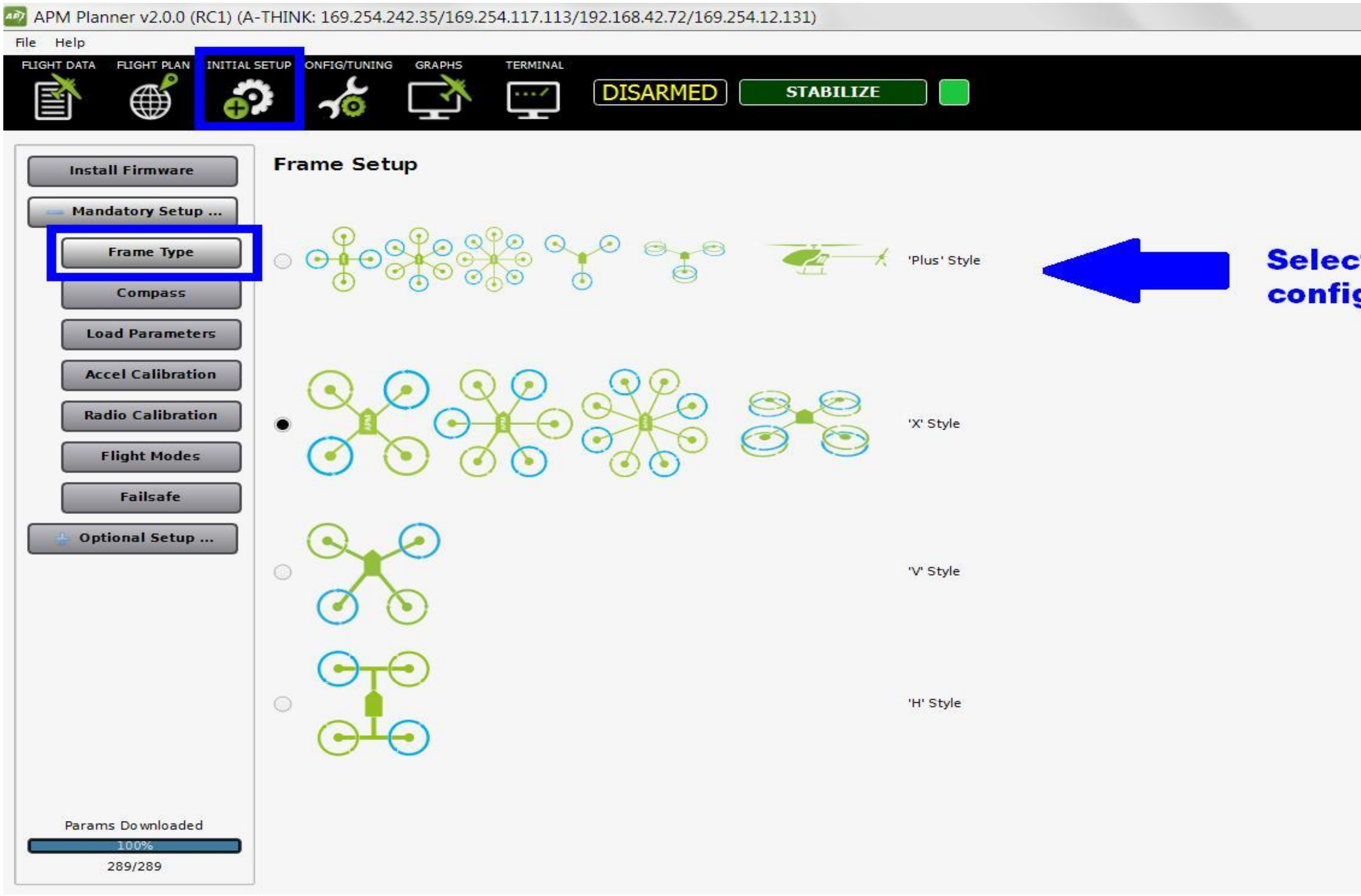
The default configuration is X. If you want one of the arms to serve as the exclusive front-facing direction, select the Plus configuration. For tricopters, traditional helis and Y6s, the frame type is ignored.

4 H frame

For an H-Frame quadcopter, use the option to set the frame type to ’3′ in the Advanced Parameter Tab. To apply the H-frame configuration, swap the left rear and right rear props and reverse the motor direction for each of those motors (by swapping any two motor wires). Repeat the same process for the front two motors.

5 V frame

Select the V frame for a quadcopter with wide-angled front arms.



COMPASS CALIBRATION:

The compass calibration process configures all connected internal and external magnetometers. QGroundControl will guide you to position the vehicle in a number of set orientations and rotate the vehicle about the specified axis.

Note

If you are using an external magnetometer/compass (e.g. a compass integrated into a GPS module) make sure you mount the external compass on your vehicle properly and connect it to the autopilot hardware. Instructions for connecting your GPS+compass can be found in Basic

Assembly for your specific autopilot hardware. Once connected, QGroundControl will automatically detect the external magnetometer.

TIP

You will need to calibrate your compass on first use, and you may need to recalibrate it if the vehicles is ever exposed to a very strong magnetic field, or if it is used in an area with abnormal magnetic characteristics. Indications of a poor compass calibration include multicopter circling during hover, toilet bowling (circling at increasing radius/spiraling-out, usually constant altitude, leading to fly-way), or veering off-path when attempting to fly straight.

Performing the Calibration:

The calibration steps are:

1.Choose a location away from large metal objects or magnetic fields.

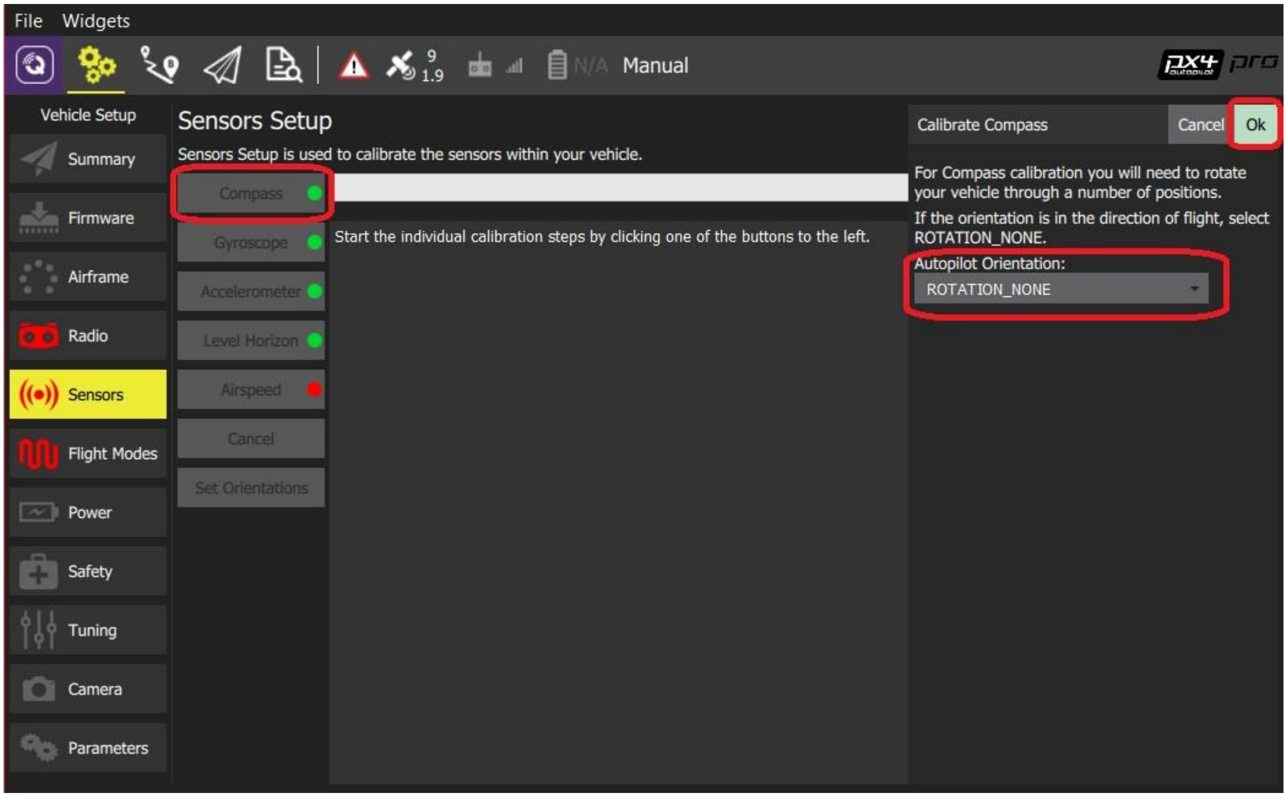
TIP

Metal is not always obvious! Avoid calibrating on top of an office table (often contain metal bars) or next to a vehicle. Calibration can even be affected if you're standing on a slab of concrete with uneven distribution of re-bar.

2.Start QGroundControl and connect the vehicle.

3.Select the Gear icon (Vehicle Setup) in the top toolbar and then Sensors in the sidebar.

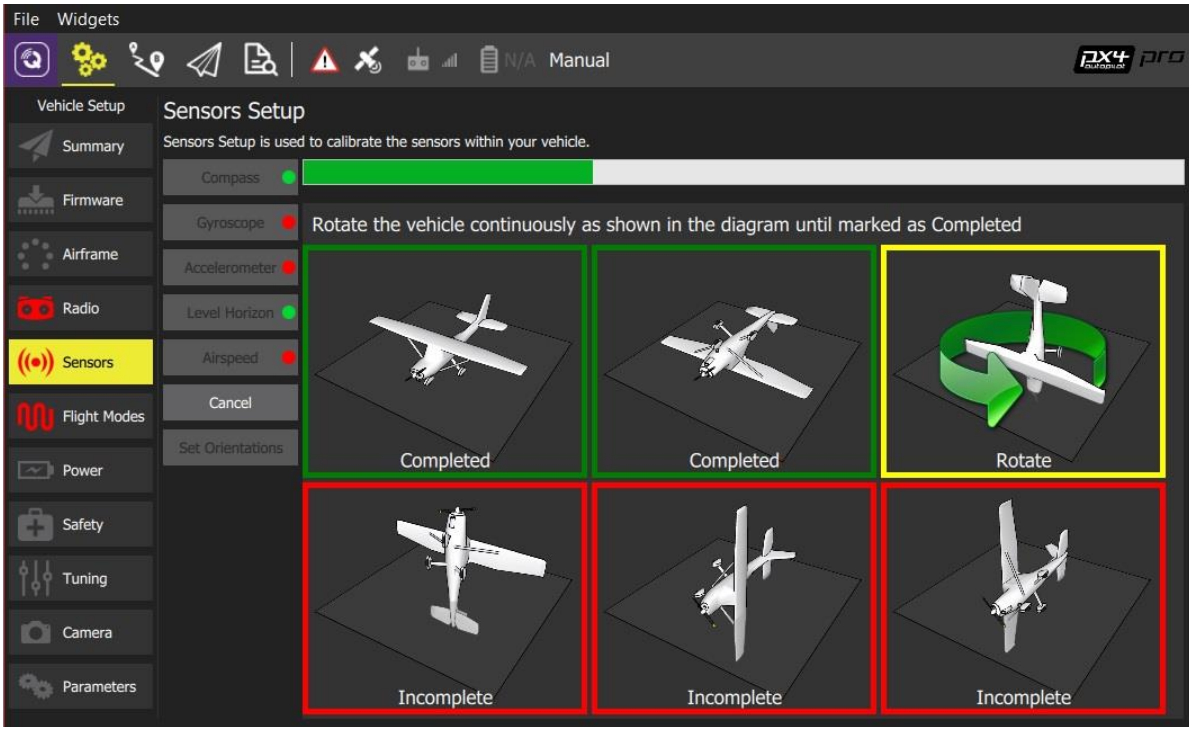
4.Click the Compass sensor button.



You should already have set the Autopilot Orientation. If not, you can also set it here.

5.Click OK to start the calibration.

6.Place the vehicle in any of the orientations shown in red (incomplete) and hold it still. Once prompted (the orientation-image turns yellow) rotate the vehicle around the specified axis in either/both directions. Once the calibration is complete for the current orientation the associated image on the screen will turn green.



7.Repeat the calibration process for all vehicle orientations.

Once you've calibrated the vehicle in all the positions Q Ground Control will display Calibration complete (all orientation images will be displayed in green and the progress bar will fill completely). You can then proceed to the next sensor.

ACCESS CALIBRATION:

This topic describes how to access the following Calibration records:

Calibration, Analog

Calibration, Discrete

Calibration, Weight Scale

Calibration, Single Component Analyzer

Calibration, Multi-component Analyzer

Calibration, Functional Test

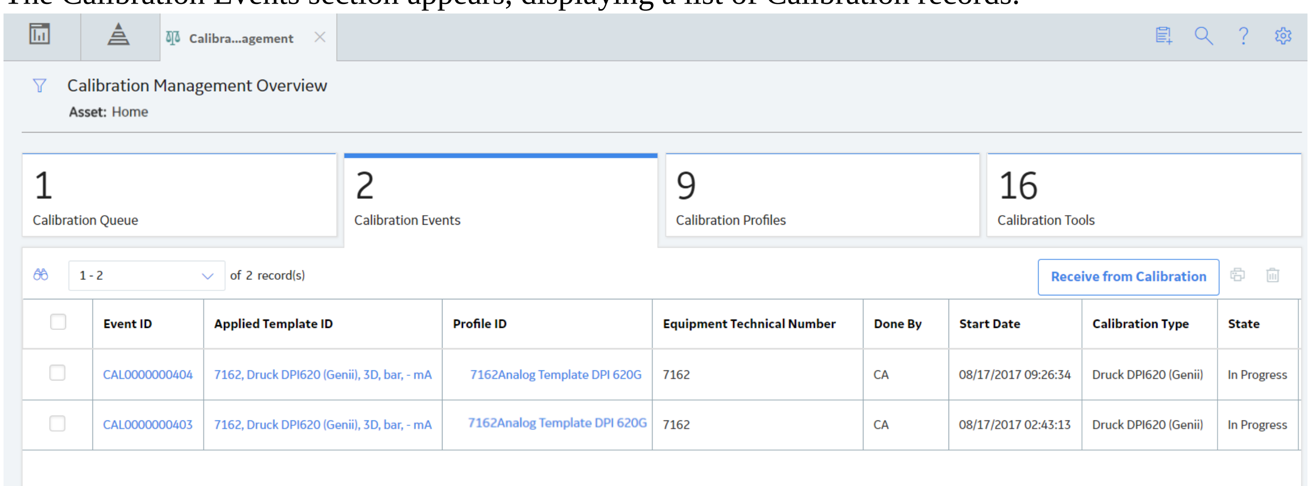
Calibration, CMX

Access the Calibration Management Overview page.

Hint: You can also access the Calibration Management Overview page for a hierarchy level.

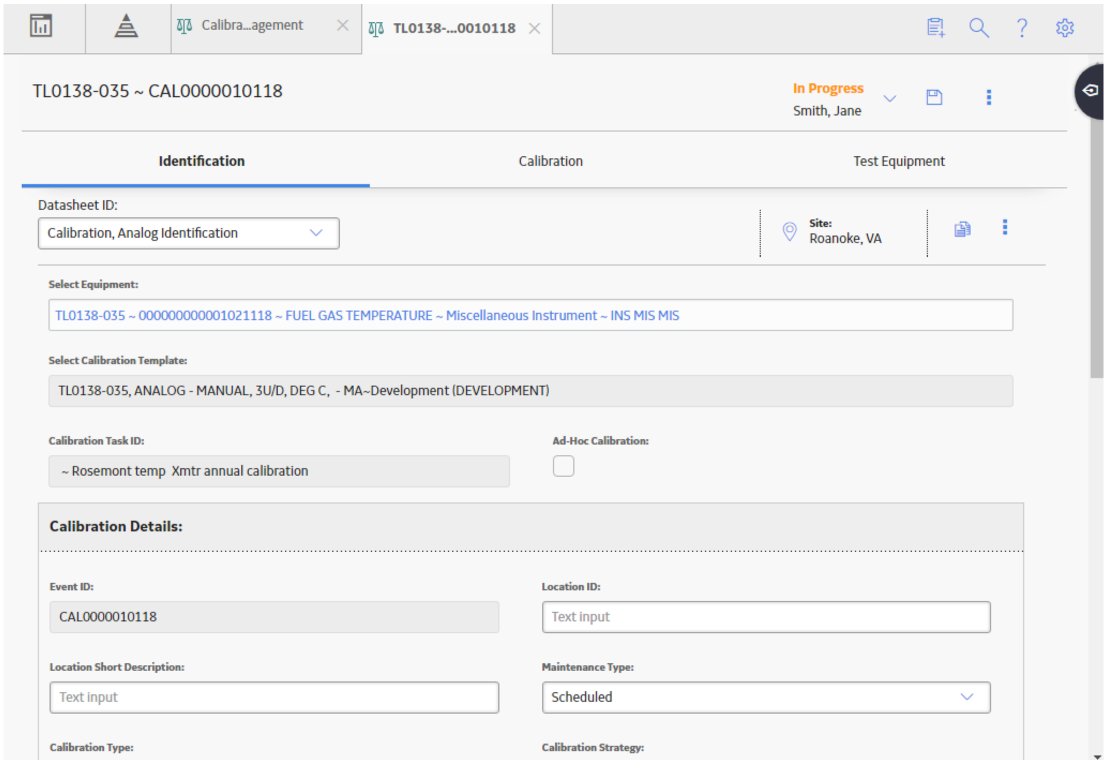
Select the Calibration Events tab.

The Calibration Events section appears, displaying a list of Calibration records.



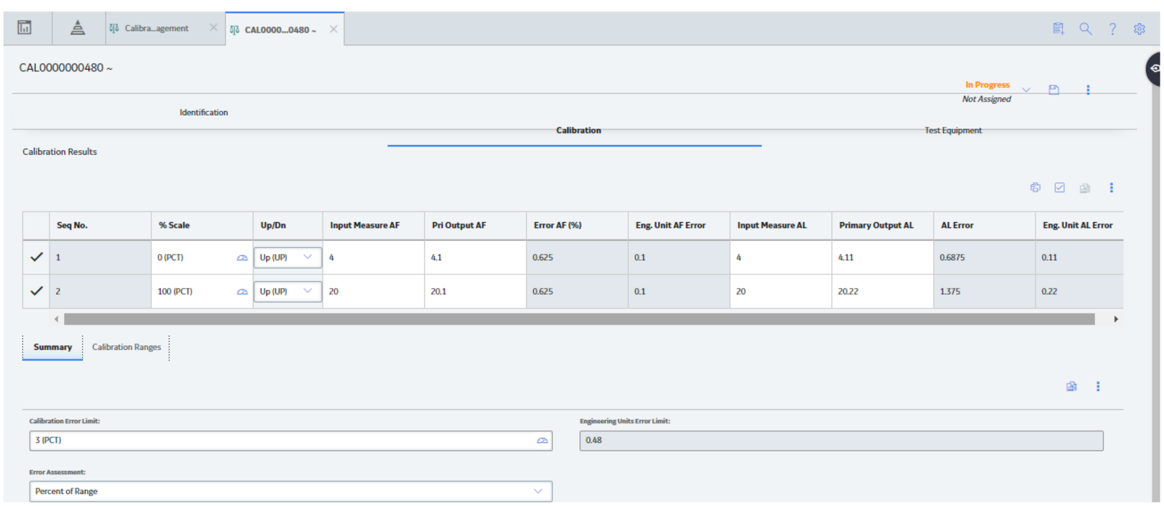
In the Event ID column, select the link for the Calibration that you want to access.

The details of the selected Calibration appear on a new page, displaying the Identification, Calibration, and Test Equipment tabs. By default, the Identification tab is selected, displaying the datasheet for the selected Calibration.



Select the **Calibration** tab.

The **Calibration** section appears, displaying a list of Calibration Results and the summary of the Calibration Event.



Steps for sensor calibration in Drones

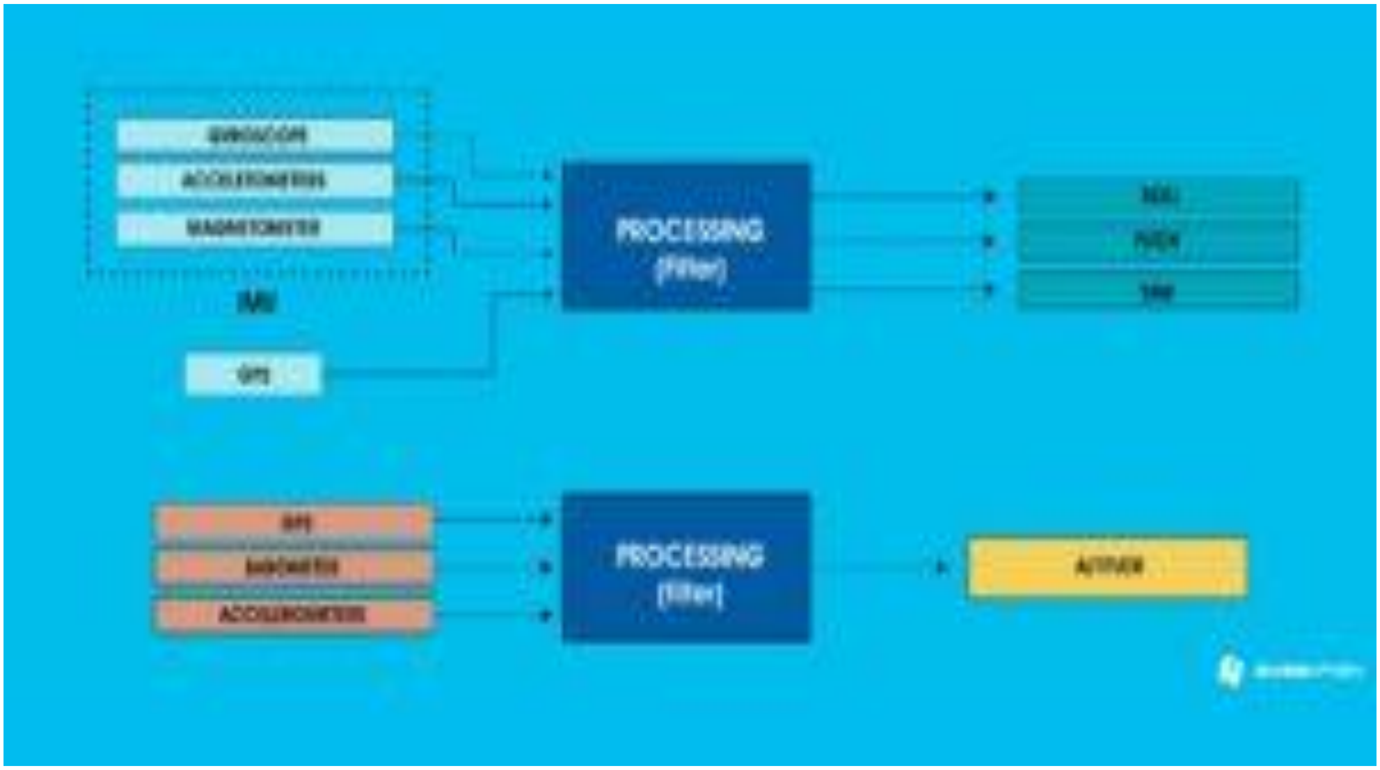
Sensor calibration is of great importance for drones and eVTOL to **maximize the accuracy and reliability in the operation**. Once the sensors are integrated, it is necessary to perform a correct calibration to obtain the maximum performance and achieve the highest accuracy in the system.

Reasons for sensor calibration in drones

The main reason why sensor calibration is performed is that, **although most sensors have a factory default calibration**, this may not be adequate for all the system operating range. Specifically, the calibration temperature range often does not match with the actual operation of the drone or eVTOL. In Embention, for example, our **Veronte Autopilot is designed to work at a temperature range between -40ºC and 65ºC**. For that reason, we must perform a calibration that covers the entire range, adapting it to the temperature required in the real operation of the autonomous vehicle.

Steps to follow

From Embention, we want to explain the steps to perform for the correct sensor calibration in drones. For this, we will set our products as an example: **[Veronte Autopilot]** and **[4x Redundant Autopilot]**.



Barometer and Pitot Calibration

In our laboratory, we have specific equipment to calibrate the pressure sensors. Both, the Veronte Autopilot and the 4x Redundant Autopilot are connected to a **precise pressure machine**. And with software created for such functionality, the calibration system sends a range of **determined and known pressures to the autopilot**. This pressure depends on the sensor being calibrated because Veronte Autopilot integrates two static pressure sensors and one dynamic pressure sensor. During this process, the Veronte Autopilot will **adjust the calibration of its sensors to the real value supplied by the high precision calibration machine**.

IMU Calibration

The IMU in Veronte Autopilot integrates two types of sensors: **gyroscopes and accelerometers, both with 3 measurement axes.** These sensors integrate small mechanical elements that, due to dilation, change in size and adjustment at different temperatures, thus changing the raw sensor measurement. For that reason, it is necessary to perform a correct calibration at different temperatures if we want to obtain the highest grade of accuracy.

A Rate Calibration Table is used to calibrate sensors at different temperatures, there we can store different calibration values for different temperature measurements. For the IMU calibration, it is rotated in its 3 axes, subjecting the IMU to calibrate to a certain centrifugal force and to known static positions.

Conclusions

To sum up, sensor calibration should be performed so that any product can achieve its highest grade of accuracy. This calibration will correct small physical differences to ensure that all sensors read the same values for the same inputs. Therefore, their calibration ranges must be adjusted for each unit independently.

RADIO CALIBRATION:

Radio Control Calibration

This article shows how to perform radio control calibration using Mission Planner

Overview

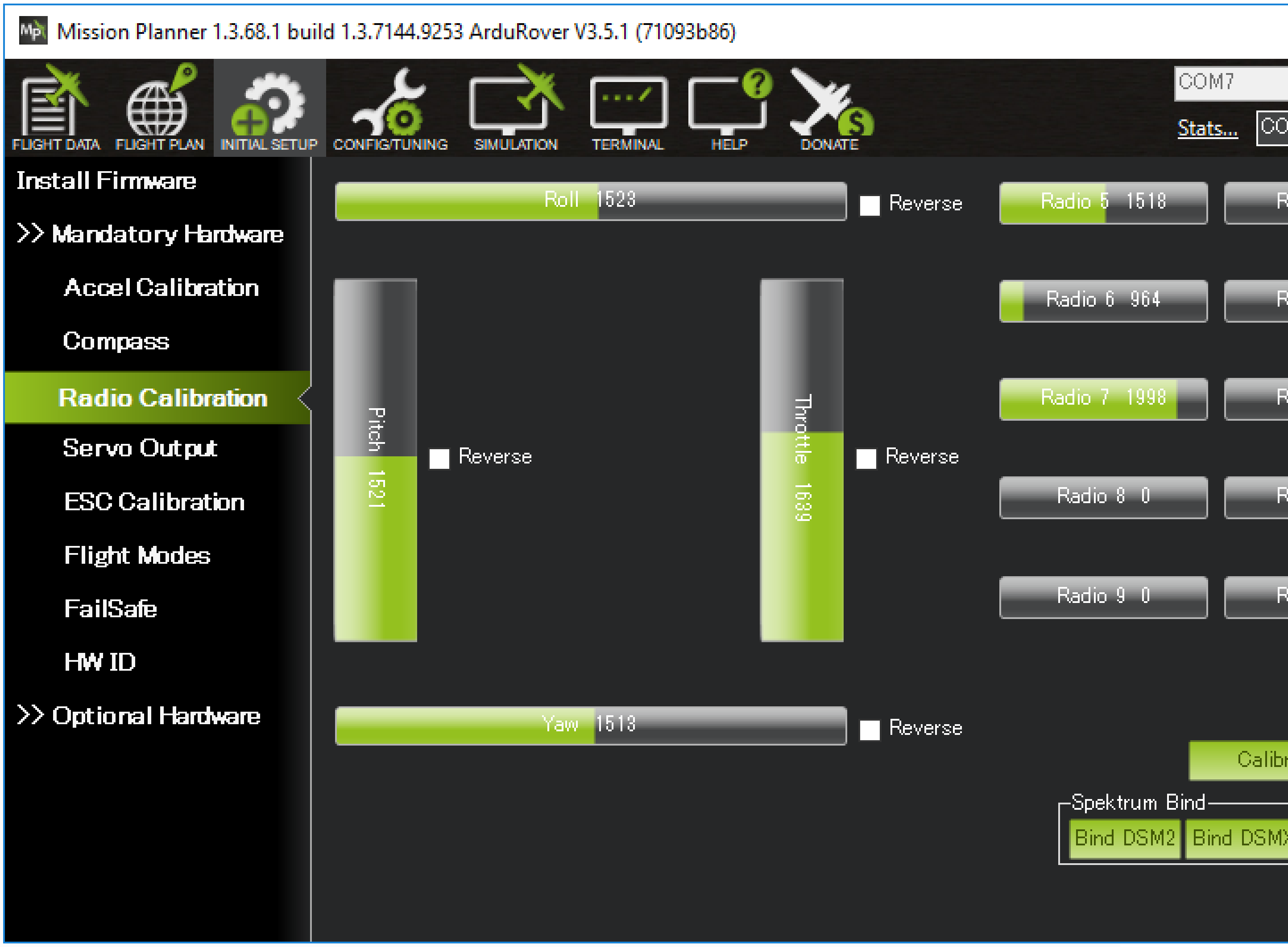
RC transmitters allow the pilot to set the flight mode, control the vehicle's movement and orientation and also turn on/off auxiliary functions (i.e. raising and lowering landing gear, etc).

RC Calibration involves capturing each RC input channel's minimum, maximum and "trim" values so that ArduPilot can correctly interpret the input.

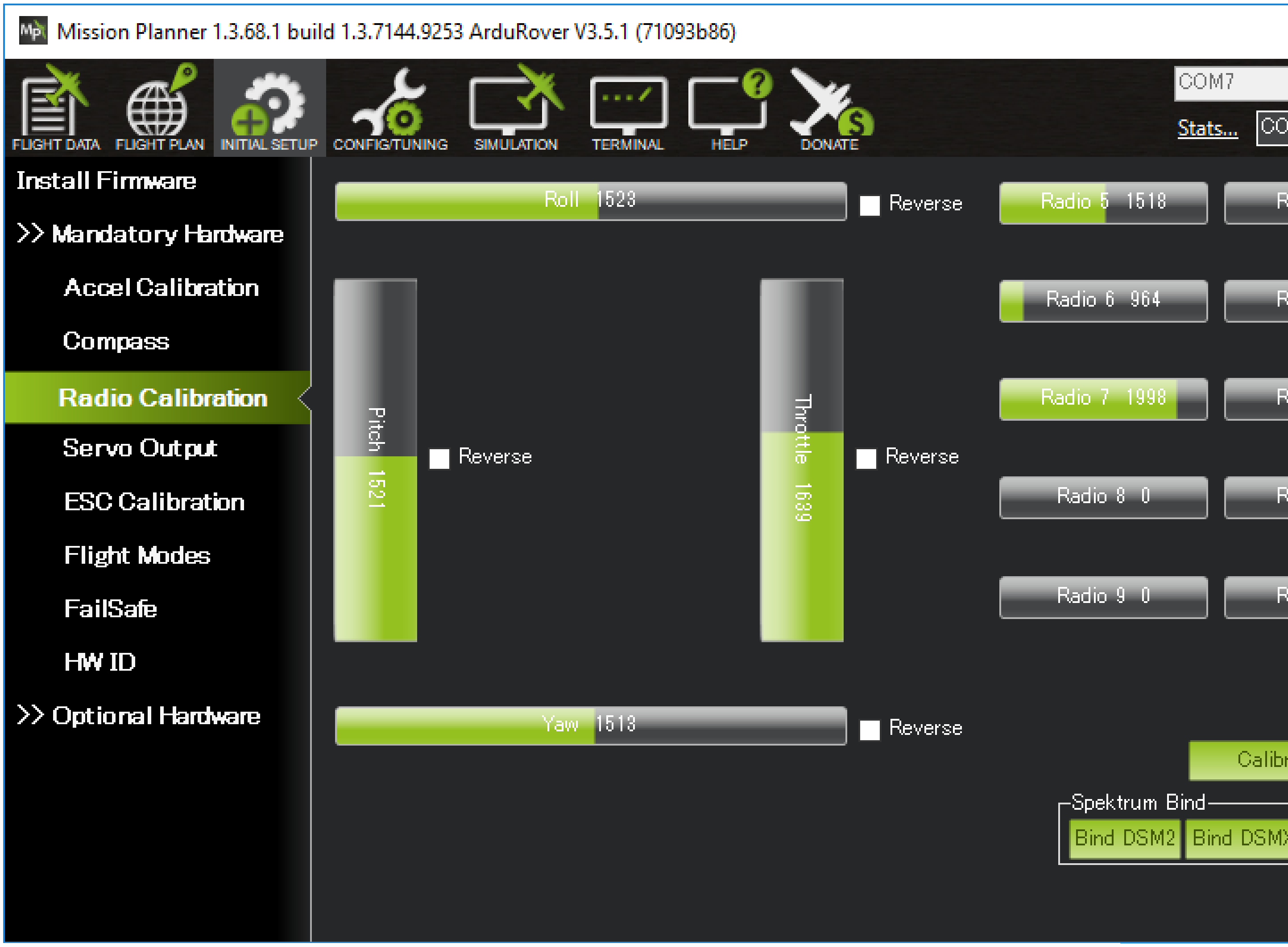
Check the Transmitter's Setup

- Ensure the battery is disconnected (this is important because it is possible to accidentally arm the vehicle during the RC calibration process)
- Ensure the RC receiver is connected to the autopilot
- Turn on your RC transmitter and if it has "trim tabs" ensure they are in the middle

- Connect the autopilot to the PC using a USB cable
- On the Mission Planner press the “Connect” button and open Mission Planner’s **INITIAL SETUP | Mandatory Hardware | Radio Calibration** screen
- Some green bars should appear showing the ArduPilot is receiving input from the Transmitter/Receiver. If no bars appear check the receiver’s LED:
    - No lights may indicate that it is incorrectly wired to the autopilot. Look for connectors that may have been inserted upside down
    - A Red or flashing LED may indicate that your RC transmitter/receiver need be bound. See the manual that came with your RC equipment for instructions

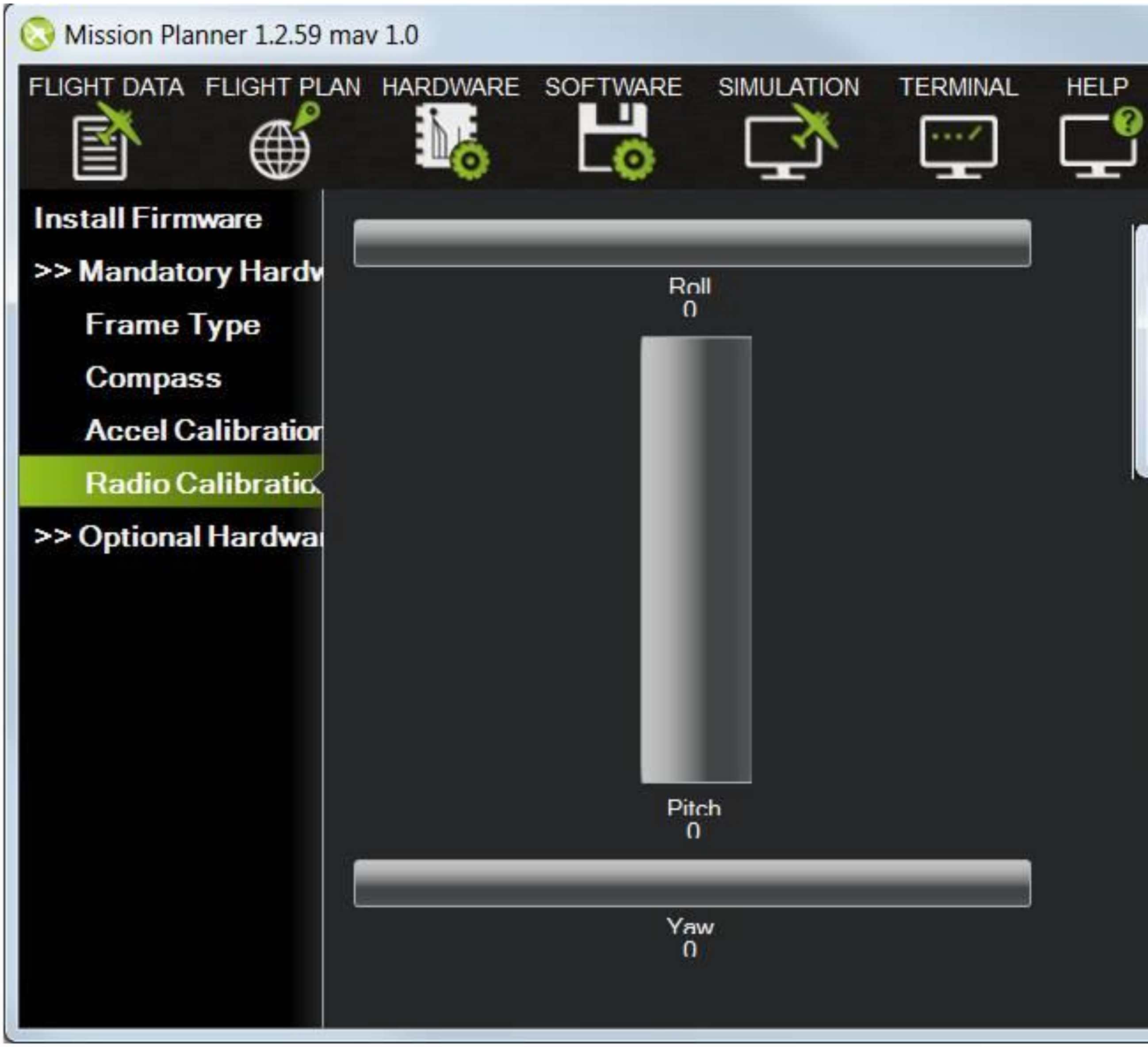


- Check the channel mapping in the transmitter (ie. check which inputs channels are controlled by the transmitter's sticks, switches and knobs) by moving the sticks, knobs and switches and observing which (if any) green bars move. If this is the first time the transmitter is being used with ArduPilot it is likely that the transmitter's channel mapping will need to be changed and normally this is done on the transmitter itself using its built-in configuration menu
    - Determine if your transmitter is Mode1 or Mode2 (see below)
    - Roll stick should control channel 1
    - Pitch stick should control channel 2
    - Throttle stick should control channel 3
    - Yaw stick should control channel 4
    - A 3 position switch (to control the flight mode) should be setup to control Channel 5 (if using Copter) or Channel 8 (if using Rover or Plane). This channel can be moved by setting the FLTMODE_CH parameter
    - On Copter, a tuning knob should control Channel 6
    - On Copter and Rover, any remaining two or three position switches can be setup to control auxiliary functions by mapping them to channels 7 to 12
- Move the transmitter's roll, pitch, throttle and yaw sticks and ensure the green bars move in the correct direction:
    - for roll, throttle and yaw channels, the green bars should move in the same direction as the transmitter's physical sticks
    - for pitch, the green bar should move in the opposite direction to the transmitter's physical stick
    - if one of the green bars moves in the incorrect direction reverse the channel in the transmitter itself. If it is not possible to reverse the channel in the transmitter you may reverse the channel in ArduPilot by checking the "Reversed" checkbox (Plane and Rover only). If the checkbox is not visible it is possible to reverse the channel by directly changing the RCx_REVERSED parameter (where "x" is the input channel from 1 to 4).

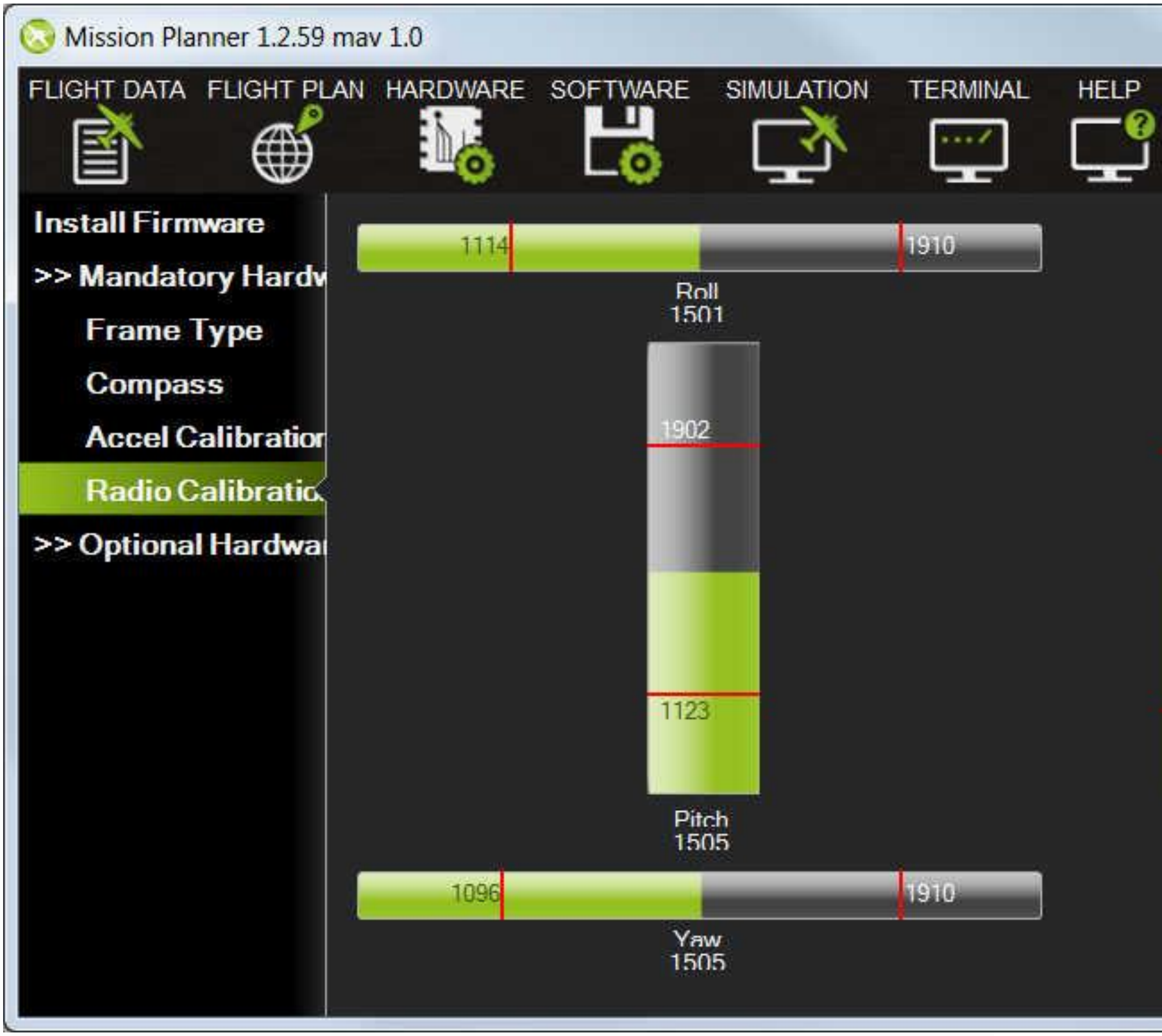


Calibration

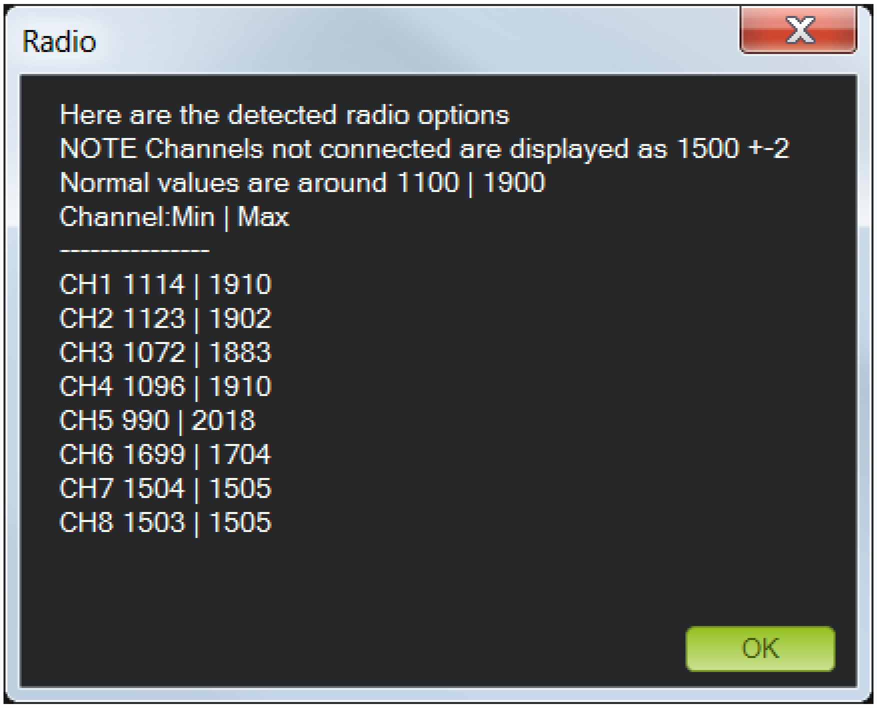
- Open Mission Planner's **INITIAL SETUP | Mandatory Hardware | Radio Calibration** screen
- Click on the green "Calibrate Radio" button on the bottom right
- Press "OK" when prompted to check the radio control equipment is on, battery is not connected, and propellers are not attached



- Move the transmitter's control sticks, knobs and switches to their limits. Red lines will appear across the calibration bars to show minimum and maximum values seen so far



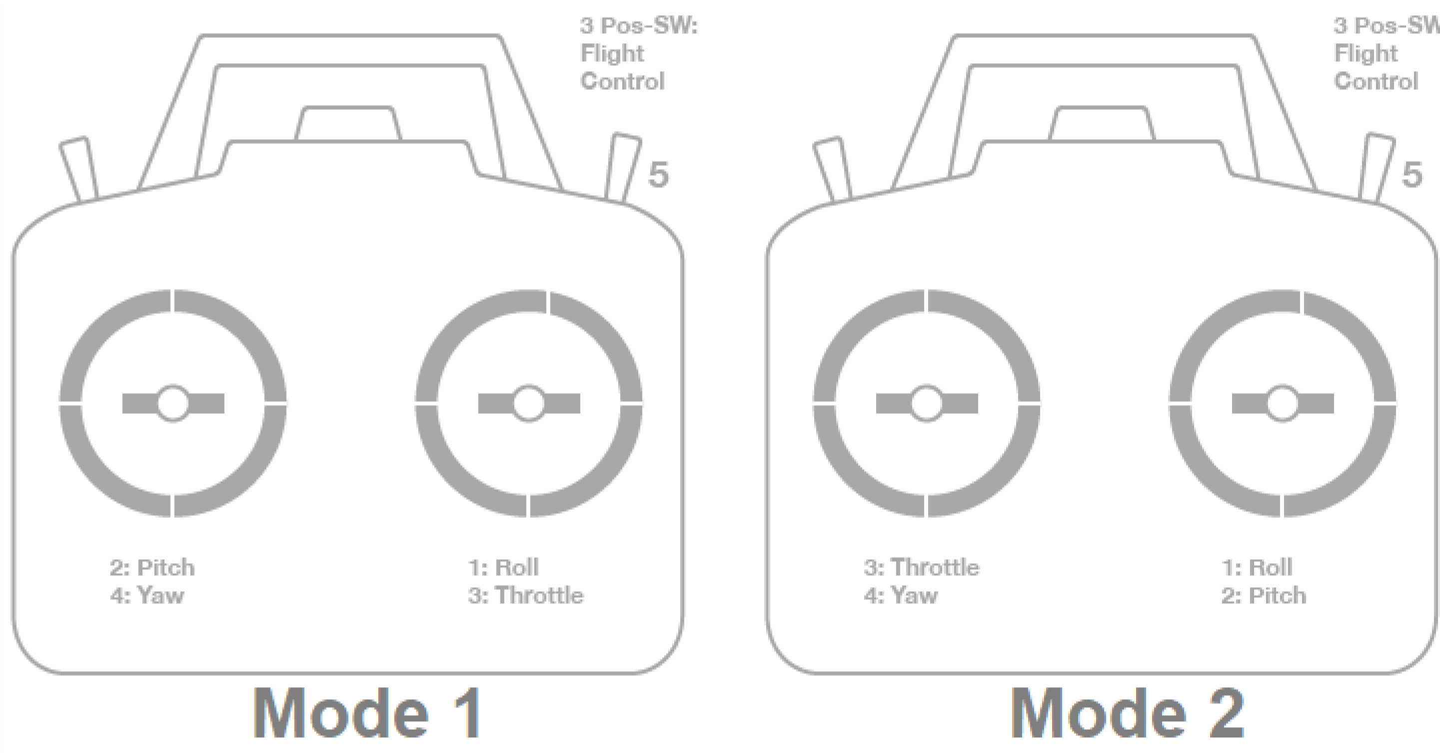
- Select **Click when Done**
- A window will appear with the prompt, "Ensure all your sticks are centered and throttle is down and click ok to continue". Move the throttle to zero and press "OK".
- Mission Planner will show a summary of the calibration data. Normal values are around 1100 for minimums and 1900 for maximums.



Mode1 and Mode2 Transmitters

There are two main transmitter configurations:

- *Mode 1*: left stick controls pitch and yaw, the right stick will control throttle and roll.
- *Mode 2*: left stick controls throttle and yaw; the right stick will control pitch and roll.



Channel mappings

Copter default channel mappings are:

- **Channel 1**: Roll
- **Channel 2**: Pitch
- **Channel 3**: Throttle
- **Channel 4**: Yaw
- **Channel 5**: Flight modes
- **Channel 6**: (Optional) Inflight tuning or camera mount (mapped to transmitter tuning knob)
- **Channel 7 to 12**: (Optional) Auxiliary function switches

Further Reading

- Roll, pitch, throttle and yaw channel mappings can be changed using RCMAP Input Channel Mapping
- Flight mode switch setup to specify which vehicle modes are enabled by each switch position can be found on the RC Transmitter Flight Mode Configuration page

FLIGHT MODE CALIBRATION AND FAILSAFE CALIBRATION:

Radio Failsafe

Copter supports several configurable failsafe options in cases where contact between the Pilot's RC transmitter and the autopilot's receiver is lost. This page explains this failsafe's setup and testing. Note the "Radio failsafe" was previously called "Throttle failsafe" because of the way in which some receivers use the throttle channel to signal the loss of contact.

Warning

For Single Helicopter, Dual Helicopter and Quad Helicopter frames, Copter 3.6 and earlier in any H_RSC Mode or Copter 4.0 in the RC Passthrough H_RSC_Mode requires the RC receiver channel 8 to hold last value when transmitter signal is lost. If the receiver sends no signal or does not hold the RC channel 8 value, the motor will be shutdown and the helicopter will crash.

Note

Copter also supports other failsafes, including: Battery, Ground Station and EKF/DCM failsafes. See the Failsafe for more details.

When the failsafe will trigger

If enabled and set-up correctly the radio failsafe will trigger if:

- The pilot turns off the RC transmitter for more than 0.5 second
- The vehicle travels outside of RC range and signal is lost for more than 0.5 second
- The pilot forces the throttle channel below FS_THR_VALUE from the transmitter
- The receiver loses power (unlikely)
- The wires connecting the receiver to the autopilot are broken (unlikely).

What will happen

When a radio failsafe is triggered, the copter can be configured via parameters to do nothing, land immediately, RTL, or SmartRTL. It can also be configured to bypass the failsafe in an Auto Mode mission, or to continue landing if already in a landing phase.

- If the copter is disarmed, no failsafe will take place.
- If the copter is armed but has landed, the copter will immediately disarm.
- If the copter is armed in Stabilize or Acro modes, and the throttle input is at minimum, the copter will immediately disarm.
- Otherwise, the copter will take the actions as configured in the parameters described below.

If the failsafe clears (i.e. transmitter and receiver regain contact) the copter will remain in its failsafe mode. It will **not** automatically return to the flight mode that was active before the failsafe was triggered. This means that if, for example, the vehicle was in Loiter when the failsafe occurred and the flight mode was automatically changed to RTL, even after the transmitter and receiver regained contact, the vehicle would remain in RTL. If the pilot wished to re-take control in Loiter he/she would need to change your flight mode switch to another position and then back to Loiter.

Receiver Configuration

By default, most newly purchased receivers will simply not output pulses if contact with the transmitter is lost. However, some low end receivers will be set-up to simply hold all channels at their last known position. This is not good because the autopilot has no way to know that the

Pilot has lost control of the vehicle. Instead the receiver must be set-up to signal to the autopilot it has lost contact and there are two ways that it can do this (the method depends upon the receiver). Each brand of Transmitter/Receiver is slightly different so please refer to your transmitter's user manual to determine which method is available and how to set it up.

Receiver configuration for low-throttle method

The **"Low-Throttle" method** pulls the throttle channel (normally channel 3) to a value below the bottom of its normal range (normally below 1000us). This method is used by Futaba systems and many older systems. Below is the setup method for a Futaba T7C Transmitter with R617FS or TFR4-B receiver which uses the "low throttle" method.

Many receivers allow for the failsafe positions to be set either by simply pressing a button on the receiver, or directly from the transmitter. In this case, the transmitter is temporarily adjusted to output a throttle signal below the normal low idle position (if low idle is 1000us, then 990uS would be sent) setting this as the failsafe value for the receiver, then adjusting low stick back to normal idle position. This below throttle idle value is then set for FS_THR_VALUE, as discussed below.

Receiver configuration for No-Signal method

"No Signal" method - the receiver stops sending signals to the autopilot. This is the preferred method and is how most modern FrSky receivers operate. Below is the setup method for a FlySky 9 channel transmitter with FrSky D4R-II receiver which uses the "No Signal" method.

Parameter Configuration

The FS_THR_ENABLE parameter can be set in the Mission Planner full parameter list or full parameter tree, or can also be set using the Mission Planner *failsafe options* dropdown in the Initial Setup >> Mandatory Hardware >> Failsafe menu.

- **Disabled** (Value 0) will disable the radio failsafe entirely.
- **Enabled Always RTL** (Value 1) will switch the copter to RTL Mode. If the GPS position is not usable, the copter will change to Land Mode instead.
- **Enabled Continue with Mission in Auto Mode ((this value has no effect in 4.0 and later with :ref:`FS_OPTIONS<FS_OPTIONS>` parameter replacing function, see below))** (Value 2) will ignore the failsafe in an Auto Mode mission. Otherwise, it will behave the same as *Enabled Always RTL*. This option no longer

exists in ArduCopter 4.0. Instead, see the FS_OPTIONS parameter for this function. Setting this value in Copter 4.0 and later version will automatically be converted and set to (Value 1) and the FS_OPTIONS will be modified to include bit (0) in the bitmask for “Continue if in auto mode on Radio Failsafe”.

- **Enabled Always Land** (Value 3) will switch the copter to Land Mode.
- **Enabled SmartRTL or RTL** (Value 4) will switch the copter to SmartRTL mode. If SmartRTL is not available, the copter will switch to RTL Mode instead. If the GPS position is not usable, the copter will change to Land Mode instead.
- **Enabled SmartRTL or Land** (Value 5) will switch the copter to SmartRTL mode. If SmartRTL is not available, the copter will switch to Land Mode instead.
- Any invaild value (Such as accidentally enter 99 as a parameter value) will will behave the same as **Enabled Always LAND**

The FS_THR_VALUE parameter can be set in the Mission Planner full parameter list or full parameter tree, or can also be set using the Mission Planner *FS PWM* value in the Initial Setup >> Mandatory Hardware >> Failsafe menu. - At least 10 PWM higher than your Channel 3’s PWM value when the throttle stick is fully down and the transmitter is **off** - At least 10 PWM lower than your channel 3’s PWM value when the throttle stick is fully down and the transmitter is **on** - Above 910 PWM

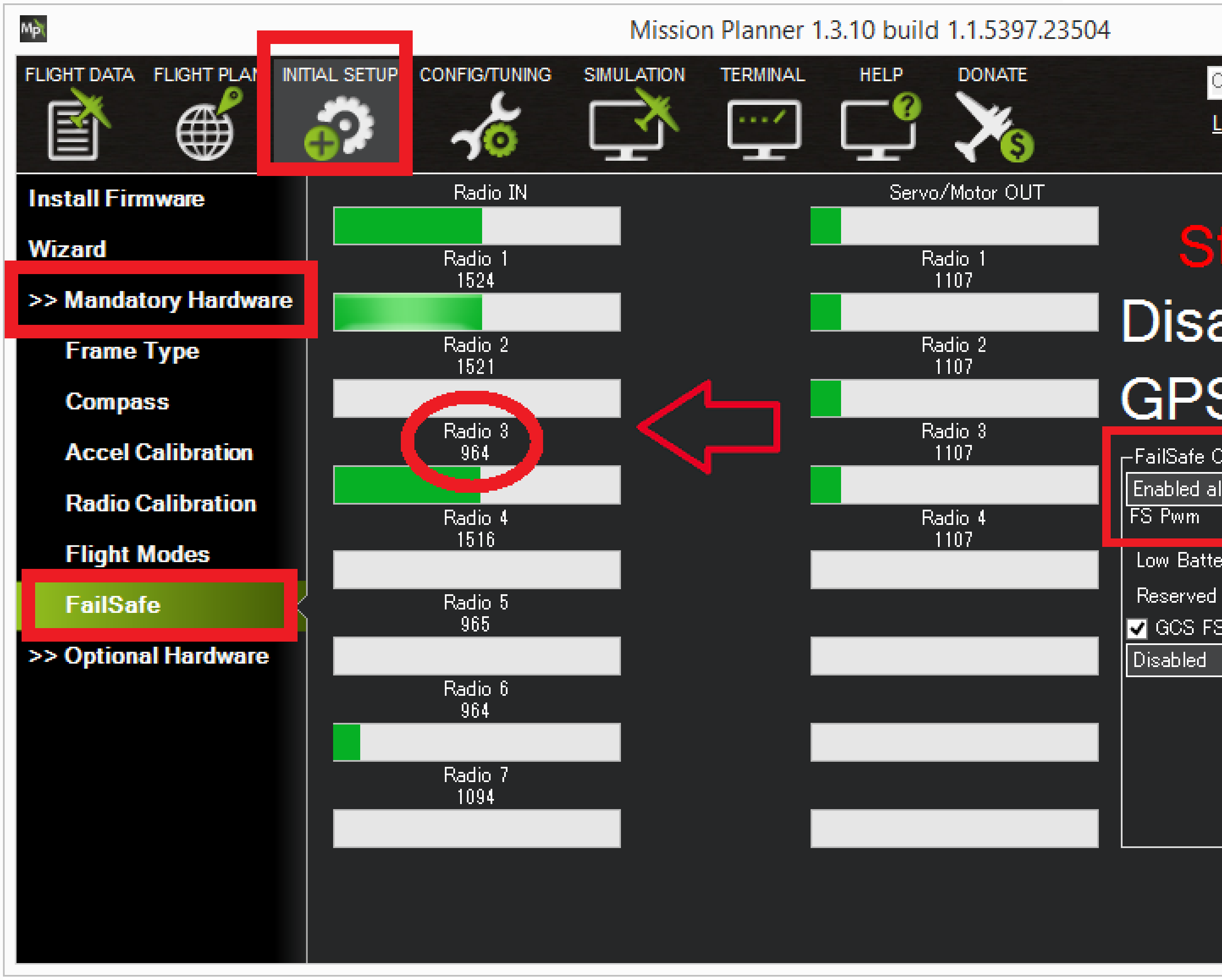
The FS_OPTIONS parameter (Copter 4.0 and later) is a bitmask parameter to select one or more options that modify the standard actions of the radio, GCS, and battery failsafe. In the Mission Planner full parameter list or full parameter tree, the handy checkbox popup window is an easy what to set this (and any other bitmask) parameter. Be sure to go to Help > Check Beta Updates to pull the latest parameter definitions first while connected to the internet.
The FS_OPTIONS bits are as follows:

- bit 0 set: Continue if in auto mode on Radio Failsafe
- bit 1 set: Continue if in auto mode on Ground Control Station Failsafe
- bit 2 set: Continue if in guided mode Radio Failsafe
- bit 3 set: Continue if landing on any failsafe
- bit 4 set: Continue in pilot control on Ground Control Station Failsafe
- if none of the above are set, then execute the FS_THR_ENABLE option as configured.

Note

Only bitmask bits 0, 2, & 3 affect actions taken during radio failsafe. This parameter also works in conjunction with the battery and GCS failsafe, so ensure you are taking all options into account when setting this parameter.

Below is a screenshot of the Mission Planner Initial Setup >> Mandatory Hardware >> Failsafe menu.

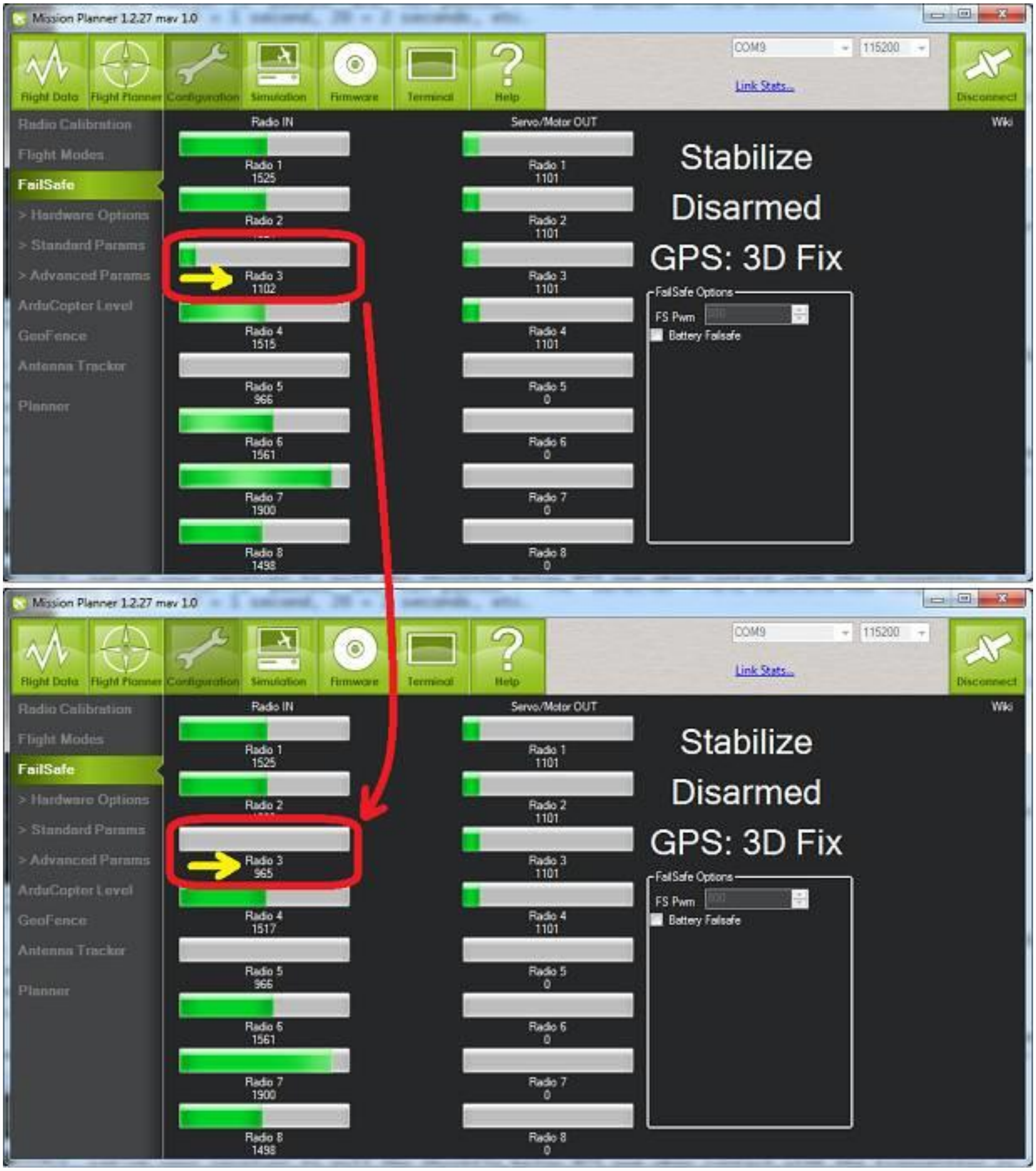


Testing

You can check your failsafe by performing the following tests with the Pixhawk/APM connected to the Mission Planner either via a USB cable or telemetry link. You can complete these tests without plugging in your LiPo battery but if you do connect a battery you should first remove the propellers.

Test #1 : if using the “Low-Throttle” method, ensure the throttle channel drops with loss of radio contact

1. Ensure your RC transmitter is on and connected with the throttle all the way down and flight mode set to Stabilize
2. The throttle (channel 3) PWM value should be approximately as in first illustration below. Its value may be higher or lower but it should definitely be at least 10 higher than the value held in the FS PWM field
3. Turn the transmitter off and the throttle PWM value should drop to be at least 10 below the FS PWM field value (as in the second illustration below) below



Test #2 : ensuring motors disarm if in STABILIZE or ACRO with throttle at zero

- Switch to stabilize mode, arm your motors but keep your throttle at zero. Turn off your transmitter. The motors should disarm immediately (red led will start flashing, DISARMED will be displayed in the Mission Planner’s Flight Data screen).

Test #3 : ensuring flight mode changes to RTL or LAND when throttle is above zero

- Switch to stabilize mode, arm your motors and raise your throttle to the mid point. Turn off your transmitter. The Flight Mode should switch to RTL if you have a GPS lock or LAND if you do not have a GPS lock (the flight mode and GPS lock status are visible in the Mission Planner's flight data screen).

Test #4 : retaking control after the failsafe has cleared

- continuing on from test #3, turn your transmitter back on
- while the flight mode is still in RTL or LAND and armed, change the flight mode switch to another position and then back to stabilize mode. Ensure that the flight mode displayed on the Failsafe page is updating appropriately.

Test #5 (optional) : removing power from the receiver

- Switch to stabilize mode, arm your motors and keep your throttle above zero.
- Carefully disconnect the power wires connecting the receiver to the autopilot
- The Flight Mode should switch to RTL or LAND as described in Test #3

Warning

Unplug the autopilot so that it is powered down before reattaching the receiver's power

Using the receiver to set the flight mode (not recommended)

Instead of setting up the receiver and autopilot as described above (i.e. "Low-Throttle" and "No Signal" methods) the receiver can be set-up to set channel 5 (flight mode channel) to a flight mode slot that has been set to RTL. For example the receiver could be setup to move ch5's pwm value to 1700us which is "Flight Mode 5" which could then be set to RTL on the Mission Planner's Initial Setup >> Mandatory Hardware >> Flight Modes screen.

Although this mostly works it is not recommended because it will not trigger if the receiver loses power or if the wires between the receiver and autopilot are broken.

SURVEYING WITH A DRONE, TWEAKS WITH THE FLIGHT PLAN SCREEN.:

A drone survey refers to the use of a drone, or unmanned aerial vehicle (UAV), to capture aerial data with downward-facing sensors, such as RGB or multispectral cameras, and LIDAR payloads. During a drone survey with an RGB camera, the ground is photographed several times from different angles, and each image is tagged with coordinates.

Reduce field time and survey costs

Capturing topographic data with a drone is up to five times faster than with land-based methods and requires less manpower. With PPK geo-tagging, you also save time, as placing numerous GCPs is no longer necessary. You ultimately deliver your survey results faster and at a lower cost.

The performance and type of drone, the quality of its components, the camera resolution, the height at which the drone flies, the vegetation, and the method and technology used to geolocate the aerial images can heavily influence the accuracy of drone survey mapping. At this point, it is possible to reach an absolute accuracy down to 1 cm (0.4 in) and 0.7 cm/px (0.3 in/px) GSD under optimal conditions with a high-end surveying drone such as the WingtraOne.

FUTURE OF DRONE SYSTEMS

THE FUTURE OF DRONES

Start a **game-changing career** working with dynamic drone technology. From a military innovation, to an exciting hobby, to a technology that’s transforming commercial industries, the use of drones has rapidly changed over the past years — and future **opportunities in the field are limitless**.

Also known as unmanned aircrafts, drones are already **breaking barriers** in the way companies do business. Huge corporations like Amazon and Google are testing ways to deliver packages with drones. Facebook is using drones to provide Internet connections in remote locations. And there's even a start-up that's using unmanned aircraft to deliver tacos to your door.

In short, the drone industry is booming. You can take part in this dynamic growth by earning a drone technology degree from California University of Pennsylvania.

One of the **first drone degree programs in the United States since the FAA release of Part 107**, Cal U's associate of science degree in unmanned aircraft systems/drone technology will give you comprehensive training in aviation principles and drone avionics. It will also prepare you for Unmanned Aircraft Systems (UAS) Certification —an essential credential if you want a competitive career edge.

How Drone Technology Is Changing Industries

Drones are becoming commonplace in both the commercial and non-profits sectors. In the near future their use will be even more widespread.

Here are some of the many ways unmanned aircraft can revolutionize how we get things done. It's easy to see why drone degree programs, like Cal U's two-year associate's degree are more relevant than ever.

- **Agriculture:** The Environmental Protection Agency already utilizes drones technology to manage livestock and survey crops. In the future farmers and ranchers could use unmanned aircraft to strategically monitor and spray their crops.
- **Conservation:** Unmanned aircraft are being used to monitor endangered species and map the changes in various ecosystems around the globe. As drone technology advances, the use and impact of unmanned aircraft in conservation efforts will expand.

- **Delivery/fulfillment:** Anything the postman can carry can also be delivered by drone. Food, prescriptions, that last-minute birthday gift for your dad—in the near future, there will be big changes in the way packages arrive to our doors.
- **Disaster mitigation and relief**: Drones can go places that humans can't access, so they are an ideal solution for dangerous search and rescue efforts, as well as for delivering emergency supplies to remote locations and disaster areas.
- **Logistics:** Heavy-duty drones can replace trucks for inventory management and moving goods between warehouses. This is likely to decrease the number of semis you see on the road.
- **Filmmaking and photography:** Low-budget filmmakers are already using drones to capture the aerial shots and Hollywood will soon be hiring full crews of drone Unmanned aircraft are also gaining ground with photojournalists who want to capture breaking news from above.
- **ISPs**: Big tech companies like Facebook and Google are experimenting with solar powered drone technology to beam Internet to remote locals. This could transform connectivity as we know it.
- **Law enforcement**: In Seattle and Miami, police forces have already applied for permits to use drones, and we'll likely begin to see unmanned aircraft supplementing police presence at large public events.
- **Real Estate:** Real Estate listings are poised to change completely with high-definition videos capture by drones that fly through neighborhoods, and into every room in a listed house.

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