DESIGN AND DEVELOPMENT OF GUIDANCE SYSTEM FOR AUTONOMOUS TARGET/DECOY UAV

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B.E. SENIOR DESIGN PROJECT REPORT
Mechatronics Specialization

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SDP COMPLETION DECLARATION

We the students of College of Engineering, batch ____________________ hereby declare that we have completed our final year project titled ____ ___________________________ and have achieved all targets set forth in the project proposal.

It is requested that we may be examined.

	NAME	REGISTRATION ID	SIGNATURE
1.	______________________________	__________________	________________
2.	______________________________	__________________	________________
3.	______________________________	__________________	________________
4.	______________________________	__________________	________________

Confirmation by Project Supervisor:

I ____________________________________, as project supervisor for the above mentioned group confirm that they have completed all requirements of the final project including the number of minimum visits for supervision, submission of all deliverables etc.

They may now be allowed to present and defend their work.

____

Date & signature

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Remarks (If any)

1. **Report submitted** ☐ **Yes** ☐ **No** ________________________
2. **Project hardware & software fully function** ☐ **Yes** ☐ **No** ________________________
3. **All other deliverables received** ☐ **Yes** ☐ **No** ________________________
4. **Presentation Date & Time** ____

Approved by Project Committee ☐ **Yes** ☐ **No**

	NAME	**SIGNATURE**
1. Chairperson	_______	__________________
2. Member	__________	__________________
3. Member	__________	__________________

Approved by the Dean/Director:

I certify, to the best of my knowledge, that the required procedures have been followed and the preparation criteria have been met for this project work.

Dated: _______________ _________________________________

(Dean/Director CoE)

PAF - Karachi Institute of Economics & Technology

PAF Base Korangi Creek, Karachi-75190, Pakistan

SDP CERTIFICATE OF COMPLETION

This is to certify that the following students of College of Engineering have completed their Senior Design Project under the title **"DESIGN AND DEVELOPMENT OF GUIDANCE SYSTEM FOR AUTONOMOUS TARGET/DECOY UAV"** in partial fulfilment of the requirement of the Bachelor of Engineering in Electronics with Telecommunications/Computer Systems/Industrial Electronics/Avionics specialization.

GROUP MEMBERS:

______________________________ ________________

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Project Advisor:

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(Name & *Signature)*

Senior Design Project Committee:

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Lecturer	**Lecturer**	**Lecturer**
Noaman Masood	**Faizan Javed**	**Atif Shahbaz**
(Chairperson)	**(Member)**	**(Member)**

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ABSTRACT

Unmanned aerial vehicle is an aircraft without a pilot. Such vehicles are controlled remotely by an operator on ground, uses aerodynamic forces to provide lift to vehicle and can fly autonomously through software-controlled flight plans in conjunction with onboard Sensors & GPS. Drone is like a flying Robot. UAVs are specially used for Intelligence, Surveillance, border security. The controllability of these vehicles is very complex. UAV is very useful to certain applications, such as agriculture, vigilance systems, environment mapping, meteorology and search and rescue operations. It is also use in defence forces specially in military and civil applications.

This project faces challenges like load reduction, controllability, and mechanical design. Our main focus was to reduce weight of batteries, controller, motors wings in order to make the plane balanced to lift it in air. The report describes objectives, motivations, and different alternatives. It briefs the mechanical, electronic design and software working. This UAV is capable of waypoint navigation, trajectory tracking, visual navigation, and automatic takeoff and landing. Our UAV performs autonomous task by using way points on mission planner and autonomous navigation using GPS module.

For these above objectives we use Ardupilot Mega APM 2.8 as our flight controller autopilot, which is an open source, efficient performance and low cost autopilot. We use Mission Planner for the Ground Control Station (GCS). The electronic and control system of UAV is developed by using built-in Gyros and accelerometer in the controller, RC transmitter and receiver were used to control different operations and activities.

In order to safely test the flight controller autopilot without the risk of damaging of any component it was first installed and tested manually. In this test, the autopilot system worked correctly. Next, the system was installed on the UAV. Several flight tests were conducted and it was verified that the autopilot was working properly even with the default parameter settings.

This project covers control theory, electronics, system design, testing and measurements. Through this project we came to know how to implement our knowledge and we have learnt new skills.

KEYWORDS

AA	Anti-aircraft
Accelerometer	Device that measures proper acceleration
Aerodynamics	Study of motion in air
Altitude	Height of UAV above terrain
Angular Speed	Change of direction of UAV with respect to time
AoA	Angle of attack
Attitude	It is the orientation of aircraft with respect to horizon
Autopilot	System used to guide a vehicle without assistance of human being
Autonomous	Undertaken or carried on without outside control
CG	Centre of gravity
DoF	Degrees of freedom
Drag	Resistance to motion through air
Dynamics	Motion created by UAV due to its maneuverings
Flight	The movement of UAV through space or atmosphere
FW	Fixed wing
GCS	Ground control station (or system)
Gyros	Device to sense angular motion of UAV
Hovering	Self-sustaining maneuver in a fixed position
Joystick	Lever used by a pilot to control the movement
Maneuvering	Changing of course
Mounted	Attached to a support; Motor mounted
MP	Mission Planner
Pitch	Vertical (up and down) axis
Propeller	that rotates to push against air
Roll	the up or down angle of UAV in horizontal plane
Speed controllers	Vary the voltage required for the motors
Stability	the condition of being stable
Thrust	propelled force developed by
Turbulence	instability in atmosphere
UAV	Unmanned (or uninhabited) aerial vehicle
Yaw	the rotation motion in which the UAV turns around its Vertical axis.

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PROJECT OBJECTIVES

The objective of this project is Autonomous flight, auto take-off and landing (using sonar or barometer), autonomous navigation (a vehicle is able to plan its path and execute its plan without human intervention), cruise control (a system that automatically controls the speed of a motor vehicle). In this project we develop a top-level guidance system to reduce ground and air communication latency. UAV will eliminate need of pilot. The target of this project is that, UAV must take-off autonomously, reach the target by covering the way points, then loiter around the targeted area and then return to its initial coordinates, but if the target is not present then it will return to its initial coordinates.

• Motivation:

There is the growing interest in the field of Robotics from few years.

Several industries like Automation, medical, manufacturing and space require robots to replace man in dangerous or time-consuming conditions. This interest has been developed in the field of small unmanned aerial vehicles with the aim to use it in dangerous places where human cannot reach or in some critical situations where there will be threat to the life of human.

Problem associated with UAV is that they have less weight carrying capacity, whereas fixed wing aircraft are able to carry greater payloads for longer distances on less power allowing to carry bigger sensors. The main advantage of fixed wing UAV is its simpler structure as compared to Rotary UAV. The simpler structure provides a less complicated maintenance and repair process thus allows more operation time at lower cost. The simple structure ensures more efficient aerodynamics that provide the advantage of longer flight durations at higher speed this enables larger survey areas per given flight.

• Desired Aims/Results/Objectives

The objective of this project is Autonomous flight, auto take-off and landing, autonomous navigation (a vehicle is able to plan its path and execute its plan without human intervention), cruise control (a system that automatically controls the speed of a motor vehicle). In this project we develop a top-level guidance system to reduce ground and air communication latency. UAV will eliminate need of pilot. The target of this project is that, UAV must take-off autonomously, reach the target by covering the way points, then loiter around the targeted area and then return to its initial coordinates, but if the target is not present then it will return to its initial coordinates.

- **Methodology:**

The development of UAV is divided into Phases

- Design phase
- Analysis and component selection
- Assembly, hardware testing
- Simulation and verification
- Development for future implementation

Conceptual Design:

Figure 1: Unmanned Aerial Vehicle (Drone)

It includes general lay out of UAV. In this phase first step is to identify the deign goals. We then decide to fulfil the following requirement

- Make a system autonomous

- **Market or Industry Adaptability/Applications:**

Drones (UAVs) came into existence for the sole purpose of reaching and traversing areas where it was hazardous for man to maneuver. Drone technology has developed and prospered in the last few years. Individuals, commercial entities, and governments have come to realize that drones have multiple uses, which include:

- Aerial photography for journalism and film
- Express shipping and delivery
- Gathering information or supplying essentials for disaster management
- Thermal sensor drones for search and rescue operations
- Geographic mapping of inaccessible terrain and locations
- Building safety inspections
- Precision crop monitoring
- Unmanned cargo transport
- Law enforcement and border control surveillance
- Storm tracking and forecasting hurricanes and tornadoes

CHAPTER # 01

INTRODUCTION

- ## INTRODUCTION:

"Flying is learning how to throw yourself at the ground and miss."
Douglas Adams

The project is to develop a guidance system for target UAV for military applications without a pilot. This project focuses on designing a guidance system for an autonomo us mission control. Such kind of drones are unmanned aerial vehicles specially used or training purpose of SAMs, training pilots and anti-aircraft guns. UAV is suited for situations which are dangerous and hazardous where direct monitoring of human is not possible.

1.1 Overview:

Human being always tries to make a better solution to resolve the problems. Manned aerial vehicles perform the missions like surveillance and target. But sometimes they can’t reach in dangerous and hazardous areas or there was latency in communication . This brings a need of solution to reduce communication latency and manufacture vehicle that reach in areas where human being can’t reach. Then the Unmanned Aeri al Vehicle was invented through which communication latency was reduced and it can fly autonomously and can reach in dangerous areas. It collects the information of that area and returns to its home position. UAV was first developed by Lawrence and Sperry in 1916. These drones are used for 3d mapping, surveillance, target and decoy. Now a day these are used for whether monitoring etc. they are characterized by their size and light weight and different operations. As compared to manned aerial vehicle they are very small and light weighted. Initially its purpose was to serve milit ary for surveillance mission and aerial attacks in golf wars. But now a days UAV can perform several tasks, like analysing crash sites, firefighting etc. There are different types of UAVs like fixed wing, rotary UAV, Blimps UAV, Flapping UAV etc., but they have so many limitations and functionalities and purpose. Rotary UAV has advantage of hovering. Blimps are of large size, it has low speed and have high endu rance.

Flapping wing UAV has flexible and small wings. It is inspired by birds. To control the UAV ground control station is necessary, through this communication between UAV and ground control station is made by wireless communication. UAVs can perform autonomous actions, provided by manned remote control, like executing missions that are GPS guided through way points mentioned in map. The user orders UAV to flight through defined GPS coordinates. This will make some error. To reduce the error an intelligent system is developed to make decisions itself and is ca able to take emergency actions.

1.2 Motivation:

The Unmanned Aircraft Vehicle (UAV) sector has become increased dynamically in the aerospace industry. According to a report entitled" Unmanned Aerial Vehicle (UAV) Market (2013-2018)" by an independent information provider, the total global UAV market is expected to reach over $8,000 million by 2018.

Due to its potential in replacing human pilots for performing high risk missions and by being a cheaper option, they have been widely used since the World War II with their development being driven by military applications. However, there are several civil applications that can take advantage of UAV capabilities, such as for ests fires, wildlife, monitoring crops, and traffic, as well as remote area delivery of medicine, photography, TV, movie production and aerial news, among others.

Although not particular prohibitive for the military sector, cost, operational complexity and size are crucial elements for civilian usage. For these reasons, the use of civilian UAVs has not been yet developed to its full extent but with new technolog ical advancements and with the perception of their potential applications, there will be a significant growth in this market.

With the growing number of civilian UAVs in the foreseeable future, there will be more and more applications that will take advantage of the numerous UAVs capabilities. There will also be cheaper technologies, that will allow low budget UAVs to have a similar performance to more expensive vehicles. This work aims to implement and analyze the performance that can be achieved with an open source autopilot that is cheaper than off-the-shelf autopilots used in modern UAVs.

A standout amongst the most basic periods of a UAV operation, paying little respect to application, is the arrival. One of a definitive objective in UAV improveme nt is to make the autopilot framework so independent that it replaces the human pilot, and where the UAV can perform both takeoff and landing completely without anyone else.

UAVs and its technology have helped global industry to increase its production in the past years. Developing solutions that can perform industry specified tasks has increased drone global market. Industries like agriculture, news media, film production, energy, public service, construction, mining and real estate can now rely on UAVs to improve process performance, lowering costs and risks for human beings. It's expected that the use of UAVs to have a compound annual growth rate of 19% for civilian purposes, when compared with 5% for military services, both between 2015 and 2020.

Growth rate of civilian purposes are much greater than military ones, because UAVs (and more specifically Micro UAVs) can now be used by civilians who wish to record aerial views, such as image recording, filmmaking, racing or just for fun, at affordable costs. Initially, UAVs were only used for military purposes such as surveillance and scouting missions. Now, it's being used by governmental public services to prevent forest fires, police patrolling and border control.

Current advancements in UAV technologies such as hardware reliability, controls and open source autopilot systems (APM 2.8) has made it possible by just us ing Google Maps point and click features, plan your mission, specify altitude, toggle between different flight modes. It also helped setup a good platform for using UAVs for maneuvering missions and long duration flights in surveillance. One of the well known and growing interest applications of UAVs is 3D Terrain mapping. Many commercial image processing tools are available, which will generate the requirements for frontal and sideways overlap for capturing images. This gives a good idea about what altitude and latitude-longitude the images have to be taken. The images are triggered at time intervals by setting up waypoints in Lawn Mower Pattern. But there are nonlinear natural conditions always present to challenge these systems such as winds. The control algorithms do compensate for this wind disturbance, but there are no real time wind speed and directions sensors onboard.

The absence of direct wind measurements that can update correct wind data lead to inaccuracy in attitude corrections applied by autopilot board. Because of this error in Wind estimation, UAVs drift a lot from their course and they tend to miss the waypoint and come back again to pass through the waypoints.

The drift in waypoint following results in reduced endurance and less area coverage in mapping missions. This report will bring out these differences and open up area for newer algorithm development.

1.3 Background:

The main objective of this thesis is to implement and test an autopilot and a Ground Control Station (GCS) for the UAV. This will allow the aircraft to be flown autonomously and to be remotely controlled, while also monitoring several flight parameters. The main goal of the project is to develop a low cost, small electric UAV that is capable of being highly flexible to perform different navigation missions, performances autonomous take-off and landing, also capable to fly autonomously, easy to build and maintain.

The main UAV features include:

- **Long Endurance:** accomplished by using green power technologies such as an electric propulsion system with solar power. This includes the use of highly efficiency solar cells, high capacity/density batteries, efficient compact motors and appropriate long endurance aerodynamic design;

- **Autonomous Flight:** accomplished by equipping the UAV with autopilot navigation systems such as inertial guiding systems and GPS;

- **Obstacle Avoidance:** accomplished by implementing an obstacle avoidance technique that includes detection, estimation, and avoidance planning of the obstacle;

- **High-strengh, Low-weight Structure:** accomplished by using composite materials, with fuselage/wing critical areas designed for good impact resistance on landing, using easy to manufacture techniques;

- **Multiple Mission:** accomplished by designing a sufficiently large payload range capability and developing upgradable modular avionics, to enable an easy software upload and/or hardware swap to meet the selected mission requirements.

To achieve the requirements and specifications of the UAV, there are several different tasks that need to be addressed in this project. These are the following:

1. Conceptual Design: This is the most important task of the project where several different configurations will be evaluated to meet or exceed the mission requirements in terms of endurance, size and cost. By the end of this task, one possible configuration will be selected and will form the basis for a further refined design in the following tasks.

2. Propulsion System: In this task several different electric propulsion system configurations will be evaluated in terms of performance, overall weight and cost. The selection of Li-Po rechargeable batteries. By the end of this task, the propulsion system configuration will be selected and the auxiliary available power for electronics estimated.

3. Aerodynamic Design: the aerodynamic design will define the wing geometry keeping in mind the battery dimensions. The fuselage and tail will also be modeled.

4. Structural Design and Aeroelasticity Analysis: The airframe will be designed in this task, where different wing structural solutions will be evaluated. It will be considered several different materials in order to meet the goal of achieving the light est and strong enough structure, while also keeping the manufacturing cost reasonable. An aeroelasticity analysis will be performed to guarantee that the UAV will fly.

5. Design for Manufacturing: In parallel with task 4, a manufacturing feasibility and integration study will be undertaken in order to ensure the manufacturability of the proposed designs.

6. Stability and Control: During this task, the control surfaces will be designed to provide enough stability and control authority to the aircraft. It will be used empirical data and results will be tunned in open air environment testing. The data gathered from open air environment testing will be used to develop the UAV controller.

7. Multidisciplinary Design Optimization: At this point, all the necessary analysis tools for the propulsion, aerodynamics, structures and controls are in place. As such, it is possible to couple all these into a multidisciplinary optimization fram work to refine the aircraft design.

8. Communication and Electronics: In this task the communications and electronic systems will be designed. There are several goals for this task:
design and implement the autopilot hardware and software, make the aircraft systems capable of flight logging and possibly telemetry to a ground station, and install all the sensors and actuators in the airframe.

9. Manufacturing: In this task the construction of the UAV will be accomplished. The goal is to build the airframe according to the detailed structural design, using advanced model building techniques. A total of two models will be built, a prototype.

10. Flight Testing: The full-scale prototypes testing will include systems checks on ground, open air environment tests to access aerodynamic performance, static thrust under varying battery voltages and, finally, flight tests. The aircraft will be operated under radio controlled mode, which allows for throughout checks of the battery powered propulsion system and used to test the overall design refinement and also the autopilot hardware and software.

The representation of the several different tasks that are required for the completion of the project of the UAV. This project work is part of the Communicatio ns and Electronics area and the main objective will be to implement and test the aut pilot hardware and software. In this process, it will also be implemented the Ground Control Station of the UAV which is an important requirement for the operation of the vehicle. The correct implementation of the autopilot is a crucial part of the project in order to fulfill the autonomous flight specification.

Unmanned Aerial Vehicles (UAVs) have lots of applications in various mission scenarios. The development in various areas has increased their endurance, payload capacity, speed, reduced mission costs.

There are many defence applications such as,

- Various surveillance scenarios
- Target mission, reaching particular location in munitions applications
- Following a moving target, and many more.

There are many civil applications as mentioned below,

- 3D mapping
- Search and rescue
- Weather monitoring and many more

Among the uses mentioned above, the current work is more focused on performance of UAVs in missions which require lot of maneuvering while navigating through waypoints. UAV maneuvering becomes more challenging in conditions wher e it needs to perform a minimum radius turns. The important condition when UAV perform minimum radius turn is UAV needs to follow a coordinated turn. Aircraft is said to be following a coordinated turn when it doesn't have any side sleep in turn. The path planning of maneuvering missions depends on various parameters of UAV, some of them are;

- UAV dynamics
- Maneuvering capabilities
- Range
- Cruise speed
- Wind conditions

Most of these parameters are known or we can have a good estimation based on the UAV design before the flight in mission planning phase. But accurate local wind conditions are difficult to calculate and predict, that's why it's estimated onboard and control actions are applied accordingly. The methods and algorithms used for estimation of wind plays very important role in robust wind tackling algorithms.

1.4 Scope of study:

This study focuses on the security application of UAVs. This necessitated the development of a mini UAV specifically for security purposes. The security system is analysed for shortcomings in the security site that was chosen. After identifying the requirements and limitations the focus shifted to integrating the mini UAV into a security system.
A fully autonomous mini UAV is developed that can send and receive telemetry from a ground control station (GCS) in order to relay its attitude and position.
The UAV can have automatic take-off and landing capabilities, but this has not been incorporated into this study. The UAV developed for this study is launched by hand in manual mode and piloted to the pre-set operational altitude. It is then switched to autopilot mode when it will automatically and independently follow waypoints at the predetermined altitude. The pilot is then required to land the UAV in manual mode.
A conventional off-the-shelf airframe is used since it is able to fly at slower speeds & still remain stable. This will expedite the development of the UAV. Further develo ment of the UAV can ultimately be done on other airframes that are more stable at higher speeds. This option will, however, not be investigated in this study.

1.5 Unmanned Aircraft System (UAS):

Unmanned Aircraft Systems (UAS), also commonly referred to as Unmanned Aerial Systems is defined as a system, whose components include the air vehicles and ass ciated equipment that do not carry a human operator, but instead fly autonomously or are remotely piloted and all equipment, UAS must be considered in a systems cont xt which includes the command, control and communications (C3) system, and pers nnel necessary to control the unmanned aircraft.

Unmanned Aircraft system (UAS) has been used recently a lot in militaryapplica ions as well as in civilian. Its importance and advantages in the search and rescue, real-time surveillance, reconnaissance operations, traffic monitoring, hazardous site inspection and range extension, recently it also used agriculture field. Moreover, UAS is suited for situations that are too dangerous and hazardous where direct monit oring of humanly not possible. In the unmanned aviation community UAS is growing field, in general terms," UAS" describes "the entire system that includes aircraft, control stations and data links". In reality, the system is far more complex organiz ation following element.

- Multiple aircraft
- Ground control shelters (C3)
- A mission planning shelter
- A launch and recovery shelter
- Ground data terminals
- Remote video terminals
- Modular mission payload modules
- Air data relays
- Miscellaneous launch, recovery, and ground support equipment

1.5.1 History of Unmanned Aircraft System (UAS):

The UAV has been expanded in some cases to UAVS (Unmanned Aircraft Vehicle System). The FAA has adopted the acronym UAS (Unmanned Aircraft System) to reflect the fact that these complex systems include ground stations and other element s besides the actual air vehicles i.e. Unmanned Aircraft. "UAS" describes "the entire system that includes aircraft, control stations and data link".

The first UAV was manufactured by the Americans Lawrence and Sperry in 1916. This is known as the beginning of "attitude control", which came to be used for the automatic steering of an aircraft. They called their device the "aviation torpedo" and Lawrence and Sperry actually flew it a distance that exceeded 30 miles. The development of UAVs began in earnest at the end of the 1950s, taking advantage of the Vietnam War or the cold war, with full-scale research and development contin uing into the 1970s. UAV called Fire bee. After the Vietnam War, the U.S. and Israel began to develop smaller and cheaper UAVs. These were small aircraft that adopted small engines such as those used in motorcycles or snow mobiles. They carried video cameras and transmitted images to the operator 's location. It seems that the prototype of the present UAV can be found in this period. The U.S. put UAVs into practical use in the Gulf War in 1991, and UAVs for military applications developed quickly after this. The most famous UAV for military use is the Predator; NASA was at the centre of the research for civil use during this period. The most typical example from this time was the ERAST (Environmental Research Aircraft and Sensor Technology) project. It started in the 1990s, and was a synthetic research endeavour for a UAV t at included the development of the technology needed to fly at high altitudes of up to 30,000 m, along with a prolonged flight technology, engine, sensor, etc. The aircraft that were developed in this project included Helios, Proteus, Altus, Pathfinder, etc., These were designed to carry out environmental measurements.

1.5.2 UAS Systems:

An unmanned aircraft system is a system comprised of three main features: the aircraft, the Ground Control Station (GCS or C3) and the operator.

- Unmanned Aircraft
- Command and Control Link/ Data Link
- Ground Control Station (GCS)

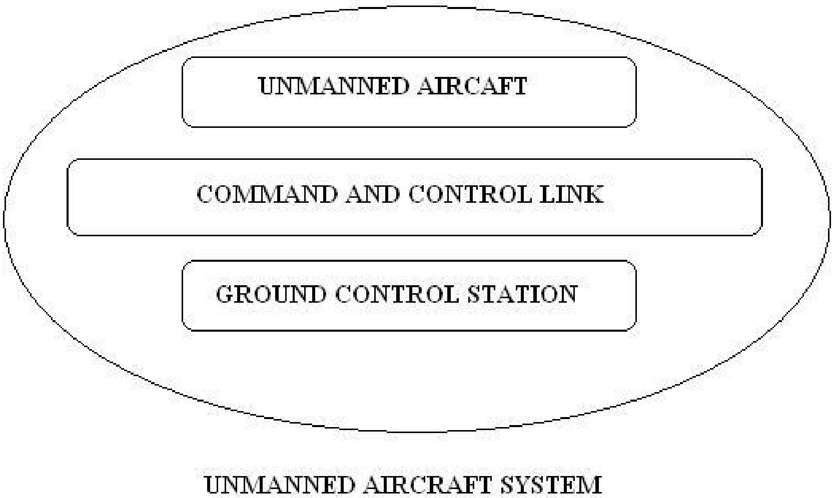


Figure 1-1: Unmanned Aircraft System Model

The UA is an acronym for Unmanned Aircraft, which is an aircraft with no pilot on board. UA can be remote controlled aircraft (e.g. flown by a pilot at a ground control station) or can fly autonomously based on pre-programmed flight plans or more complex dynamic automation systems and can carry a lethal or non lethal payload (These payloads can be high and low resolution cameras/video cameras, day and night reconnaissance equipment, warfare machinery (ESM, ECM, ECCM) weapons and generally any equipment required for the mission the UAV is designed for).

1.5.3 Classification of Unmanned Aircraft:

A powered vehicle that does not carry a human operator, can be operated autonomously or remotely, can be expendable or recoverable, and can carry a lethal or nonlethal payload. Ballistic or semi-ballistic vehicles, cruise missiles, artillery projectiles, torpedoes, mines, satellites, and unattended sensors (with no form of propulsion) are not considered unmanned vehicles. But as per increasing use in military area of UA, in battle field it may be possible above element is a component of UA. The UAV or UAVs (aircraft component(s)) and the required flight control and operating system which includes the control station(s), communication links, data terminal(s), launch and recovery systems, ground support equipment and air traffic control interface. Recently as per increasing use of UAS in Military, Civil and Other areas for different special purpose task. Significant efforts have been devoted to increasing the flight endurance and payload of UA, resulting in various UA configurations with different sizes, endurance levels, and capabilities. Here, classify UA according to their characteristics (aerodynamic configuration, size, etc.). UA platforms typically fall into one of the following four categories:

Fixed-wing UA:

which refer to unmanned airplanes (with wings) that require a runway to take off and land, or catapult launching these generally have long endurance and can fly at high cruising speeds.

Rotary-wing UA:

also called rotorcraft UAVs or vertical take-off and landing (VTOL) UAVs, which have the advantages of hovering capability and high maneuverability. These capabilities are useful for many robotic missions, especially in civilian applications. A rotorcraft UAV may have different configurations, with main and tail rotors (conventional helicopter), coaxial rotors, tandem rotors; multi rotors, etc.

Blimps:

such as balloons and airships, which are lighter than air and have long endurance, fly at low speeds, and generally are large sized.

Flapping-wing UA:

which have flexible and/or morphing small wings inspired by birds and flying insects. There are also some other hybrid configurations or convertible configurations, which can take-off vertically and tilt their rotors or body and fly like airplanes, such as the Bell Eagle Eye UAV. Another criterion used at present to differentiate between aircraft is size and endurance.

1.6 Unmanned Aerial Vehicle (UAV);

Unmanned Air Vehicles, or UAVs, are air vehicles capable of operating without any internal pilot, being remotely controlled by a Ground Control Station (GCS). The system that comprises all the required elements, personal and network to control and command the UAV is known as an Unmanned Aircraft System (UAS). They were first developed to support military operations, with focus on reconnaissance and attacking ground targets, but, nowadays, the importance of using UAVs for civilian applications is growing.

1.6.1 UAV Categories:

There are several different types of UAVs with different characteristics such as maximum ceiling, endurance, size or mission purpose. Based on these characteristics, Unmanned Aircraft Systems can be categorized as follows:

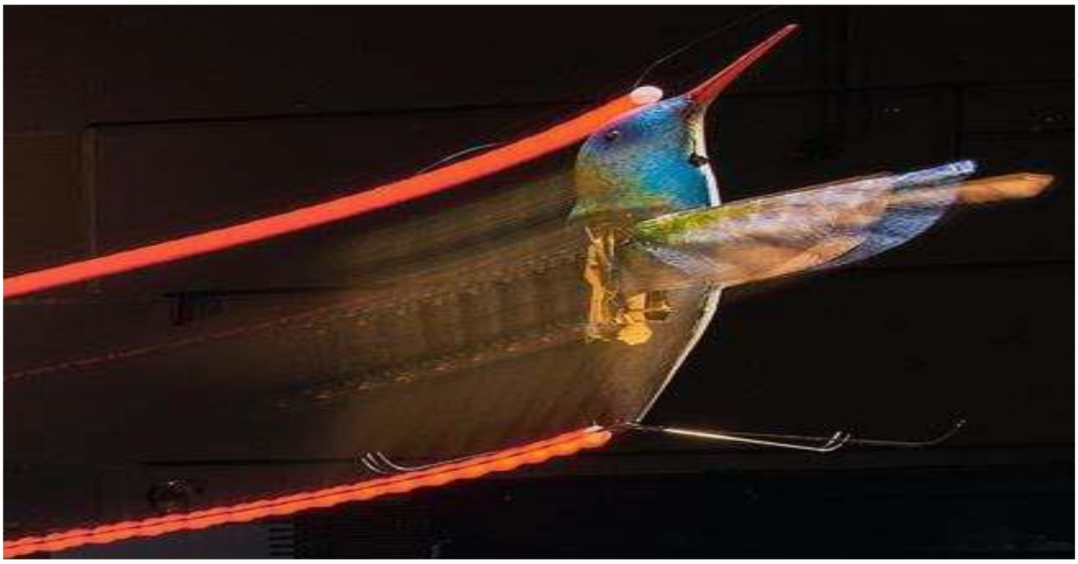
1. ***High Altitude Long Endurance (HALE)*****:** With a ceiling of over 15000 m of altitude and over 24 hours of endurance, they are used to carry out extremely long-range surveillance and reconnaissance missions, and are increasingly being armed. Usually operated from fixed bases.
2. ***Medium Altitude Long Endurance (MALE)*****:** They have a ceiling that varies from 5000m to 15000m and have 24 hours of endurance. Usually operated in a fixed base in similar missions of HALE UAVs but with a shorter range.

3. ***Medium Range or Tactical UAV (TUAV)*****:** They have a range between 100 km and 300 km and are smaller and operated within simpler systems than MALE and HALE UAVs.
4. ***Close-range UAV*****:** They usually operate at ranges of up to about 100 km & have both military and civil applications, such as reconnaissance, target designation, airfield security, power-line inspection, crop spraying, traffic monitoring, among others.
5. ***Mini UAV.(MUAV)*****:** Are usually UAVs lighter than 20 Kg but heavier than a Micro UAV, capable of being hand-launched and operating at ranges of up to 30 km. They are used by mobile battle groups and for diverse civilian purposes.
6. ***Micro UAV (MAV)*****:** They were originally defined as being an UAV with a wing span no greater than 150 mm and are principally required to fly in an urban environment. It is required to fly slowly and to have the ability to hover and even to be able to stop and sit on a wall or post. To achieve this some MAVs have less conventional configurations such as flapping wing aircraft. They are usually hand-launched.
7. ***Nano Air Vehicles (NAV)*****:** These are very small UAVs and are proposed to be used in swarms for radar confusion and conceivability. If with technological advancements it is possible to make cameras, propulsion and control systems small enough for these UAVs, they could be used for ultra short range surveillance.
8. ***Remote Piloted Helicopter (RPH) and Vertical Take-Off UAV (VTUAV)*****:** They are both UAVs capable of vertical take-off and landing, and also capable of hovering during a mission.
9. ***Unmanned Combat Air Vehicle (UCAV)*****:** These are UAVs which are capable of launching weapons and even air-to-air combat.

In figure 1-2 (a, b, c) shown several different UAV topologies are represented. While fixed-wing aircrafts are the more used, there are some applications that benefit from the use of less conventional configurations. Rotary-wing UAVs, such as quad copters, have vertical takeoff and landing capabilities, the ability to hover and have great flight stability which makes them a good option for providing a stable camera platform. The flapping-wing configuration is used in MAVs allowing them for blending in with the environment.

(a) General Atomics Predator XP - Fixed-wing UAV

(b) MikroKopter - Quadrotor UAV



(b) Nano Hummingbird - Flapping-wing UAV

Figure 1-2: Different UAV topologies

Category	UAS/ RPV	Weight of UAV	Normal Operating Altitude	Radius of Mission	Endurance	Altitude	Typical Use
SMALL	Kapothaka (RPV)	130 kg (AUW)	Low	(LOS)	90 min	Low Altitude	Surveillance/Reconnaissance
	Ulka	360 kg	100 m to 9 km	70 km (LOS)	5 min (max.)	Low Altitude	Surveillance/Reconnaissance
	Nishant	370 kg	3600 m AMSL	175 km (160 km) (LOS)	4 ½ h	Low Altitude	Surveillance, day/night reconnaissance gathering
TACTICAL	Lakshya	700 kg	9000 m (clean); 6000 m (tow)	100 km (LOS)	45 min	Low Altitude	Surveillance/Reconnaissance
MALE	Rustom	750* kg	25000 ft AGL	Upto250km (LOS)	12-15h	Medium Altitude	Surveillance/Reconnaissance
	Rustom-H (Future Project)	750 * kg	Up to up to 30,000 AGL	250 km And up to 350km (LOS)	up to 35 h	Medium Altitude	Surveillance/Reconnaissance
STRIKE/ COMBAT	Auro (IUASV)		30,000 ft with payloads	Expected to draw Several Evolutionary Technologies from the Rustom-2			

Table – 1-1: UAV Classification of Categories Wise

1.6.2 UAV Types:

Target and decoy - providing ground and aerial gunnery a target that simulates an enemy aircraft or missile

- **Reconnaissance** - providing battlefield intelligence
- **Combat** - providing attack capability for high-risk missions
- **Research and development** - used to further develop UAV technologies to be integrated into field deployed UAV aircraft
- **Civil and Commercial UAVs** - UAVs specifically designed for civil and commercial applications.

<u>We select TARGET and DECOY type of UAV for our project:</u>

Target UAVs (drones) are used for air defense training and scenario simulation.

Decoy drones are used to "fool" enemy aircrafts, AAA guns, SAMs and Radar.

1.6.3 UAV Roles/Tasks:

An aircraft, whether manned or unmanned, is designed to perform a particular task. It is up to the designer to decide if that task is better suited with a manned aircraft or not. But there are several roles in which having an UAV performing will always be an advantage.

Dull Role: Military and civilian applications such as extended surveillance can be a dulling experience for the crew, with many hours spent without relief. This can lead to a loss of concentration and, consequently, a loss of effectiveness of the mission. An UAV can be a better and cheaper option for performing these roles, while also having a better efficiency. The use of UAVs also allows for the ground operators to work in a shift pattern reducing their working hours.

Dirty Role: Also applicable to military and civilian applications, roles such as monitoring the environment for nuclear and chemical contaminations puts the aircrew unnecessarily at risk, while detoxification the aircraft in case of an UAV is easier. Another important role that is becoming more and more successfully conducted by UAVs is crop spraying.

Dangerous Roles: In military roles such as reconnaissance in a heavily defended area an UAV will always be better option than a manned aircraft. Due to their smaller size and greater stealth ability, an UAV will be more difficult to detect and to be strike down by the enemy defense system. Another advantage is that the UAV operator is under no personal threat and will, therefore, be able to concentrate and perform the task with a more probability of success. There are civilian tasks such as power-line inspection and forest fire control that an UAV can carry out without the risk of personnel endangerment. Another dangerous role that can be carried out by an UAV is operating under extreme weather conditions.

Covert Roles: In both military and civilian policing operations, there are roles where it is important not to alert the" enemy" to the fact that they have been detected. UAVs can have lower detectable signatures due to their smaller size which make this role more readily achievable.

Research Roles: UAVs are being used in the aeronautical field for research and development. The use of UAVs as small replicas of manned aircraft, for test purposes, enables airborne testing to be carried out under real conditions but more cheaply and with less hazard.

Environmentally Critical Roles: More related to civilian roles, UAVs will usually cause less environmental pollution than a manned aircraft. UAVs are usually smaller, with less mass and with a lower power consumption thus reducing the levels of pollution and noise created. Roles where the local inhabitants may object to the noise produced by low flying aircraft or roles that may cause disturbance to farm animals are better suited with an UAV.

1.6.4 Applications of UAV:

UAVs were originally designed and developed for military applications and UAV deployment is expected to reduce the risk of human life loss. Examples of military uses of UAVs are border patrol, search-and-rescue, bombing, reconnaissance and target acquisition. Recently, however, great interest has been shown in using UAVs in civilian applications. Possible civilian applications of UAVs are listed below:

- Natural disaster monitoring
- Humanitarian relief
- Environmental monitoring
- Weather and storm tracking
- Agricultural applications, such as crop monitoring
- Cargo transport
- Wireless communication
- Wildlife monitoring
- Security surveillance
- Traffic and accident monitoring
- Area mapping
- Emergency supply delivery
- Law enforcement
- Riot control
- Aerial photography

It can be seen that there are many civilian applications for UAVs, mainly because they can substitute the “dull, dirty and dangerous” CPA missions. It seems as if there are numerous gaps in the market that can be filled by UAVs when the regulation is finalized.

Currently, the main UAV applications are defence related and the main investments are driven by future military scenarios. Most military unmanned aircraft systems are primarily used for Intelligence, Surveillance and Reconnaissance (ISR) patrols and strikes. It also uses for Chemical, Biological, Radiological and Nuclear (CBRN) detection, or simply those tasks considered too dangerous or politically challenging for manned aircraft to undertake. UAS are preferred over manned aircraft not only because of downsizing risk and increasing confidence in mission success avoiding at the same time the human cost of losing lives if the mission is unsuccessful, but also because unmanned vehicles have better and sustained alertness over humans during dull operations. Furthermore, many other technological, economic, and political factors have encouraged the development and operation of UAS. Unmanned aircraft operations have been under the scope of the Japanese Ministry of Agriculture, Forest and Fisheries and its affiliated association, the Japanese Agriculture Aviation Association.

Military Applications: UAVs are capable of performing a variety of missions supporting military and intelligence purposes. The list below presents the military applications that UAVs have served up to now.

- Reconnaissance Surveillance and Target Acquisition (RSTA).
- Surveillance for peacetime and combat Synthetic Aperture Radar (SAR).
- Deception operations.
- Maritime operations (Naval fire support, over the horizon targeting, anti-ship missile defence, ship classification).
- Electronic Warfare (EW) and SIGINT (SIGnals INTelligence).
- Special and psyops.
- Meteorology missions.
- Route and landing reconnaissance support.
- Adjustment of indirect fire and Close Air Support (CAS).
- Battle Damage Assessment (BDA).
- Radio and data relay
- Nuclear cloud surveillance

Military roles according to arm and forces

Navy:

- Shadowing enemy fleets
- Decoying missiles by the emission of artificial signatures
- Electronic intelligence

- Relaying radio signals
- Protection of ports from offshore attack
- Placement and monitoring of sonar buoys and possibly other forms of anti submarine
- Warfare

Army:

- Reconnaissance
- Surveillance of enemy activity
- Monitoring of nuclear, biological or chemical (NBC) contamination
- Electronic intelligence
- Target designation and monitoring
- Location and destruction of land mines

Air Force:

- Long-range, high-altitude surveillance
- Radar system jamming and destruction
- Electronic intelligence
- Airfield base security
- Airfield damage assessment
- Elimination of unexploded bombs

Civil Applications: Today, the civilian markets for UAVs are still emerging. However, the expectations for the market growth of civil and commercial UAVs are very high. Potential civil applications of UAVs are Inspection of terrain, pipelines, utilities, buildings, coast guards, border patrol organizations, rescue teams, police, etc.

- Policing duties
- Traffic spotting
- Fisheries protection
- Pipeline survey
- Sports events film coverage
- Agricultural operations

- Power line survey
- Aerial photography
- Border patrol
- Surveillance of coastal borders, road traffic, etc.
- Disaster and crisis management search and rescue
- Environmental monitoring
- Agriculture and forestry
- Firefighting
- Communications relay and remote sensing
- Aerial mapping and meteorology
- Research by university laboratories
- Communications relay
- Law enforcement
- And many other applications

1.7 General context:

In recent years, we have seen a rapid growth of UAV's (Unmanned Aerial Vehicle) technology. Primarily this technology has only been used in the military field. Because of the creation of autopilots at a reasonable price and the fast growth of developer communities that are constantly developing drone firmware, there was a big spread of this technology in the professional and hobbyist fields. A drone is controlled by a remote control (allowing pilots to control the vehicle manually) or by a ground control station (allowing pilots to create a flight plan that includes a set of waypoints and some flight modes). Some of the most used applications (using ground control station) include surveying, maintenance and surveillance tasks, transportation, search and rescue.

The two main components that make a drone fly are the autopilot and the firmware. Other components can be connected in order to permit the controlling vehicle (as the two control tools mentioned above) or the accurate detection of vehicle information (using additional sensors). A simple configuration of a drone suite is shown. This configuration includes an autopilot with some components installed (RC receiver and GPS module), a radio control transmitter or a ground control station, a battery and finally the quadcopter which contains all these components except the control tools. In the autopilot is also installed the firmware which manages sensor readings and executes tasks that make the drone fly.

Ardupilot is an open source autopilot platform created from the DIY Drones community, able to control autonomous multicopters, fixed-wing aircraft and ground rovers. It is based on the Arduino platform. Its tools for altitude detection evolved from using thermopile technology to the use of Inertial Measurement Unit (IMU) that combine the accelerometer, gyroscope and magnetometer sensors. In addition, other sensors can be installed such as GPS or sonar to provide more accurate information about position or altitude.

Referring to the firmware, a very important aspect is how the system manage these sensor values. We want to have vehicles that react immediately to new sensor readings. For example, when external factors are so strong as to affect the desired position, the system should notice it and adjust the vehicle position. Another fundamental aspect is that no computation must be done when the sensors do not detect new values (or at least the computation time must be decreased). Decreasing the computation time, the system has more time to execute other tasks. This implies an optimized use of battery (one of the limitations of drones is the autonomy, for a simple quadcopter the autonomy is about 20 minutes.

CHAPTER # 02

DESIGN OBJECTIVES, ISSUES & THEIR ANALYSIS

2.1 Design Goals, Aims & Objectives:

The main goals of our project is to design and develop a guidance system for an autonomous target/decoy UAV and to implement and test an autonomous flight control system for the UAV. This system will be composed by an autopilot, a GCS and all the required equipment for data transmission between the autopilot and the GCS. To meet this goal, there are several objectives that need to be accomplished. The objectives in this project include:

- Detailed design of the autonomous flight control system;
- Assembly of the flight control system using off-the-shelf components;
- Operate in remotely piloted and fully autonomous modes throughout all phases of flight.
- Modular with 5 minutes' land to launch by replacing battery and swapping data storage.
- Aircraft does not exceed 2.5 kg gross takeoff weight.
- Flight demonstration using waypoint navigation.

The main objective is to develop an autonomous system for target and decoy UAVs, for

- **Autonomous flight**
- **Auto take-off and landing**
- **Auto stable**
- **Cruise Control.**
- **Autonomous way-point navigation**

The main aim is to develop a top-level guidance system

- **To reduce ground and air communication latency.**
- **Eliminate the need of pilot**
  Mission scripting

2.2 Design Issues/Problems & their Analysis:

2.2.1 Autopilot resetting:

1. Issue/Problem:

While the autopilot is in manual mode the pilot has full control. If the autopilot is switched into any other mode, the GCS reports an autopilot telemetry link loss. As a result, no information is available on the GCS and the UAV flies independently. The pilot is able to switch into manual mode again, but the UAV does not report linking with the UAV again.

It was originally thought to be a problem with the baud rate or package size used to communicate with the UAV. The information that needs to be sent during manual mode is less than the information sent during autopilot mode. If the baud rate is set too low the GCS would report no telemetry in autopilot. The original baud rate was set to 38,400 and re-adjusted to 57,600. This did not solve the problem and further research was done.

While testing the autopilot on the ground it was noted that the autopilot resets itself when it was switched to any other mode than manual. The problem was the ESC that was not supplying enough current for the autopilot through its battery eliminator circuit (BEC) causing the telemetry link loss.

1. Solution/Analysis:

The autopilot required 15 s to recalibrate all the sensors during start-up.
Thus, if it stayed in autopilot mode it would probably have collided before being able to complete the calibration cycle. The UAV was always able to switch back to manual mode. This allowed the pilot to resume manual control and avoid collisions.

The speed control was switched from the standard 20 A to a 40 A speed control. Changing the speed control allowed the ESC to supply adequate power for both the autopilot and brushless out-runner motors. This kept the autopilot from resetting itself.

2.2.2 Maintaining airspeed in level flight:

2 Issue/Problem:

With Arduino ArduPilot Mega the throttle is adjusted to maintain a constant airspeed. The user must specify an upper-, lower- and cruise throttle setting, as well as the req-uired cruising airspeed (13 m.s-1 for this project). The autopilot would then regulate the airspeed by applying the maximum specified throttle percentage (62% for this project) until the mini UAV reaches the required airspeed. It would then lower the airspeed by setting the throttle to the cruise throttle position (52% for this project). If the speed exceeds the required airspeed it would lower the throttle setting to a minimum, namely the lower throttle setting (35% for this project).

Some autopilots regulate the throttle by using a climb-, cruise- and descend setting. Using speed feedback allows the UAV to maintain its airspeed more accurately than when compared to the three different throttle settings. An airframe with a low stalling speed was essential when the throttle is adjusted too low by the autopilot.

2. Solution/Analysis:

The UAV was flown in manual mode to determine the throttle settings. The throttle percentage required to maintain a steady flight speed was then noted by the flight operator. The cruise throttle was set to this percentage. The maximum throttle was adjusted to 10% above the cruise throttle setting which prevented the autopilot from setting the throttle too high.

2.2.3 Maintaining height:

3 Issue/Problem:

The UAV lost height during the test flight. It followed the waypoints successively, but went through each waypoint at a lower height. It was originally thought to be an electronic navigation gain problem. Adjusting the navigation gain on the elevator servo only reduced the rate of descend over each waypoint.

3. Solution/Analysis:

The first problem was that the waypoint altitude was specified Above Mean Sea Level (AMSL). Thus, it was tracking the waypoints at a height of 50 m above sea level rather than 50 m above ground altitude. This was corrected by downloading another GCS called ArduPilot Mega Planner. It allowed the default altitude to be set at a height above ground altitude. This setting was retained when using GCS.

4 Issue/Problem:

Another problem was that the UAV was not supplying enough up-elevator deflection during the turns which caused the UAV to lose height while turning.

4. Solution/Analysis:

This was corrected by adjusting the pitch compensation value which adjusts the amount of up-elevator that aids in maintaining a constant altitude turn. The pitch compensation value is the proportional gain of the PID loop that coordinates the turns.

2.2.4 Errors and Problems Occurs during this project:

At the time of working on this project we faced many errors and problems, these errors and problems are discussed below;

- The first and foremost problem we faced is in the selection of Flight Controller, whose performance is efficient, intelligent, cheaper and cost effective solution. So we choose ArduPilot Mega APM 2.8.
- Errors occurs with the version of Mission Planner software with the Flight controller that’s why we use older version (Mission Planner 1.2.92 version).
- Errors occurs during selection of board and com port of Flight controller APM 2.8.
- Flight controller APM 2.8 firmware uploading error through Mission Planner.
- Errors occurs during calibration and interfacing of Compass, GPS (Global Positioning System), RX/TX Remote (Transmitter/Receiver), Telemetry Radio and Servos.

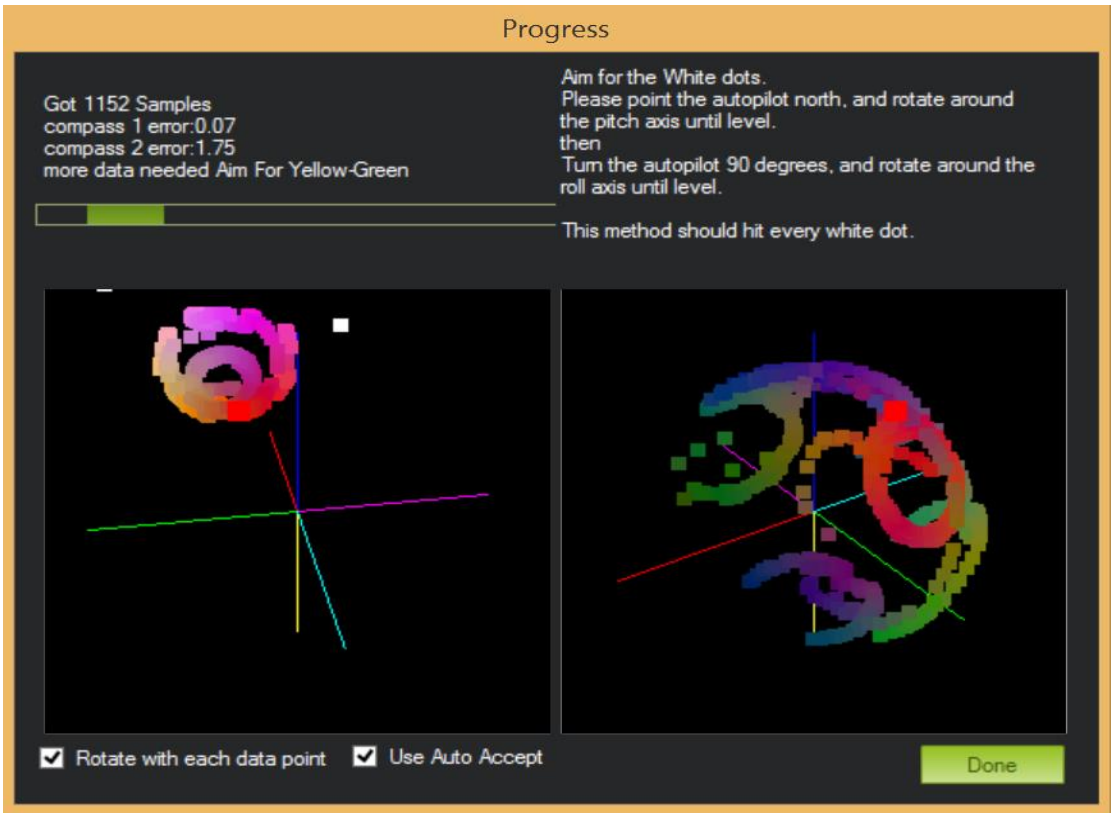


Figure 2-1: Compass Calibration Error

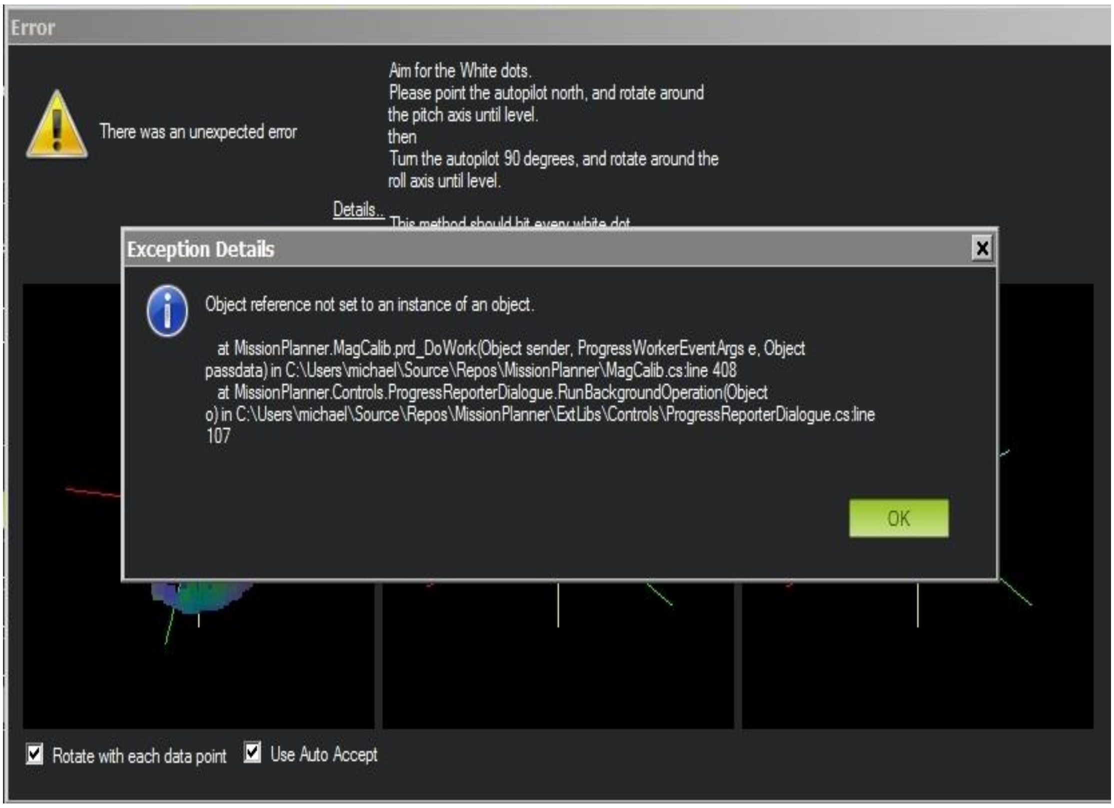


Figure 2 –2: Unexpected Error during compass calibration

- GPS interfacing errors, we cannot get the GPS/Compass to work in Mission Planner, they gave Bad GPS Health message.

- Issues and errors occurs during the wireless connection of telemetry radio with the flight controller from ground to air.
- Learning and understanding of software (Mission Planner & X-plane 10) takes a lot of time.
- Faced communication errors, when connecting Mission Planner & X-plane with each other for HIL (Hardware In Loop) simulation.
- Power issues because APM 2.8 requires input of 2000mA current and 5.37 V voltage that's why we connect APM Power module with it, which converts the input current and voltage into desired output current and voltage.

Figure 2–3: Data Logging and graph Error

- Errors occurs during data logging and graphs of different parameters.
- Faced the problem of delaying our shipment of our UAV's parts & electronic components.
- In designing phase of our plane structure, we faced problem of weight (weight of plane structure + battery weight), due to which we have to use a high torque and RPM Throttle motor.

Issues occurs with battery timing 1700mAh Li-Po battery gives 5 to 7 minutes' flight time backup and 2200mAh Li-Po battery gives 7 to 10 minutes' flight time backup, so we go for the heavy 3 cells 5200mAh Li-Po battery that gives 12 to 15 minutes' flight time backup, which is also compatible with the maximum weight of the whole plane that Throttle motor can handle.

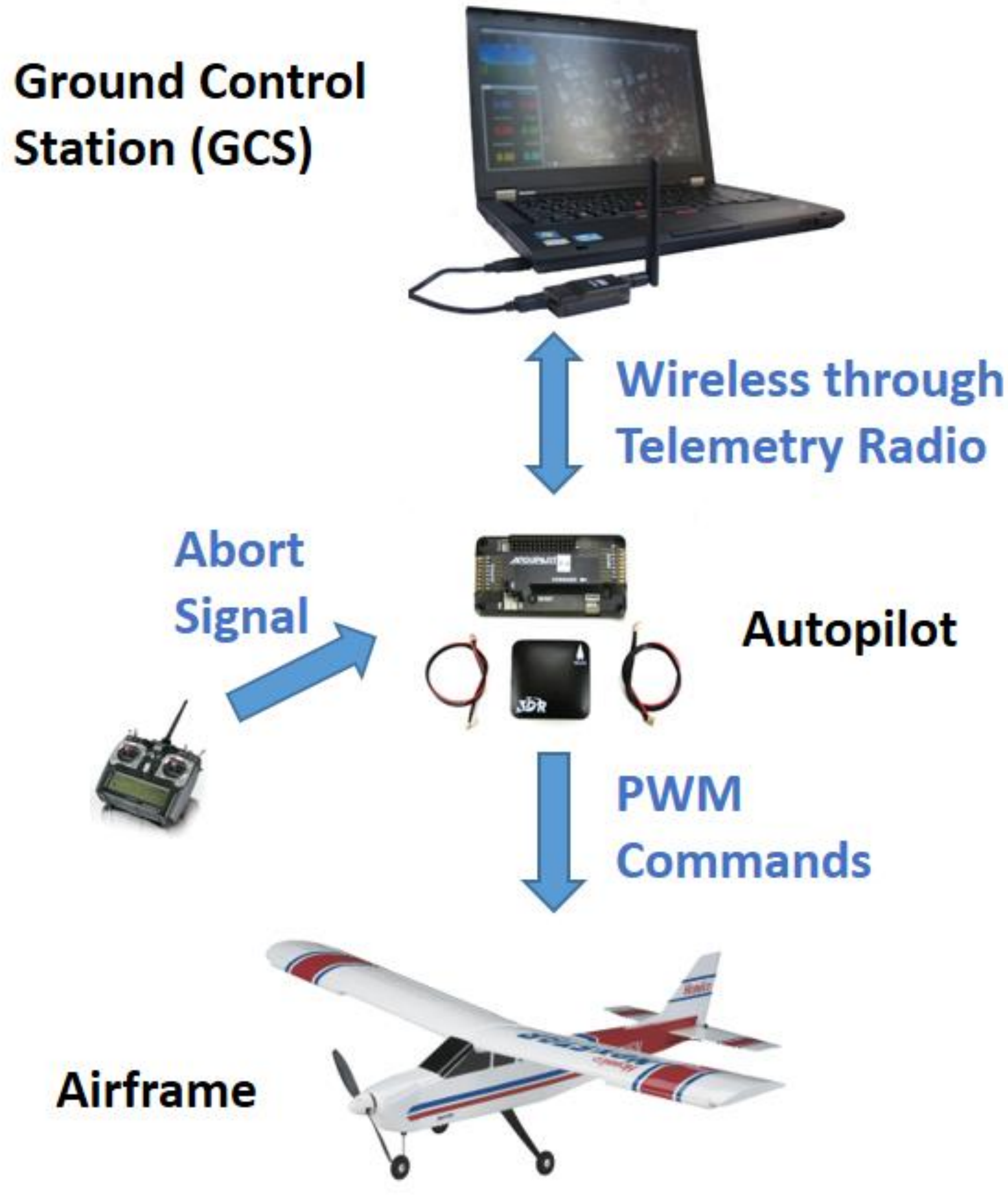
CHAPTER # 03

DESIGN SPECIFICATIONS

3.1 UAV Hardware Architecture Overview:

There are three main components of UAV Hardware Architecture. They are as follows:

1. Ground Control Station (GCS)
2. Autopilot
3. Airframe



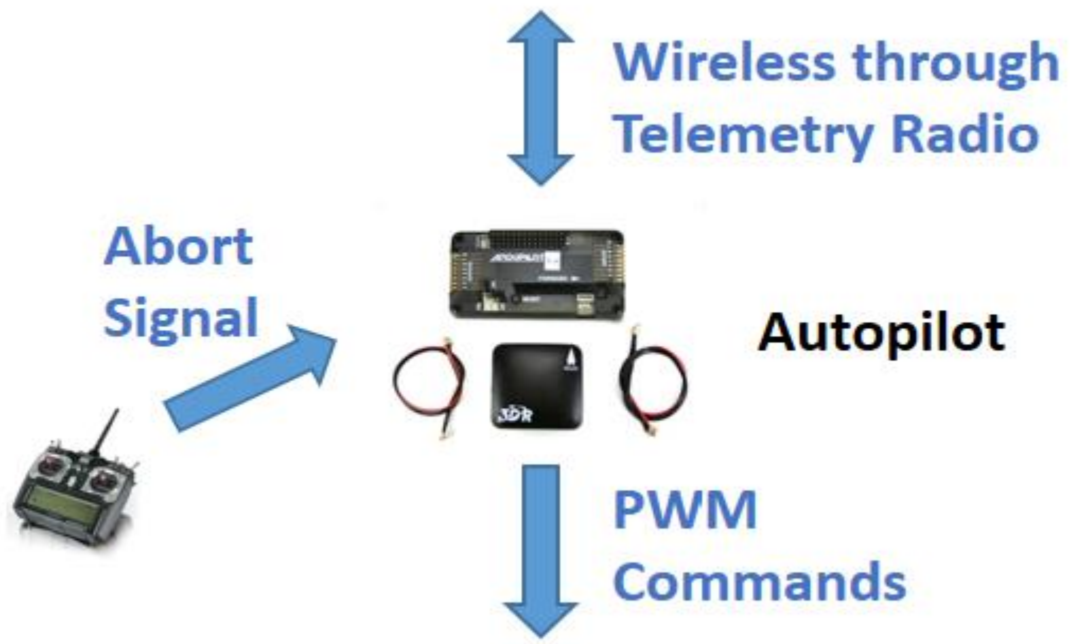
ELECTRICAL COMPONENTS:

This section will cover the hardware and software used in the project, as well as why each was chosen. The following section will describe how this hardware and software was setup, connected, and used in order to achieve the desired functionality.

HARDWARE:

3.1.1 UAV Autopilot Components:

1. 1 x Autopilot/Flight Controller (Ardupilot Mega APM 2.8)
2. 1 x Ardupilot Mega APM Power Module
3. 1 x Battery Elimination Circuit (UBEC) (5Amp)
4. 1 x GPS with Compass (Ublox NEO 7m)
5. 1 x Radio Control RC Transmitter Receiver (Fly Sky FS-CT6B)



3.1.2 UAV Air Frame Components:

1. 1 x Frame/Body of Aircraft (Wooden Mechanical Structure)
2. 1 x Brushless DC (BLDC) Motor (Turnigy G46)
3. 1 x Electronic Speed Controller (ESC) (40 Amp 30C)
4. 3 x Servo Motors (Futaba 3001)
5. 1 x Battery (11.1V 5200mAh 30C Li-Po Battery)

3.1.3 UAV Ground Control Station (GCS) Components:

1. 1 x Telemetry Radio (433MHz)
2. 1 x Laptop (Mission Planner & Xplane softwares pre-installed in the Laptop)

3.1.1 UAV Autopilot Components:

Autopilot:

An autopilot is a system that is used to automatically guide a vehicle without the assistance of a human operator. They have been widely used in air vehicles, boats, spacecraft's, missiles and even on autonomous land vehicles. There has been a significant evolution of the autopilots over the time, and they have evolved from simple autopilots, that only held altitude, to autopilots that are capable of complex operations such as landing an aircraft.

The Autopilot is the essential component in the autonomous UAV navigation. The Autopilot must have these necessary features which are derived directly from the mission requirement analysis:

1. Autonomous and accurate navigation along the planned mission.

2. The Autopilot must have a ground control station which could retrieve GPS, altitude of the plane, Airspeed of plane, Orientation and other essential plane parameters.

3. Configurable or Programmable fail-safe mechanism for both radio-link loss and GPS loss.

An UAV autopilot has to be capable of consistently guiding the UAV through waypoints or following reference paths. It is an integrant part of any UAV flight control system. The flight control system communicates with the GCS using telemetry, receives GPS data for position update and sends out control inputs for the servo motors on the UAV.

An UAV autopilot system is a closed-loop control system that has two parts: the controller and the state observer. Usually, the state observer is an inertial guidance system that includes gyro, acceleration and magnetic sensors. There are other attitude determination devices such as infrared and vision based ones. The sensor measurements and GPS data is passed to a filter that generates estimates of the current position of the vehicle. These estimates are then passed to the controller that, based on the control strategy employed, will send control inputs to the actuators. A schematic of an autopilot system is shown in Figure 3-1.

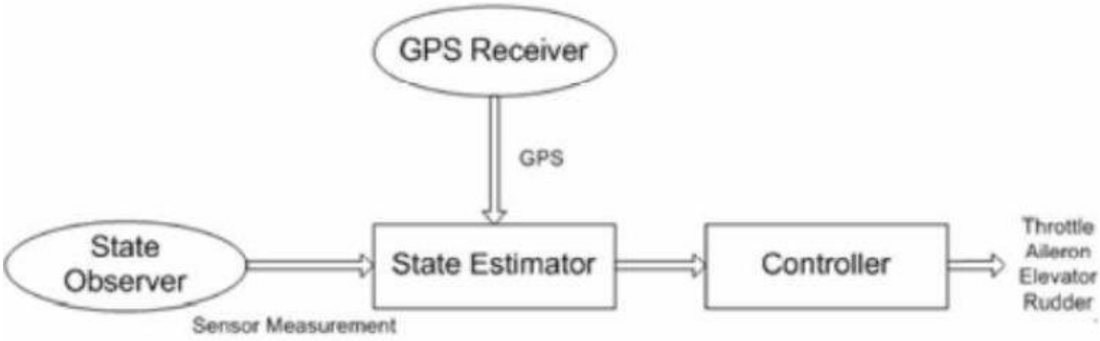


Figure 3-1: Structure of UAV Autopilot

For this project it is important that the selected autopilot respects the following requirements:

- Small dimensions & weight;
- Low price;
- Waypoint following capabilities;
- Auto take-off & landing;
- Configurable.

The comparison & selection of the of the autopilot that will be implemented on the UAV will be presented below.

Autopilot Hardware Design and Prototyping:

The UAV autopilot hardware system consists of two parts, the first part is for sensor processing and the second part is for stabilization and navigation control.

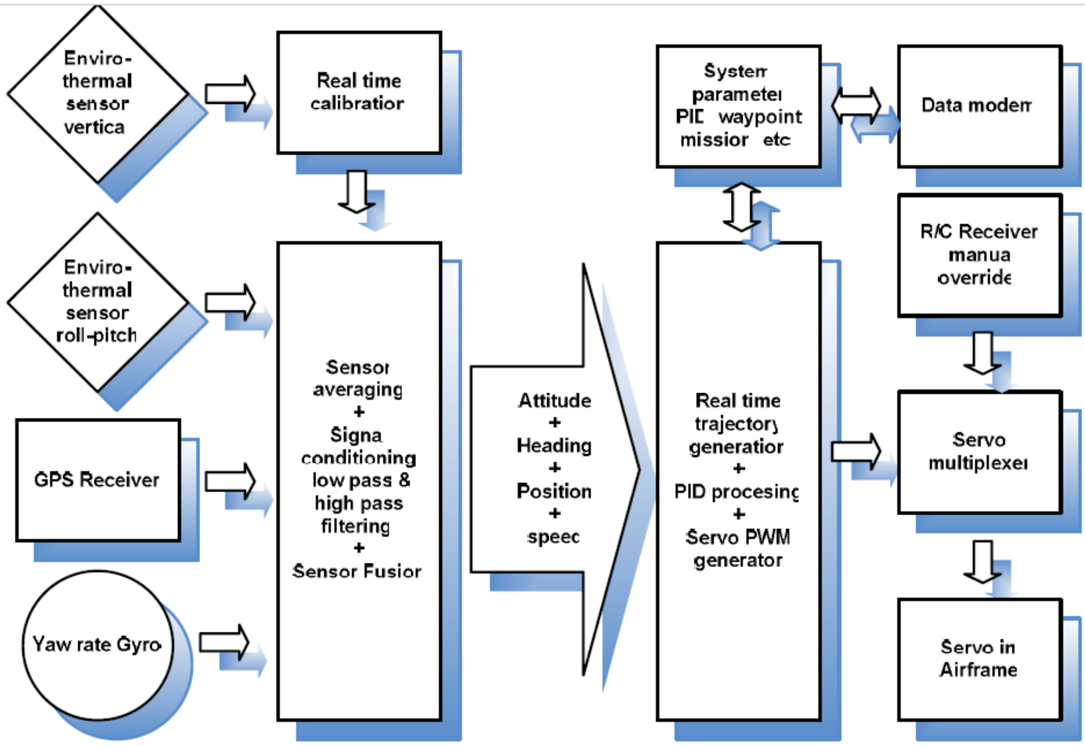


Figure 3-2: Autopilot hardware block diagram

Comparison of Various Autopilots:

The tables below summarize specifications of the commercial and open source autopilots, physical specifications, sensor ranges, & autopilots functions.

A. *Physical Specifications:*

Autopilot	Commercial				Open Source	
	Vector	Mp2028g	Kestrel v2.4	Piccolo SL	APM 2.8	Revolution
Size (cm)	6.88x4.5x7.45	10.0x4.0x1.5	5.08x3.5x1.2	13.1x5.7x1.9	7.1x4.5x1.35	3.6x3.6x1.2
Weight (gm)	300	28	16.8	110	43	14
Power	2.5W	140mA@6.5V	500mA @ 3.3V	4W	200mA @ 5V	Is very low
Price	> $3500	$3500	$5000	> $5000	< $250	$120
Temp. (C)	-40 to 85		-40 to 85	-40 to 85	-40 to 85	
I/p. voltage. V	7 to 36	4.2 to 26 v	5 – 30	5 – 6	5 – 6	4.8 – 8.4
CPU	Dual 200 MIPS	3		16 MHz	16 MHz	210 MIPS
Memory	8 MB	-	-	4Mb	4Mb	-

Table 3-1 (a): Physical Specifications of various Autopilots

B. *Sensor Ranges:*

Autopilot	Vector	Mp2028^{g}	Kestrel v2.4	Piccolo SL	APM 2.8	Revolution
h (m)	-600 – 9000	12000	-800 to 7000	-	-	-
a_{max} (g)	8	2	10	6	2	-
Va_{max}	230 m/s	140 m/s	130 m/s	100 m/s	-	-
ω_{max}	300 deg./sec	150 deg./sec	300 deg./sec	300 deg./sec	250 deg./sec	-

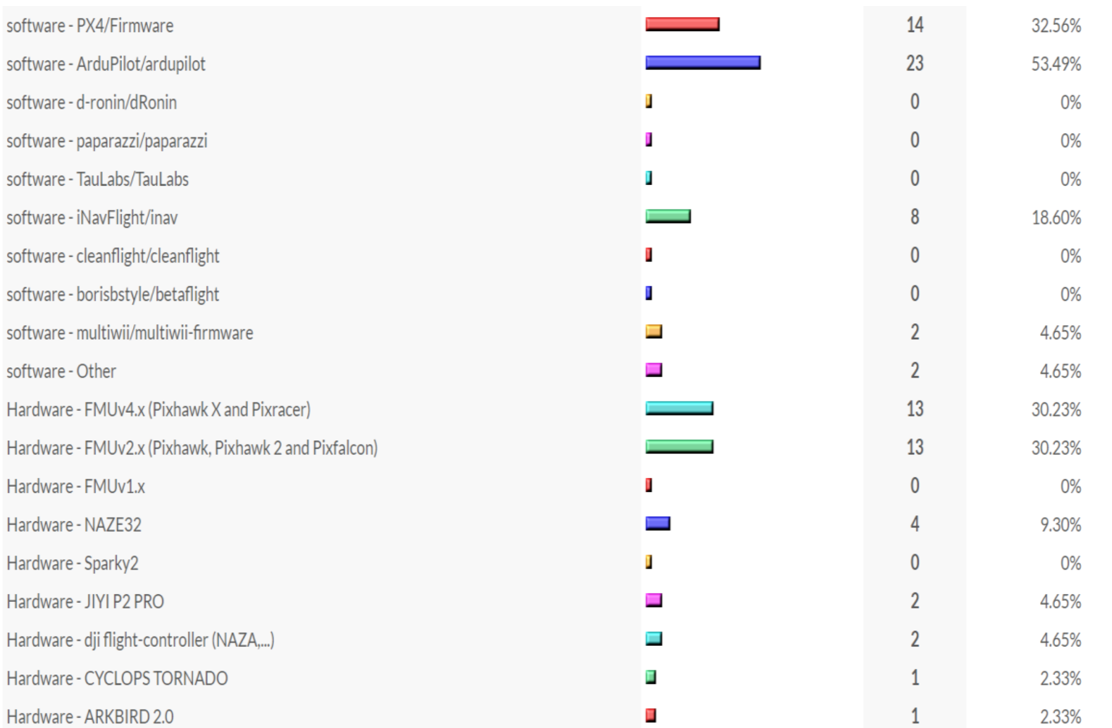
Table 3-1 (b): Sensor Ranges of various Autopilots

C. *Autopilot Functions:*

Autopilot	Vector	Mp2028^{g}	Kestrel v2.4	Piccolo SL	APM 2.8	Revolution
Waypoint navigation	√	√(1000 pts.)	√	√(1000 pts.)	√	√
Auto takeoff / landing	√	√	√	√	√	√
Altitude hold	√	√	√	√	√	√
Airspeed hold	√	√	√	√	√	√
Multi-UAV support	√	√	√	√	√	√
Return home	√	-	-	-	√	√

Table 3-1 (c): Autopilot Functions of various Autopilots

Selection of Autopilot/Flight Controller:



Hardware - Other		5	11.63%
Ground Control Station - tower		6	13.95%
Ground Control Station - ez-gui		3	6.98%
Ground Control Station - openPilot		1	2.33%
Ground Control Station - taulabs		0	0%
Ground Control Station - Other		13	30.23%
OSD - mwosd		5	11.63%
OSD - night-ghost/minimosd-extra		6	13.95%
OSD - Other		6	13.95%

Table 3-1 (d): Comparison table of Autopilot/Flight Controller

So, for the selection of Flight Controller, we'll select **Ardupilot APM 2.8** because it is **cheaper, cost effective, efficient, intelligent** and **easy to configure** as compare to the other flight controllers.

3.1.1.1 ARDUPILOT MEGA APM 2.8 (Autopilot/ Flight Controller):

The autopilot system chosen for the project was the ArduPilot Mega 2.8 (APM 2.8). This autopilot system is plug and play, completely an open source autopilot system based on an Arduino platform. Figure below illustrates some features of APM 2.8 autopilot for example. The last version of these types of autopilots are APM 2.8.

This autopilot can be used in fixed-wing and rotary-wing vehicles such as helicopters and multi-rotors. The specifications are given below The Ardupilot board consists of the main processor and the Inertial Measurement Unit. It has 4 serial ports, ports for GPS, wireless telemetry, power module and external compass connection, and an USB port. This autopilot is capable of autonomous take-off and landing, waypoint navigation, two-way telemetry and has a built-in hardware failsafe that allows the aircraft to return to the launch base when the radio signal is lost. The APM 2.8 can be used with an open source ground station application such as the Mission Planner, shown in Figure below. This software allows the user to calibrate and configure the autopilot, plan and save missions and view live flight data. The nominal voltage requirement for the autopilot system is 5.37 V +/ 0.5 V and it has a current draw in the 2000 mA range. The ArduPilot Mega 2.8 is shown below in Figure.

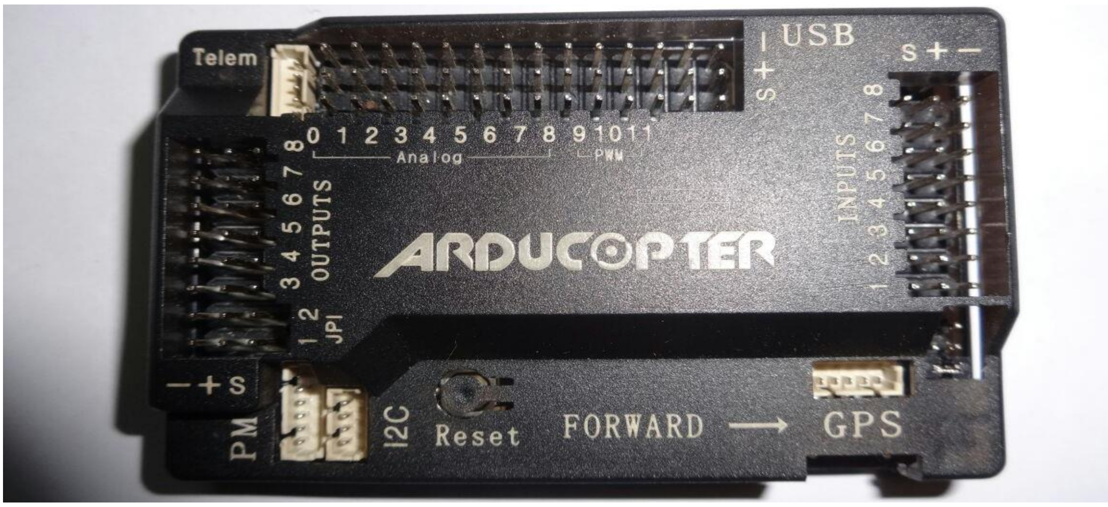


Figure 3-3 (a): Ardupilot Mega (APM) 2.8

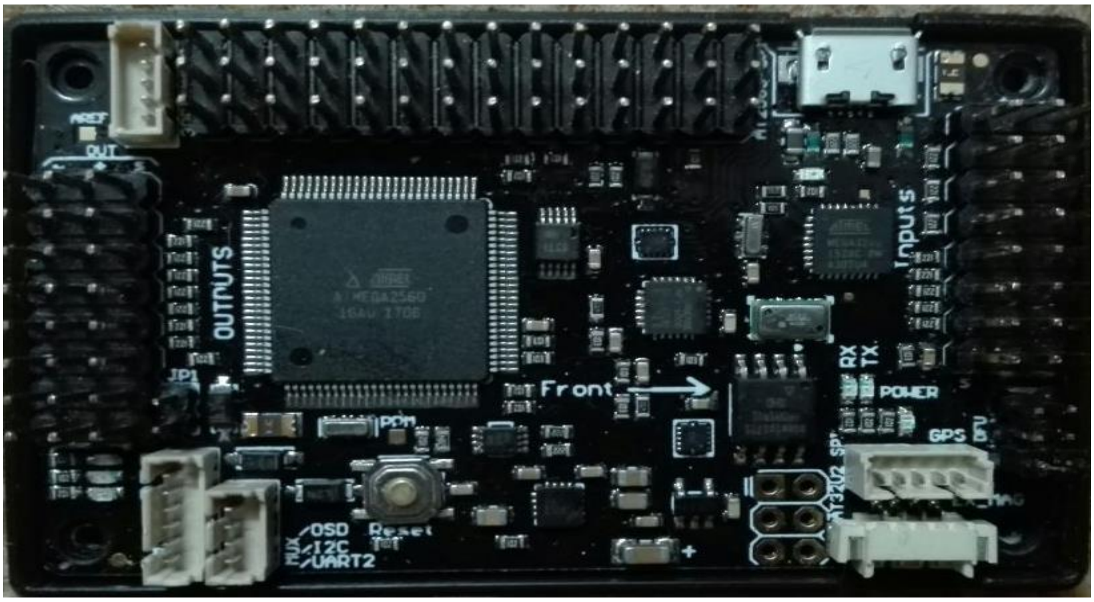


Figure 3-3 (b): APM 2.8 Internal front side

Figure 3-3 (c): APM 2.8 Internal back side

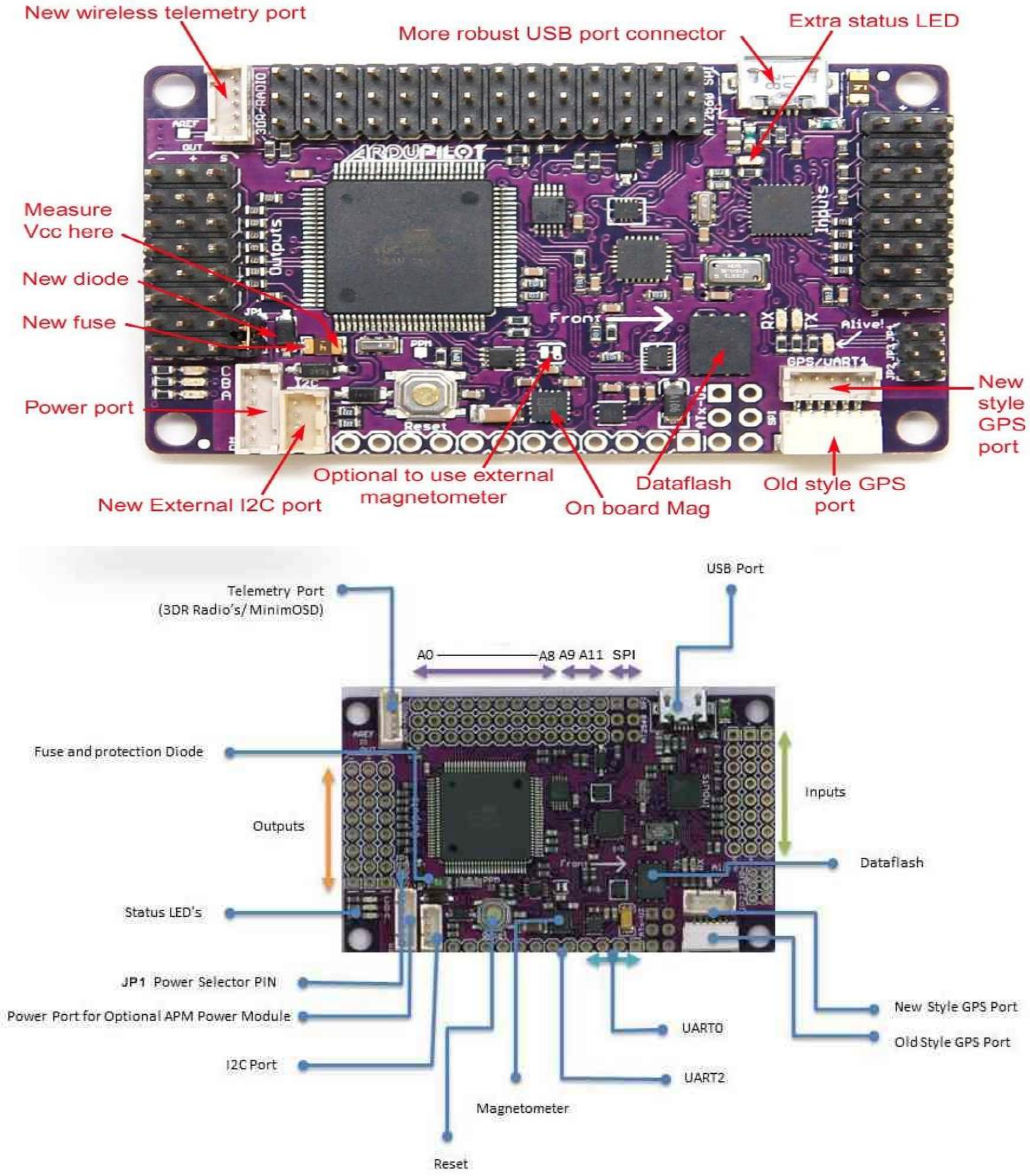


Figure 3-3 (d): Ardupilot Mega autopilot pin assignment

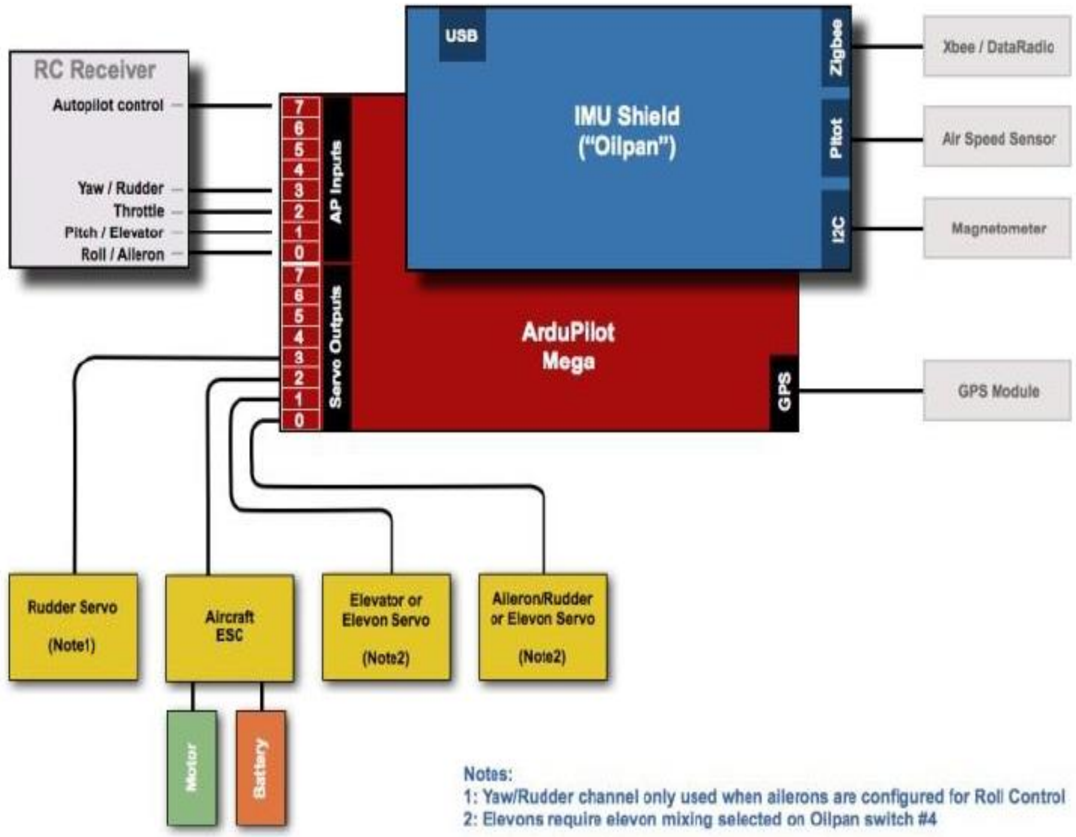


Figure 3-3 (e): Ardupilot Mega Block Diagram

Capability	**APM**	**Proposed Solution**
GPS	On-board	On-board
3-axis Accelerometer	On-board	On-board
3-axis Gyroscope	On-board	On-board
3-axis Magnetometer	On-board	On-board
Pressure Sensor (for altitude)	On-board	On-board
Battery	Extra	On-board
Camera	Optional Extra	On-board
Power	Run off existing RC Airplane power source	On-board
Ground Communication	Through Radio (Line-of-sight only)	Through Cellular Network (world capable)
Flight Software	Extra (download + install)	Extra (install from App Store)
Mission Planning Software	Extra (download + install)	Included with Flight Software

Table 3-2: Capabilities of APM vs. Proposed Solution

Main Features of Ardupilot Mega (APM) 2.8:

- Arduino Compatible
- Free open source autopilot firmware that supports planes, multicopters (tri, qu ad, hex, oct, etc.), traditional helicopters and ground rovers!
- Simple setup process and firmware loading via a point-and-click utility. No programming required!
- Autonomous take-off, landing and special action commands such as video and camera controls
- With the addition of a telemetry kit, you can track your UAV in real time, or even change your mission while your ArduPilot Mega powered UAV is in the air.
- Full mission scripting with point-and-click desktop utilities
- Can support hundreds of 3D waypoints
- Two-way telemetry and in-flight command using the powerful MAVLink protocol.
- Choice of free Ground Stations, including the state-of-the-art **HK GCS**, which includes mission planning, in-air parameter setting, on-board video display, voice synthesis, and full datalogging with replay.
- Supports full "hardware-in-the-loop" simulation with Xplane and Flight Gear
- 4MB of onboard data-logging memory. Missions are automatically datalogged and can be exported to KML
- Built-in hardware failsafe processor, can return-to-launch on radio loss.
- Pre-soldered and tested
- 3-axis gyro, accelerometer, and high-performance barometer
- Built in 4 MP Dataflash chip for automatic datalogging
- Invensense's 6 DoF Accelerometer/Gyro MPU-6000
- Measurement Specialties MS5611-01BA03 Barometric pressure sensor.
- Atmel ATMEGA2560 and ATMEGA32U-2 (processing and USB function).
- Micro-USB
- External compass support
- GPS input, I2C, Power module input
- Telemetry radio, OSD and airspeed sensor ports
- Operating voltage 5V.

- Input voltage (recommended) 7-12V.
- Digital I/O pins 54 (of which 14 provide PWM output).
- Analog input Pins 16.
- DC current per I/O pin 40 mA.
- DC current for 3.3V pin 50 mA.
- Flash memory 256 KB of which 8 KB used by bootloader.
- SRAM 8 KB.
- EEPROM 4 KB.
- Clock Speed 16 MHz
- Communication ports.
- I2C (inter integrated circuit) ports (for IMU).
- SPI (Serial Peripheral Interface).
- UARTs serial ports.

Main Specifications of Ardupilot Mega (APM) 2.8

3 Dimensions: 44x70x15mm (with case)

4 Weight:32g (with case)

3.1.1.2 ARDUPILOT MEGA APM Power Module:

The Ardupilot board needs to be supplied by a power source and this can be achieved by using a 3DR Power Module, shown in Figure. This is useful as it can be connected to the battery that is used to power the servos of the UAV. The Power Module will allow the monitoring of the battery voltage level while also supplying the Ardupilot board with the required power. In order to supply the board and the components connected to it with the Power Module, the user has to ensure the JP1 jumper is not connected. The power module is directly connected to a battery with a maximum voltage of 18 V and will supply the ardupilot board with a stable 5.3 V and 2.25 A current through the Power port.

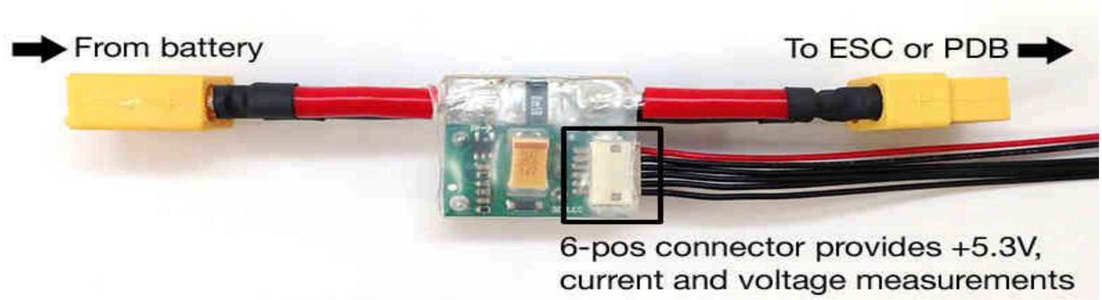


Figure 3-4 (a): Ardupilot Mega APM Power Module

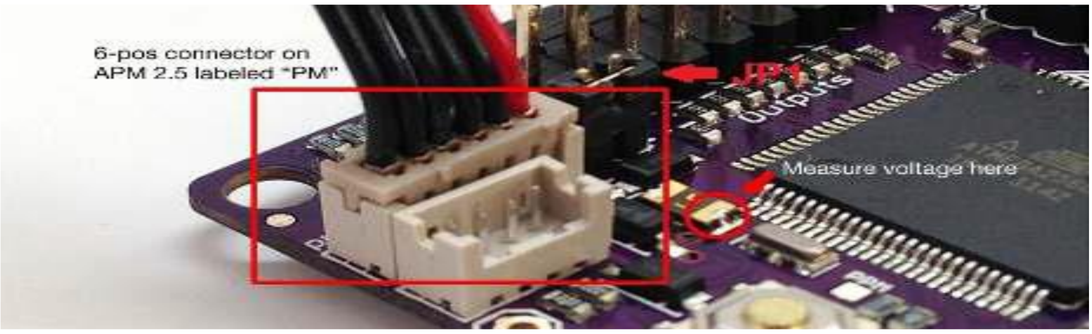
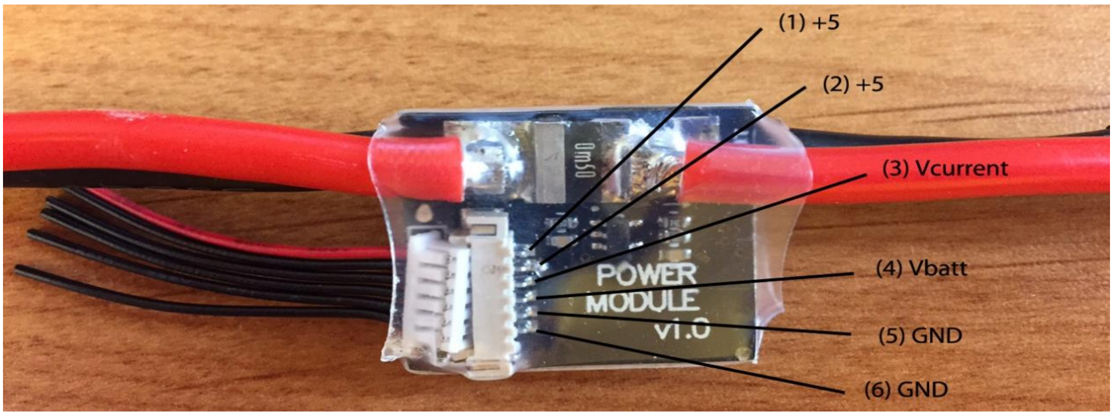


Figure 3-4 (b): APM Power Module connection with APM 2.8 controller



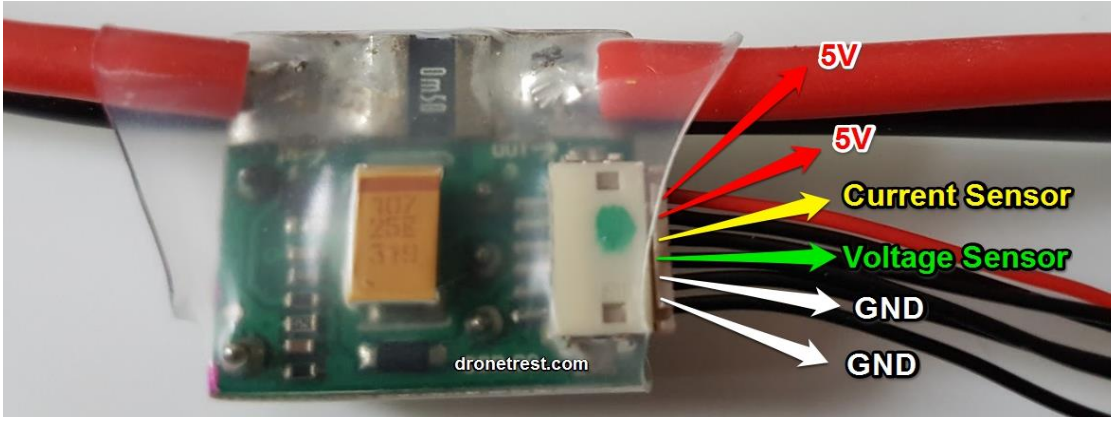


Figure 3-4 (c): APM Power Module Pin Configuration

APM Power Module's Battery Monitor Configuration/Setting in Mission Planner:

After connecting the Power Module to the Ardupilot Board, it needs to be correctly configured through the Mission Planner. This is shown in Figure below.

Figure 3-4 (d): APM Battery Module Configuration on Mission Planner

In order to enable voltage and current sensing the user has to select the following options:

• **Monitor** - 4: Voltage and Current

• **Sensor** - 4: 3DR Power Module

• **APM Version** - 2: APM 2.5+ - 3DR Power Module

• **Battery Capacity** - Battery Capacity in mAh

The Mission Planner can be configured to alert verbally when the battery is low. This can have configured by checking the *MP Alert on Low Battery* box. The user will be prompted to enter the warning that he wishes to hear, the voltage level and finally the percentage of the remaining current.

The voltage of the battery can be checked if it is being correctly measured by the Ardupilot by comparing the voltage reading on the Mission Planner to a reading from a handheld voltage meter. If it is found that the Ardupilot is not reading the correct voltage this can be corrected by doing the following:

• Set the “Sensor” field to ”0: Other”;

• Enter the voltage measured using the voltage meter in the” Measured battery voltage” field.

Main Specifications of Ardupilot Mega APM Power Module:

- Max input voltage: 28V
- Max current sensing: 90A
- Voltage and current measurement configured for 5V ADC
- Switching regulator outputs 5.3V and 3A max
- 6-pos DF13 cable plugs directly to APM 2.5/2.6's 'PM' connector
- Supports 6S battery

3.1.1.3 TURNIGY Battery Elimination Circuit (UBEC):

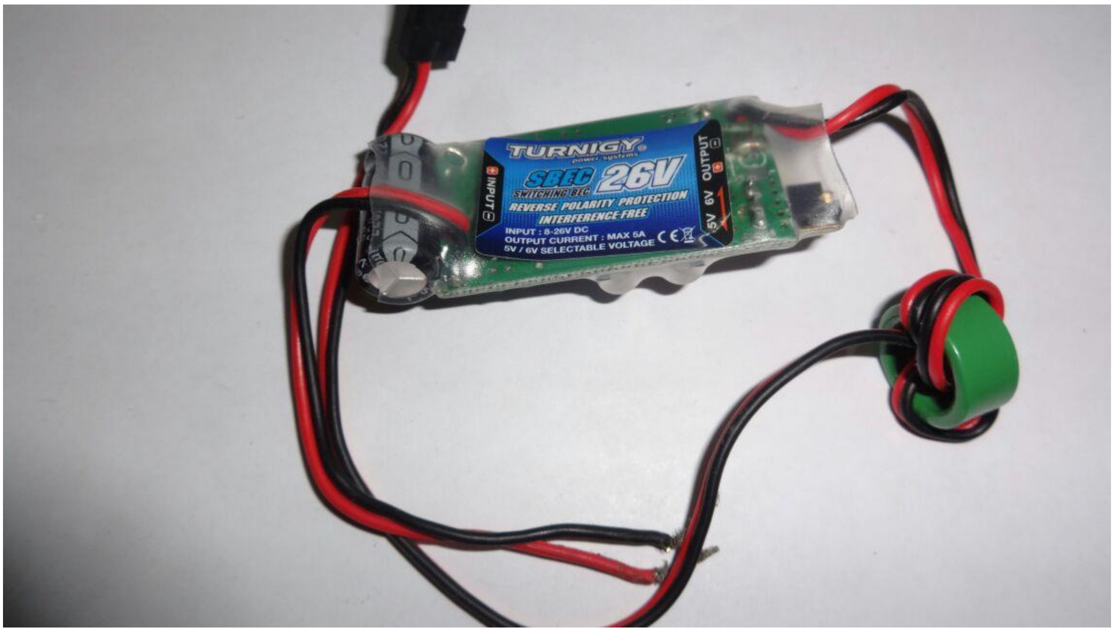


Figure 3-5: Turnigy Battery Elimination Circuit (UBEC)

Main Description of TURNIGY UBEC (Battery Elimination Circuit):

Brand Name: Hobbywing

Item Name: 3A-UBEC

Output Voltage: 5V@3A or 6V@3A (Selectable by using a jumper connector)

Continuous output current: 3 Amps

Input: 5.5V-26V (2-6S Li-Po or 5-18 cells NiMH/NiCd)

Size: 43x 17 x 7mm

Weight: 11g

Main Features of TURNIGY UBEC (Battery Elimination Circuit):

Uses an advanced switch mode DC-DC regulator IC.

The output is powerful enough even working with 4S to 6S Li-Po battery.

Battery polarity reversal protection.

A metal shield and a filter significantly reduce the electromagnetic interference.

The working status is shown by an LED, it lights when the UBEC works normally.

The 3A-UBEC is a switch mode DC/DC regulator, it outputs a consistent safe voltage for the receiver, gyro and servos.

It is very suitable for RC helicopter and other RC models especially when the built-in BEC in the speed controller has a very limited output capability.

3.1.1.4 GPS with Compass Module UBLOX NEO-7M:

The GPS (Global Positioning System) that was used in this project is the GPS+Compass module Ublox 7m. We used GPS for gave waypoints/mission. The GPS is shown below in Figure.

Figure 3-6 (a): GPS with compass Module Ublox NEO-7M

Main Features of GPS with Compass Module UBLOX NEO-7M:

- 56 channel Ublox NEO 7M Module
- GPS L1 C/A, GLONASS L1 FDMA
- QZSS L1 C/A
- Galileo E1B/C
- SBAS: WAAS, EGNOS, MSAS
- 10Hz update rate

- 25x25x2 Ceramic patch antenna
- Rechargeable 3V Backup battery
- Low noise 3.3V regulator
- I2C EEPROM storage
- Power and fix LED's
- Pedestal Mount/Case
- Pixhawk/PX4 compatible
- LNA MAX2659ELT+
- Pre-configured 38,400 Baud and prams for Arduplane or Arducopter

Main Specifications of GPS with Compass Module Ublox NEO-7M:

- Size: **60x11.5mm**
- Cable length: **20cm**
- Weight: **26g**
- Connection: **Compass 4 pin/ GPS 5 pin for APM (Spare 6 pin connector i ncluded for Pixhawk/PX4**

GPS with Compass Module Ublox NEO-7M Connection with APM 2.8:

The GPS with compass Ublox NEO-7M Module provides both the GPS and Compass data. This module is easily connected to the ardupilot board using the GPS & the I2C ports. The connection of this component is explained in Figure below

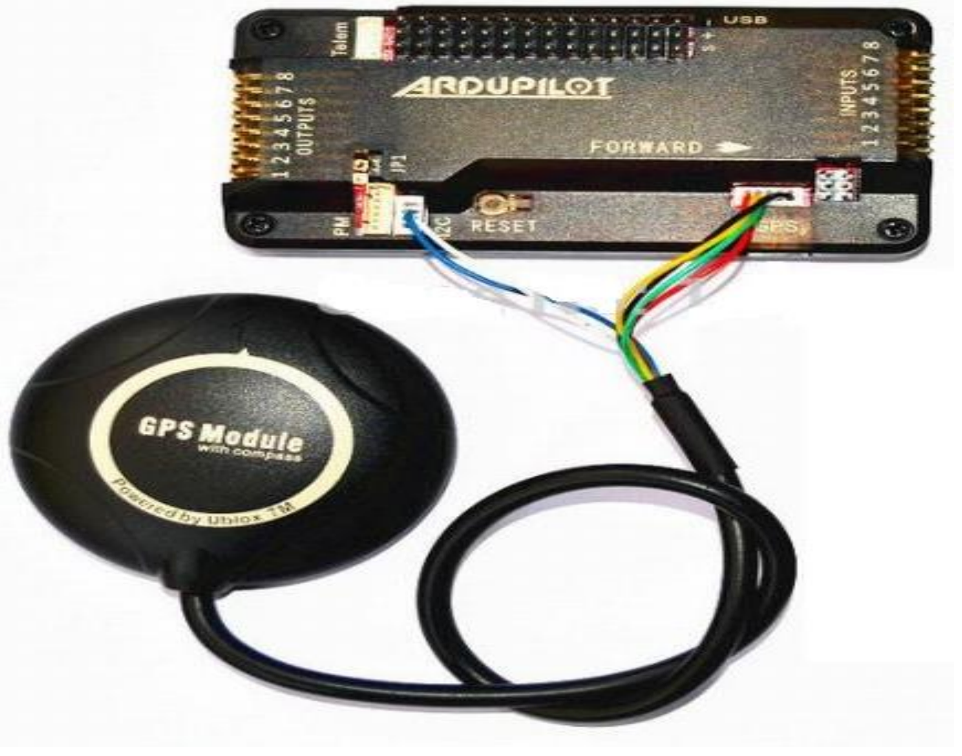


Figure 3-6 (b): GPS with compass connection with APM 2.8

GPS with Compass Module's Configuration/Setting and Calibration in Mission Planner:

In order to configure the compassreadings, the Ardupilot needs to be connected to the Mission Planner. Then, as shown in Figure 3.10, the compass needs to be enabled by checking the **Enable** box.The declination of the location of the UAV can be manually input in the **Degrees** and **Minutes** boxes, or it can be set to Auto by checking the **Auto Dec** box. The **APM with External Compass** box has to be selected.

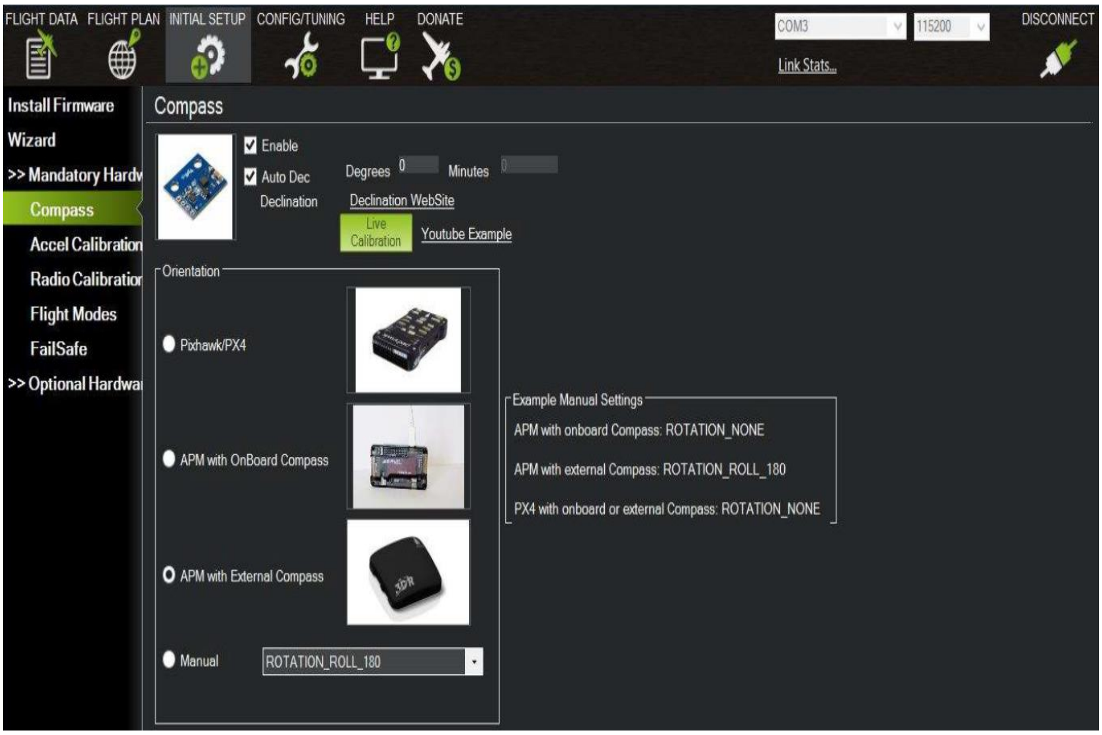


Figure 3-6 (c): GPS with compass module configuration on MP

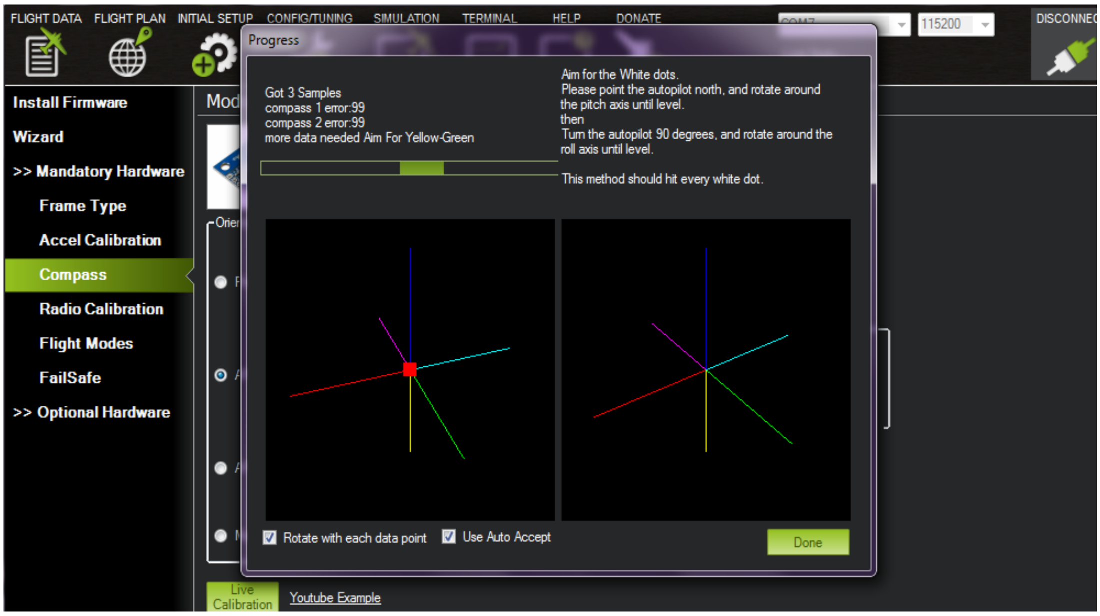


Figure 3-6 (d): GPS with compass module calibration on MP

3.1.1.5 FLYSKY FS-CT6B Radio Control RC Transmitter Receiver:

The transmitter & receiver would be used as a safety precaution in case there is the malfunction in the APM 2.8, we used 5-channel roll, pitch, throttle, yaw, & switch modes, we set switch modes at 5-channel. Also, the transmitter was being used in the radio calibration of the APM 2.8 to set minimum & maximum radio values of the throttle & servos used to fly the plane. The picture of the transmitter & receiver is shown in Figure below.

- Channels: 6 Channels
- Model Type: Heli, Airplane, Glid
- RF Power: Less than 20db
- Modulation: GFSK

Figure 3-7 (a): Fly Sky FS-CT6B Radio Control RC Transmitter Receiver

Setting up and Calibrating the Receiver/Transmitter in Mission Planner:

First, the transmitter and receiver were setup. This was done by inserting the binding cable into the receiver, plugging in the battery pack with the correct polarity to match the connection to the APM (ground down), turning on the transmitter while holding the training switch, and waiting for a connection to be established. Once the communication between the receiver and transmitter was correctly established the receiver was connected to the APM using female to female connection cables for Futaba servos. Each port of the receiver was connected to match the same port on the input of the APM to correctly control the servos.

Once this connection is correctly established the radio configuration on Mission Planner was set to determine the maximum and minimum values of the servos. This is done so that the APM can accurately control the servos on the UAV (Drone) and fly the Drone as desired. The setting and calibration of Receiver Transmitter in Mission Planner is shown in Figure below.

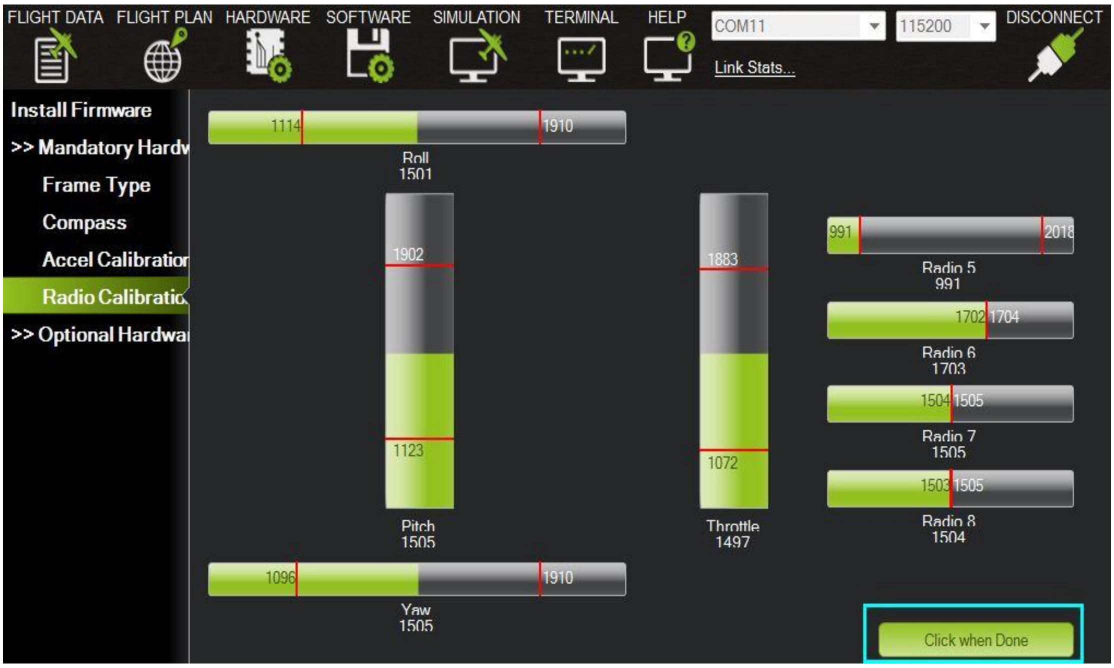


Figure 3-7 (b): Receiver/Transmitter calibration on MP

3.1.2 UAV Air Frame Components:

MECHANICAL DESIGN:

3.1.2.1 Frame/Body of Aircraft (Wooden Mechanical Structure):

Aircraft

Figure 3-8: Mechanical Structure/Body of Aircraft made on Balsa Wood

The airframe being used by the team is the Courage-10 60" ARF. The airframe is powered by 450W - 500W, 760kv Electric DC Brushless out-runner motor running a 12*10 or 13*10 propellers. The motor provides more than sufficient thrust. An airframe back-up with identical specifications as of the main airframe has also been prepared.

Specifications of the Aircraft:

Wingspan	60”
Aspect Ratio	6
Empty weight	1.5Kg
MTOW	2.5Kg
Motor power	450W-500W
Endurance	~25 min
Speed	40km/h – 60km/h

Table 3-3: Specifications of the aircraft

Airframe

The Courage-10 60" ARF airframe was chosen because it is a cost-effective and stable airframe. It consists of a conventional airframe with four-channel control. The airframe is made from the balsa wood. The Courage-10 60" ARF is an RC High winger electric aircraft with a conventional tail dragger landing gear. With a wingspan of 5 ft. and a length of 4.15ft, the aircraft has a no-payload (excluding the autopilot, sensors) take-off weight of 2kg, a maximum take-off weight (MTOW) of 3kg. The flight duration of the aircraft is over 25 minutes.

The airframe has been tested over all the flight tests. Modifications and reinforcements to the fuselage have been done after reviewing each flight test. The landing gear has also been strengthened so as to cope up with the extra weight.

3.1.2.2 TURNIGY G46 Brushless DC Motor (BLDC):

We use BLDC motor as an electric propulsion of our UAV for the throttle control of the Drone. Designed to be a direct swap out for your .40 to .46 size glow engine. This brushless outrunner will provide more power and with its high efficiency, long run times. A quality motor, built specifically for planes designed to fly with a .40 ~ .46 glow engine.

Figure 3-9: Turnigy G46 Brushless DC Motor

Main Specifications of TURNIGY G46 BLDC Motor:

Battery: **4~5 Cell /14.4~18.5V**

RPM: **670kv**

Max current: **40A**

No load current: **10V/3.9A**

Current capacity: **55A/15sec**

Internal resistance: **0.04 ohm**

Weight: **303g (not including connectors)**

Diameter of shaft: **6mm**

Dimensions: **76x50mm**

Required:

40A ESC

4S~5S Li-Po / 12 ~ 16-cell Ni-MH/Ni-Cd

12x8 ~ 14x10 prop

Suitable for sport and scale airplanes weighing 4 to 7 pounds (1.8–3.2 kg).

Propulsion:

Our UAV is propelled by a 450-500W Electric DC Brushless out-runner motor running a 13*10 or 12*10 prop. Different sized propellers (12, 13, 14 size) were tested during the flight tests. Based on the performance, flight stability and the optimum speed for imagery, the team finalized on the 13x8 propeller.

3.1.2.3 Electronic Speed Controller (ESC) (40Amp 30C):

An **electronic speed control** or **ESC** is an electronic circuit with the purpose to vary an electric motor's speed, its direction and possibly also to act as a dynamic brake. ESCs are often used on electrically powered radio controlled models, with the variety most often used for brushless motors essentially providing an electronically generated three-phase electric power low voltage source of energy for the motor.

An ESC can be a stand-alone unit which plugs into the receiver's throttle control channel or incorporated into the receiver itself, as is the case in most toy-grade R/C vehicles. Some R/C manufacturers that install proprietary hobby-grade electronics in their entry-level vehicles, vessels or aircraft use onboard electronics that combine the two on a single circuit board.

Figure 3-10 (a): Electronic Speed Controller (ESC) (40Amp 30C)

As you probably know, an electronic speed controller (or ESC) controls how fast your airplane's motor spins. It serves the same purpose as the throttle servo of a glow powered airplane.

It's an interface between the airplane's radio receiver and the power plant.

An ESC will have three sets of wires. One lead will plug into your airplane's main battery. The second lead will have a standard servo wire that plugs into the throttle channel of your receiver. And finally, the third set of wires actually power the motor.

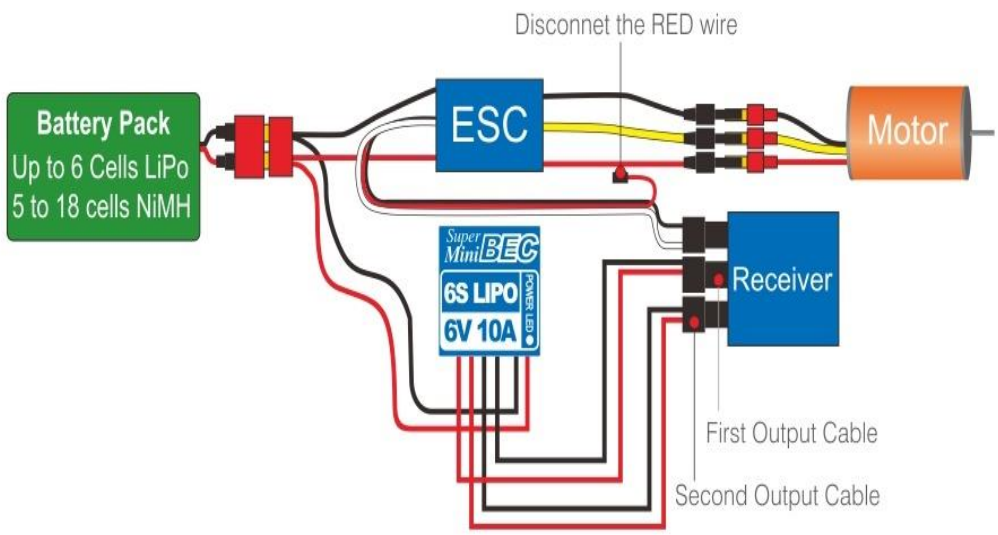


Figure 3-10 (b): Electronic Speed Controller (ESC) connections

3.1.2.4 Servo Motors (FUTABA S3001):

We use Servo Motors for the movement of control surfaces that is Ailerons, Elevators and Rudder movement, so we use 3 servos one is for each control surface movement.

This is a Standard Servo with a Ball Bearing on the output shaft. This has a "J" connector and uses a nylon gears.

This servo can produce high-current draw from your batteries. If using NiMH or Li-Po batteries, make sure they are capable of delivering sufficient amps.

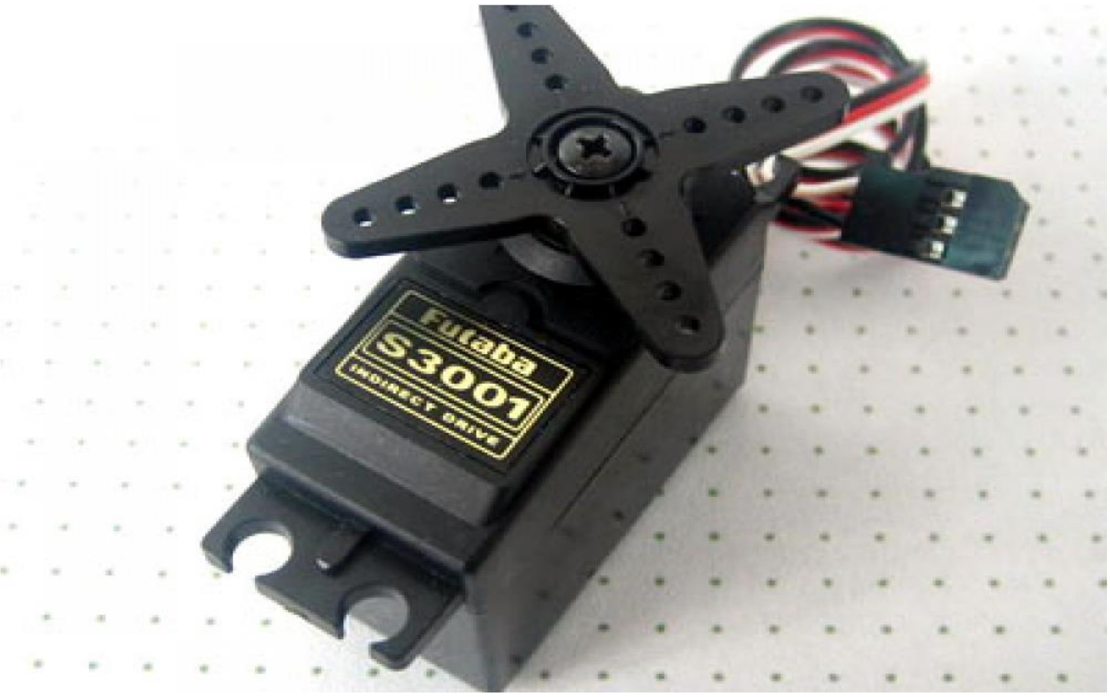


Figure 3-11: Futaba S3001 Servo Motor

Main Features of FUTABA S3001 Servo Motor:

Single Top Ball Bearing

Same mounting as S148 and S9201 (individual rectangular grommets)

3-pole motor

Nylon gears

Main Specifications of FUTABA S3001 Servo Motor:

Dimensions: 1.6 x 0.8 x 1.4" (1-9/16 x 13/16 x 1-7/16")

(40 x 20 x 36mm)

Weight: 1.6oz (1-9/16oz) (44g)

Torque: 33 oz-in (2.4kg-cm) @ 4.8V

42 oz-in (3.0kg-cm) @ 6V

Transit: 0.28 sec/60° @ 4.8V

0.22 sec/60° @ 6V

Control System: +Pulse Width Control 1520usec Neutral

Required Pulse: 3-5 Volt Peak to Peak Square Wave

Operating Voltage: 4.8-6.0 Volts

Operating Temperature Range: -20 to +60 Degree C

Operating Speed (4.8V): 0.23sec/60 degrees at no load

Operating Speed (6.0V): 0.19sec/60 degrees at no load

Stall Torque (4.8V): 44 oz/in. (3.2kg.cm)

Stall Torque (6.0V): 57 oz/in. (4.1kg.cm)

Operating Angle: 45 Deg. one side pulse traveling 400usec

360 Modifiable: Yes

Direction: Counter Clockwise/Pulse Traveling 1520-1900usec

Current Drain (4.8V): 7.2mA/idle

Current Drain (6.0V): 8mA/idle

Motor Type: 3 Pole Ferrite

Potentiometer Drive: Indirect Drive

Bearing Type: Ball Bearing

Gear Type: All Nylon Gears

Connector Wire Length: 12″

Dimensions: 1.6″ x 0.8″x 1.4″ (41 x 20 x 36mm)

Weight: 1.6oz. (45.1g)

3.1.2.5 Battery (11.1V 5200mAh 30C Li-Po Battery):

Our UAV relies on either of the two batteries for flight operations. The 11.1 V, 5000mAh Lithium Polymer battery powers the 12V payload or a Turnigy Nano-tech 6000mah 3S 25~50C Li-Po Pack.

Our system has demonstrated the ability to provide over 25min minutes of battery life across both power rails under flight conditions. Battery voltages are monitored by the autopilot operator during flight and the plane is landed if the voltage drops below a safety threshold.

Figure 3-12: Battery (11.1V 5200mAh 30C Li-Po Battery)

3.1.3 UAV Ground Control Station (GCS) Components:

3.1.3.1 3DR Telemetry Radio 433MHz Module:

The wireless telemetry accessory allows the user to communicate with the autopilot while it is being flown. There are many advantages to being able to communicate with the airplane in flight, some of the most important being logging data directly to a computer, monitoring performance while in flight, giving commands to the autopilot, and changing missions while in flight.

The telemetry radio was used for communication between GCS (ground control station) & APM 2.8 when the drone is in air. It is the easiest way to communication. The telemetry radio picture is shown below in Figure.

Figure 3-13 (a): 3DR Telemetry Radio 433MHz Module

Description of 3DR Telemetry Radio 433MHz Module:

Item Name: 3DR Radio Telemetry Module

Band: 433MHz

Antenna connectors: RP-SMA connector

Output Power: 100mW (20dBm), adjustable between 1-20dBm

Sensitivity: -117dBm sensitivity

Interface: Standard TTL UART

Connection status: LED indicators

Country: for Europe

Main Features of 3DR Telemetry Radio 433MHz Module:

Very small size, light weight

433Mhz frequency band

Receiver sensitivity to -117 dBm

Transmit power up to 20dBm (100mW)

Transparent serial link

Air data rates up to 250kbps

Range of approx. 1 mile with supplied antennas

Demonstrated range of several kilometers with a small omni antenna
Can be used with a bi-directional amplifier for even more range
MAVLink protocol framing and status reporting
Frequency hopping spread spectrum (FHSS)
Adaptive time division multiplexing (TDM)
Support for LBT and AFA
Configurable duty cycle
Built in error correcting code (can correct up to 25% data bit errors)
Open source firmware
AT commands for radio configuration
RT commands for remote radio configuration
Adaptive flow control when used with APM
Based on the HopeRF HM-TRP radio module, featuring an SiLabs Si1000 RF microcontroller.

The telemetry connection between Ardupilot and the Ground Station is achieved by using 3DR Radios, shown in Figure. These use antennas with 10 centimeters long. There are two 3DR radios, one for the Ardupilot board and another that connects directly to the ground station computer. The Ardupilot's radio has a FTDI 6-pin header, allowing it to be directly connected to the telemetry port on the board. The ground station model can be connected to the computer using an USB connector. The required drivers of the 3DR radios should be automatically installed to the computer when the radio is first connected. If, for some reason, they are not automatically installed, they can be manually downloaded and installed from http://www.ftdichip.com/Drivers/D2XX.htm.

The 3DR radios have two status LEDs, one green and another red. The meaning of the different state of the LEDs is the following:

- green LED blinking - searching for another radio;
- green LED solid - link is established with another radio;
- red LED blinking - transmitting data;
- red LED solid - in firmware update mode.

Configuration and Calibration of Telemetry Radio:

To configure the telemetry radios using the Mission Planner, first it is required that in the upper-right corner of the Mission Planner the port where the 3DR radio is connected to the computer is selected. The **Baud rate** must be set to **57600**.

Then, in the *Initial Setup* menu, on the *3DR Radio* tab, under *Optional Hardware*, and selecting **Load Settings**, it is necessary the several boxes have the values shown in Fig. 3.18. After this step, it is required to select **Save Settings**. Now, it is possible to press on the **Connect** to establish the connection between the ground station and the autopilot using the telemetry radios.

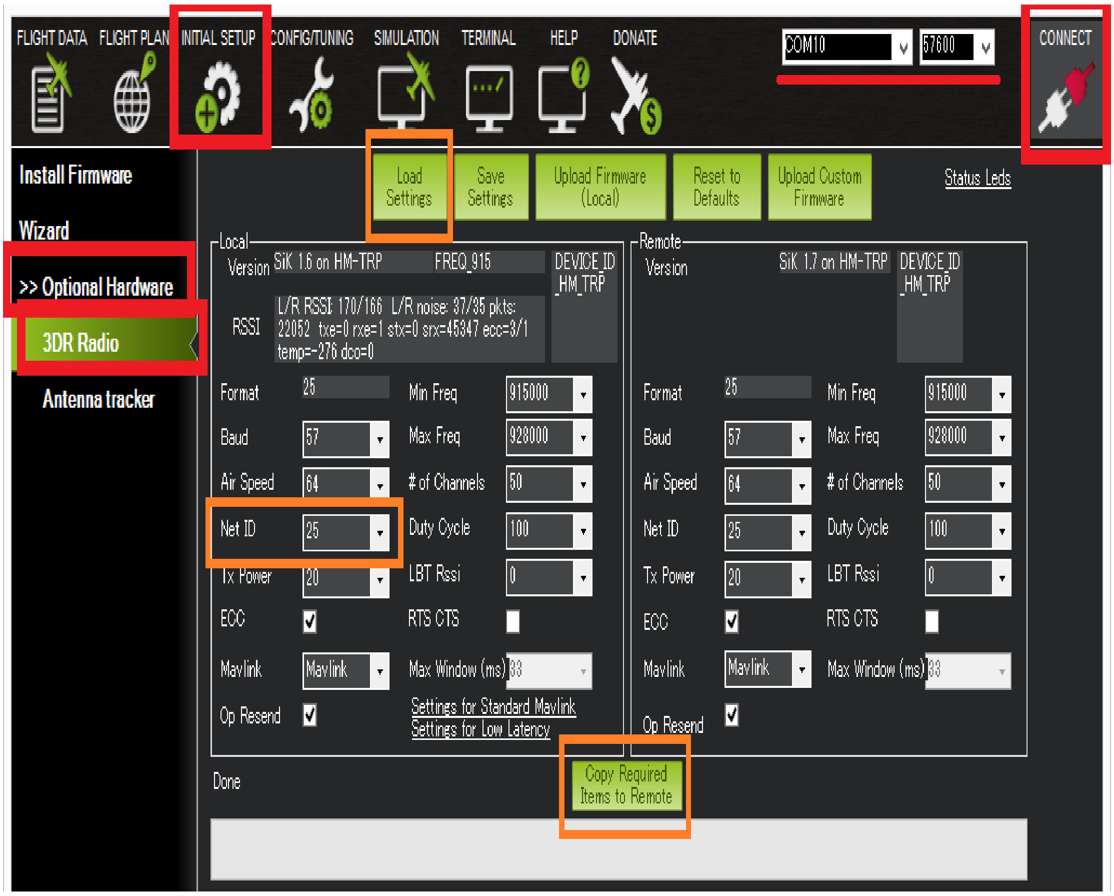


Figure 3-13 (b): Telemetry radio configuration on MP

Control Surfaces movement w.r.t Positioning & Orientation of plane:

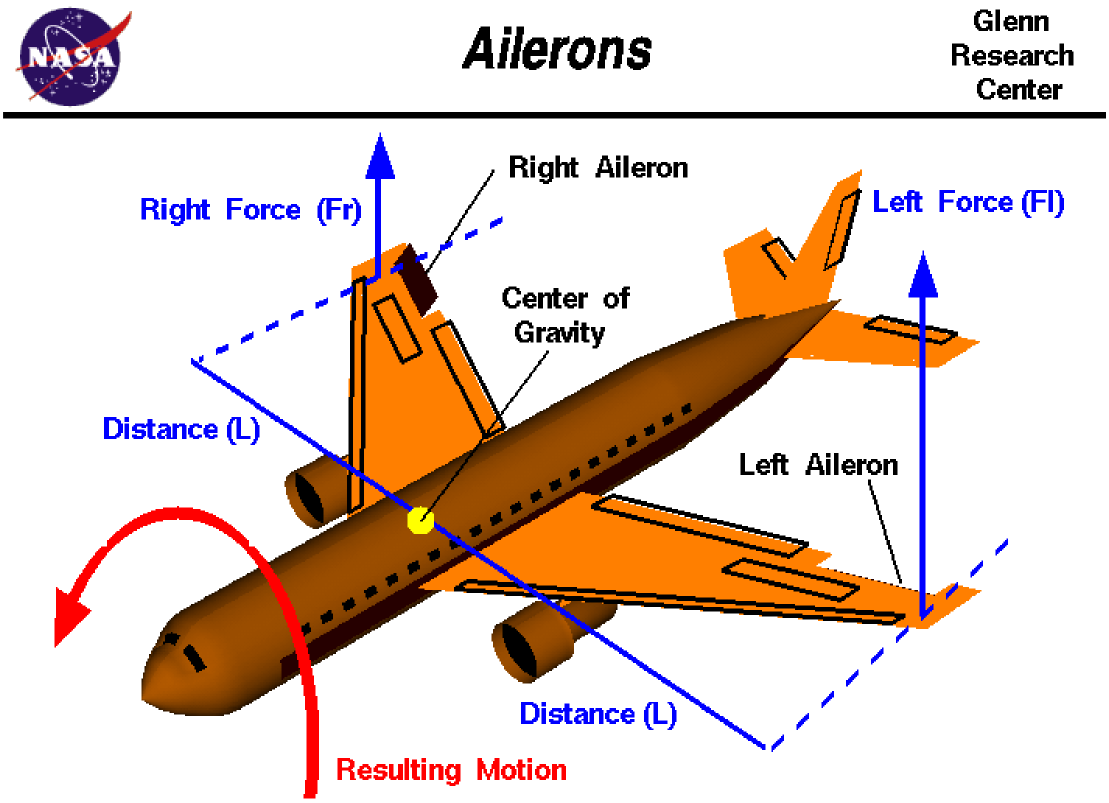


Figure 3-14 (a): Ailerons Control Surface Orientation on plane

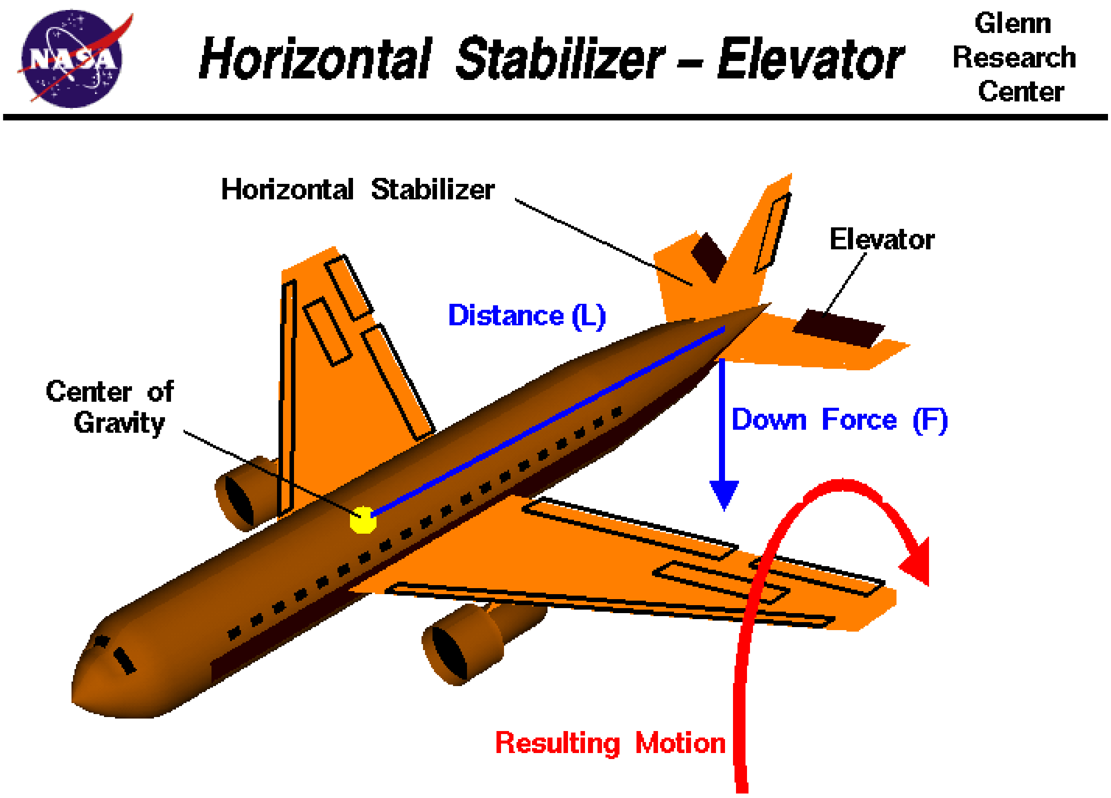


Figure 3-14 (b): Elevator Control Surface Orientation on plane

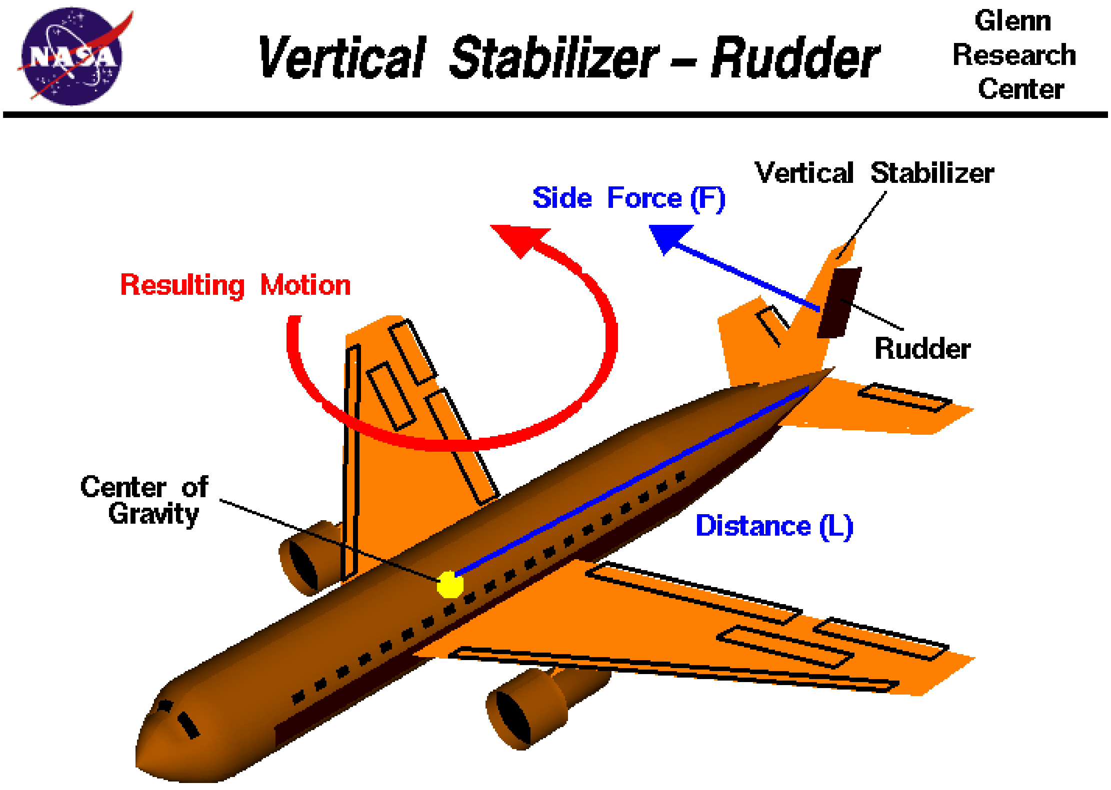


Figure 3-14 (c): Rudder Control Surface Orientation on plane

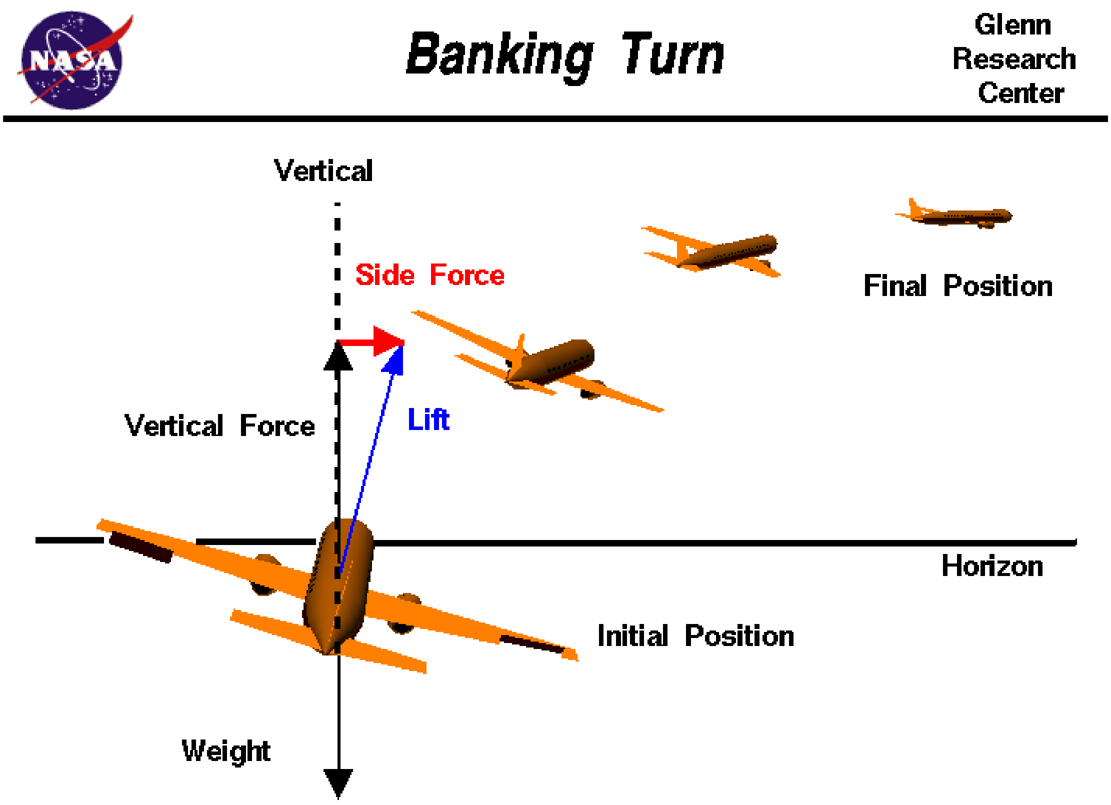


Figure 3-14 (d): Banking Turn Orientation on plane

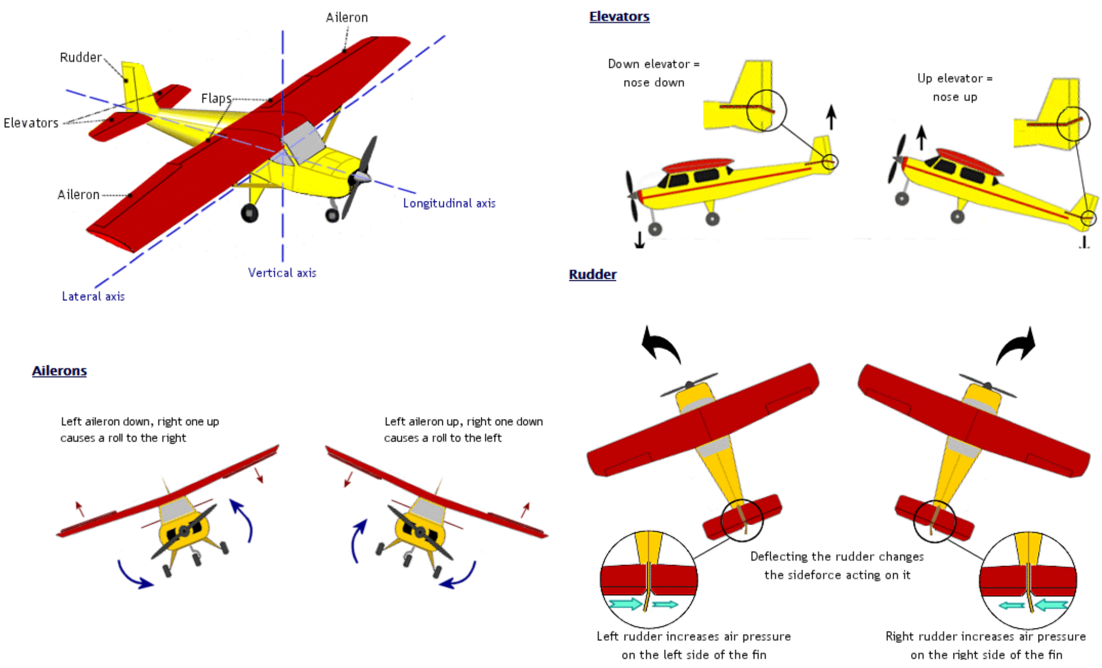


Figure 3-14 (e): All three Control Surfaces Orientation on plane

Control Interfaces (Physical):

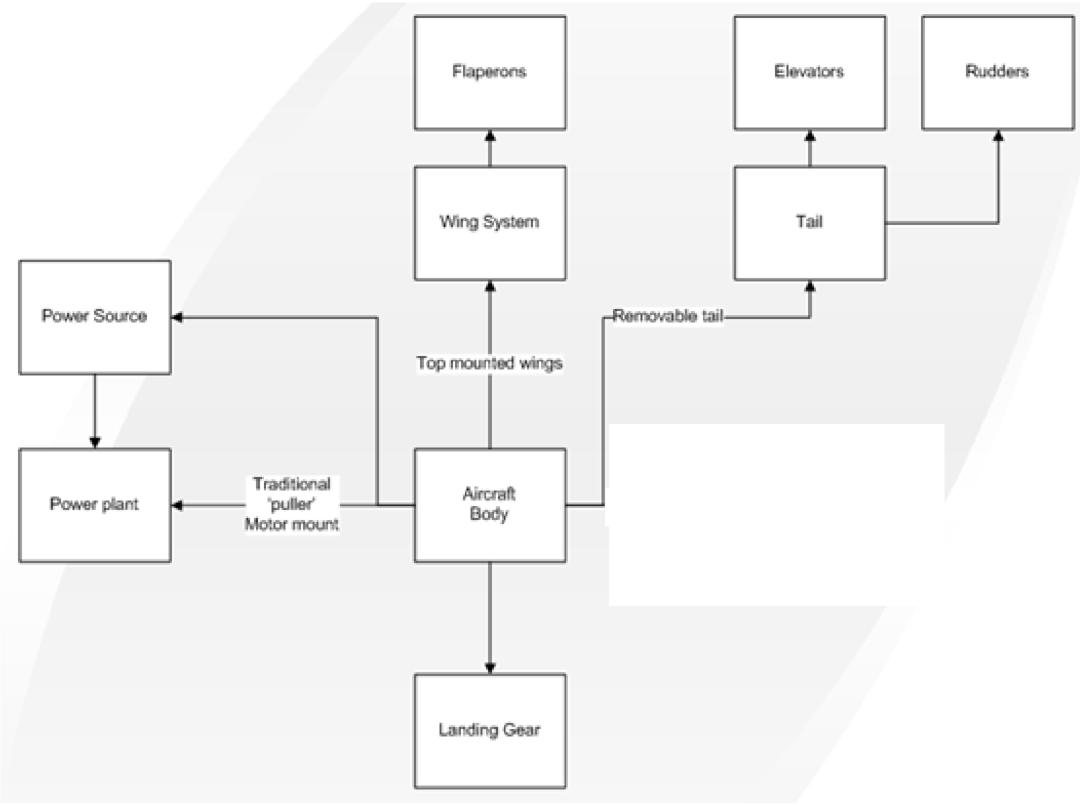


Figure 3-15 (a): Control Interfaces (Physical) Block Diagram

Control Interfaces (Electrical):

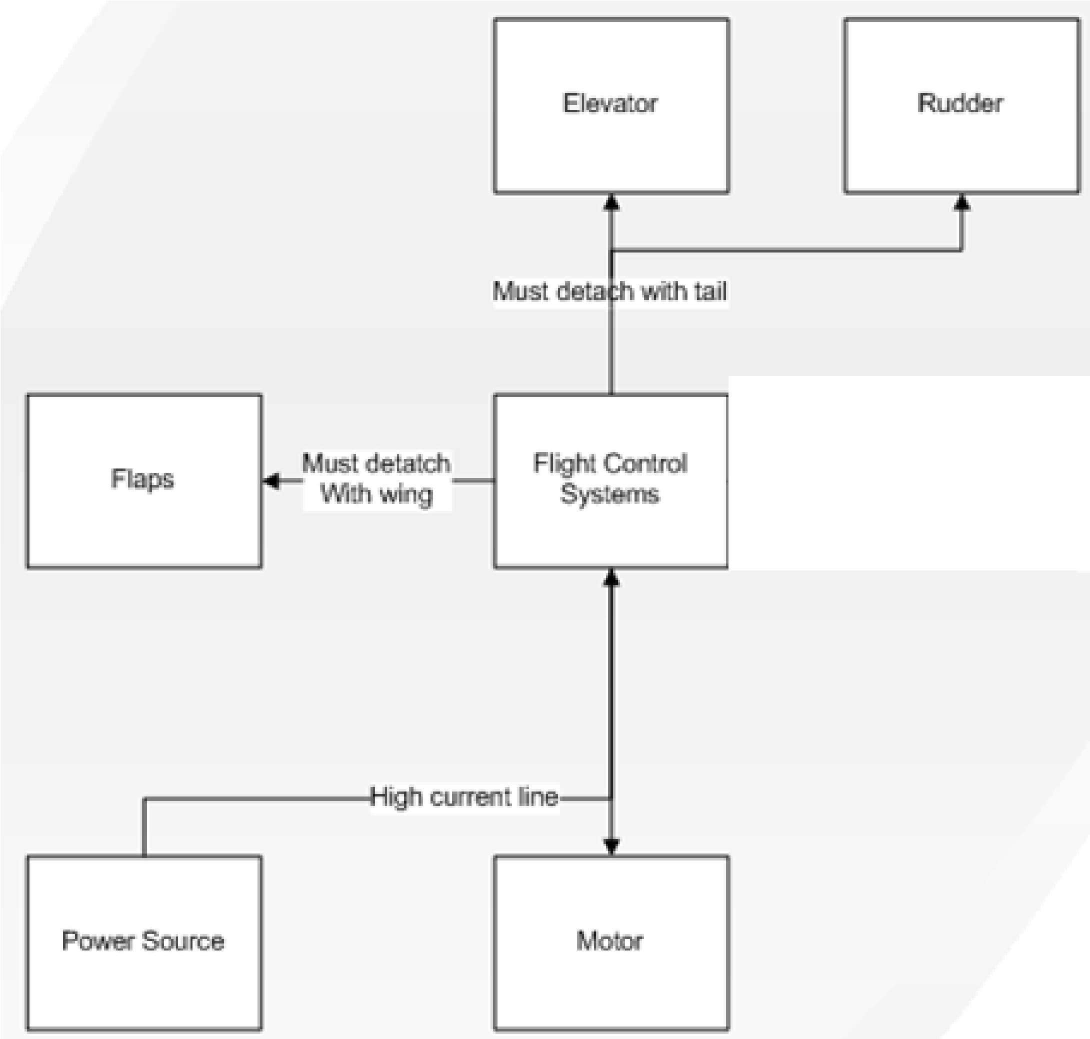


Figure 3-15 (b): Control Interfaces (Electrical) Block Diagram

3.1.3.2 Ground Control Station (GCS):

A ground station is typically a software application, running on a ground-based computer, that communicates with your UAV via wireless telemetry. It displays real-time data on the UAVs performance and position, showing many of the same instruments that you would have if you were flying a real plane. A GCS can also be used to control a UAV in flight, uploading new mission commands and setting parameters. The GCS used was my personal laptop for monitoring the flight with the help of software Mission Planner. So we are using Mission Planner software as our GCS software.

Figure 3-16: Laptop as a GCS (Ground Control Station)

SOFTWARE:

3.1.3.2.1 Mission Planner:

The Mission Planner (MP) software will be used to communicate with the APM 2.8. It is our main software in the project, we control the all parameters of plane through this software. Also, script the mission or change the mission through this software, it is very far software to work on it, we control the speeds, angle, pitch, roll, yaw, throttle & mission through Mission Planner.

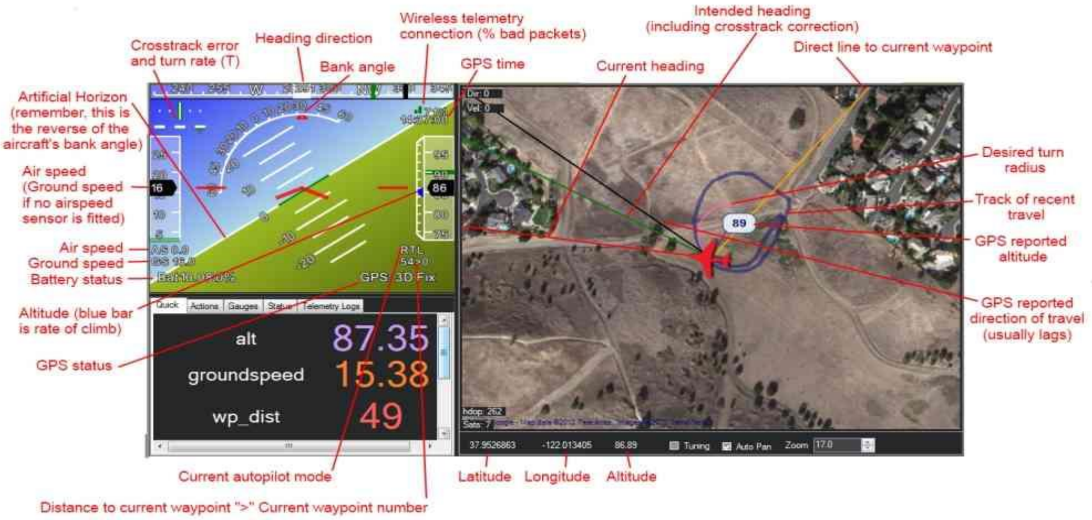


Figure 3-17 (a): Mission Planner main screen

Mission Planner Features:

The Mission Planner versions that were used is the version 1.3.5 and version 1.2.9. This software has several tabs with different functions. In Figure 3-17 (b) It is shown the *Flight Data* tab which is where it is possible to view live data that is being transmitted through telemetry from the autopilot to the ground station. It has an artificial horizon in the upper-left corner of the screen that shows the orientation of the vehicle, and other important information such as the groundspeed or altitude. The information displayed in the artificial horizon can be configured by right-clicking on it and selecting **Items**.

Bellow the artificial horizon there are several tabs with different functions. In *Quick* it can also be seen the same information of the artificial horizon. By double-left clicking on any field, it can be configured the information that is going to be displayed in that field. In the *Actions* tab, the user can give commands to the auto-pilot, and in the *Status* tab it is displayed the values of the several parameters that are being transmitted by the autopilot.

The current position of the vehicle will be displayed in the map when the autopilot has acquired a GPS lock. By right-clicking on the map, it is also possible to give commands to the vehicle. An important feature of the Mission Planner is that it allows the creation of missions by setting waypoints for the vehicle to follow. This is done in the *Flight Plan* that is shown in Figure 3-17 (c).

The waypoints can be manually created by right clicking on the map and selecting **Insert Wp**. The waypoints list will appear in the pannel bellow the map. This list can be saved to a file by clicking on **Save WP File** on the right pannel and can be sent to the autopilot, when connected to the Mission Planner, by clicking on **Write WPs**.

The waypoints can also be recorded by the autopilot and then loaded into the Mission Planner. In this case, when the autopilot has recorded the desired waypoints clicking on **Read WPs** will load the waypoints list into the Mission Planner.

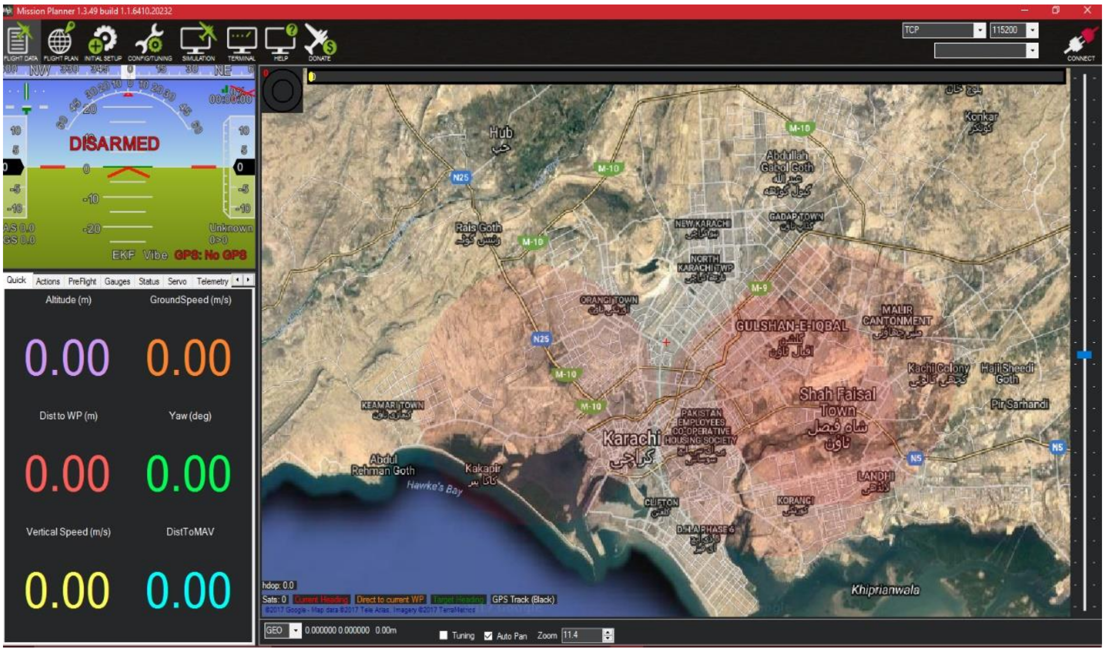


Figure 3-17 (b): Mission Planner flight data

Figure 3-17 (c): Mission Planner flight plan using waypoints

The *Initial Setup* tab is used for the installation of the firmware of the autopilot and configuration of the several components of the Autopilot such as the GPS, Power Module, Sensors, Telemetry Radios and the OSD. The detailed explanation about these components will be made in the following sections. In the *Config and Tuning* tab the several parameters of the Ardupilot can be configured to tune the performance of the autopilot.

Loading Firmware into Ardupilot 2.8:

After installing the Mission Planner on the ground station computer, the Ardupilot board can be connected to the computer using a micro USB connector for the Ardupilot micro USB port and a direct USB port on the computer. If the operating system does not automatically install the Ardupilot board drivers, they can be manually downloaded from http://ardupilot.com/downloads/?did=19.

After connecting the Ardupilot board to the computer, in the Mission Planner upper-right corner drop down menus, the correct port where the Ardupilot is connected needs to be selected. This will appear as **Arduino Mega 2560**. The Baud rate has to be set to **115200**.

Depending on the vehicle configuration, there are several options that can be selected for the Ardupilot firmware. This is shown in Figure 3-17(d). The installation of the desired configuration firmware is done by clicking on the corresponding icon. Then, the Mission Planner will prompt to confirm the firmware download and installation.

ArduPlane Firmware and HIL Simulator Firmware:

The firmware for a fixed wing aircraft can be found online and uploaded to the APM 2.8 using MP. This firmware is the software that is responsible for controlling the RC aircraft when it is in any other mode other than manual. A screen shot of how the firmware is uploaded to the APM 2.8 is shown in Figure 3-17 (d). In Figure is the link to install the HIL Simulator firmware for the ArduPlane. This firmware is used to test the functionality of the APM and Mission Planner in an HIL Simulator.

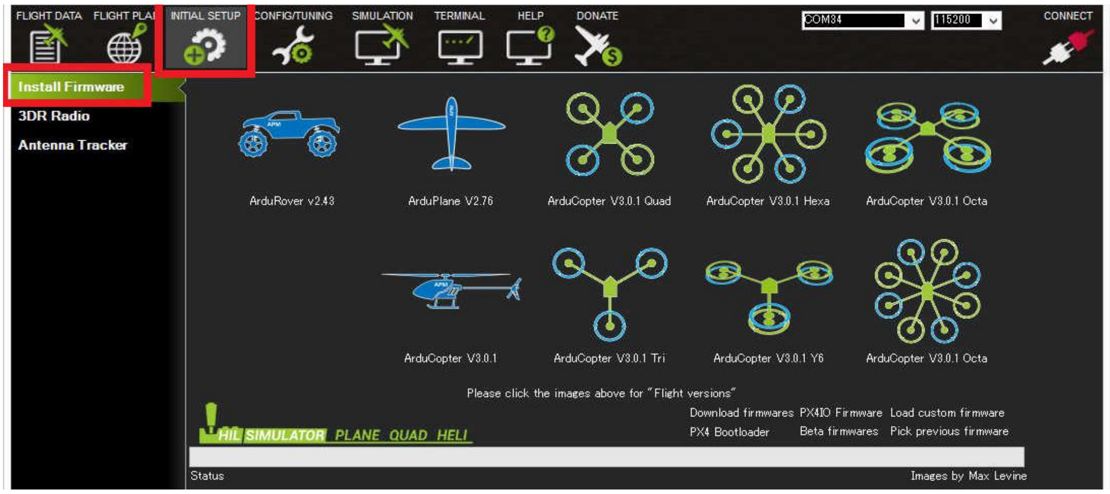


Figure 3-17 (d): Mission Planner firmware selection

After installing the desired firmware on Ardupilot, the MavLink parameters can be loaded by clicking **Connect** on the upper-right corner.

Telemetry Logs

The flight data can be recorded in two different ways:

• Dataflash logs - These use the autopilot onboard flash memory and can be downloaded after use;

• Telemetry logs (tlogs) - These are automatically recorded by the Mission Planner when the autopilot is connected using the telemetry link. The tlog file will be saved in the” logs” subfolder in the Mission Planner installation folder.

Figure 3-17 (e) shows how the desired rate at which data sent by the autopilot to the ground station can be controlled in the Mission Planner. The values that were used are also presented in Table 3-4.

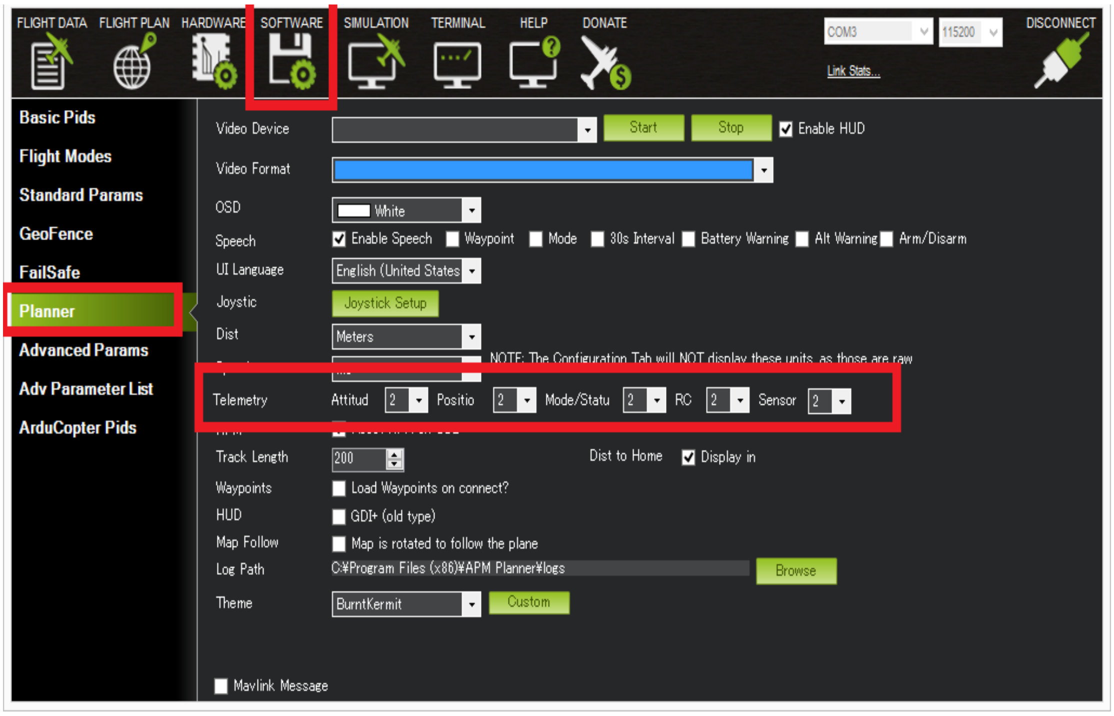


Figure 3-17 (e): Mission Planner log data-rate

Parameter	Telemetry Rate (Hz)
Altitude	10
Position	3
Flight Mode	2
RC	2
Sensor	2

Table 3-4: Telemetry rates

The Mission Planner can also be used to play back missions from tlog files. This can be done in the Flight Data screen and selecting the Telemetry Logs tab. Then the tlog can be loaded by clicking on **Load**. The slider can be used to jump to any point in time of the log file. When the log is playing, the HUD will move and show all the available information as it was shown during the real flight. By clicking on the tuning checkbox, at the bottom of the screen, any individual data value can be displayed in a graphic.

These logs can also be used to create 3D profiles of the flight paths. This is a chieved by clicking on the **tlog to Kml or Graph** button. It will open a new menu, shown in Figure 3.17 (f), where by clicking on **Create KML+GPX** and selecting the desired log will create a kmz and a kml file on the log folder. This can be opened in Google Earth to interactively view the 3D flight path.

In this menu there are also several other options. Selecting **Extract Params** will cause a param file to be created along the tlog file. This file contains a full list of parameters along with their values during flight. **Extract WPs** will create a text file containing any missions uploaded to APM. This file can be used in the Mission Planner to load the mission.

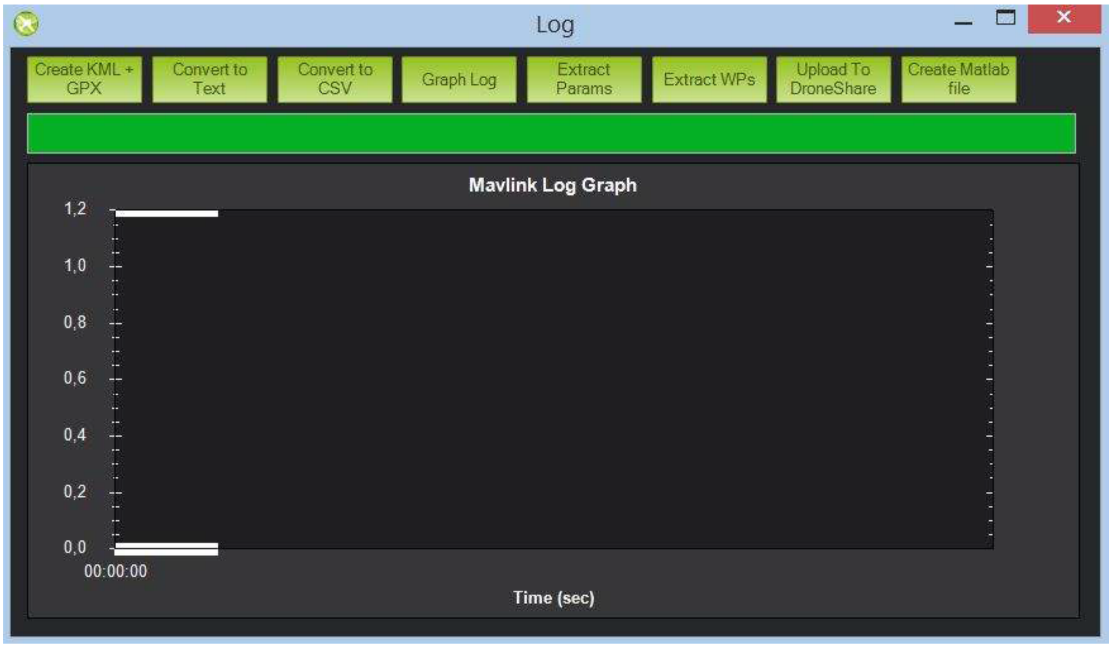


Figure 3-17 (f): Mission Planner Logs Menu

Any parameter recorded in the log can be displayed in graphical form by clicking on the **Graph Log** button and selecting the desired log. This will open a graphic with a list of all the parameters that can be displayed. To display a parameter, it needs to be selected.

3.1.3.2.2 X-Plane:

The X-Plane software was used in conjunction with Mission Planner to perform HIL simulations to determine how the autopilot system will function when implemented in the RC aircraft. It is extremely important to test the equipment and be confident that it is working properly before taking a test flight and risking damaging the aircraft, as well as all of the components in it. A diagram of the setup of a HIL Simulator is shown in Figure below.

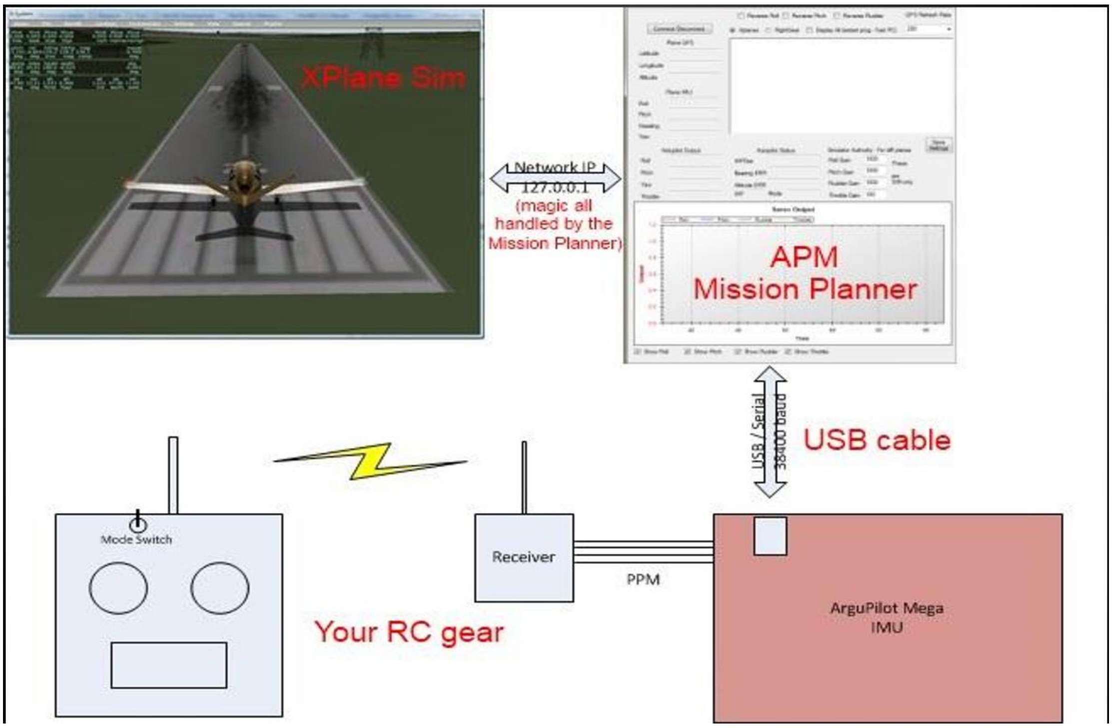


Figure 3-18 (a): Setup of a HIL Simulator using X-Plane

Figure 3-18 (b): X-plane 10 Main screen

3.2 BLOCK DIAGRAM:

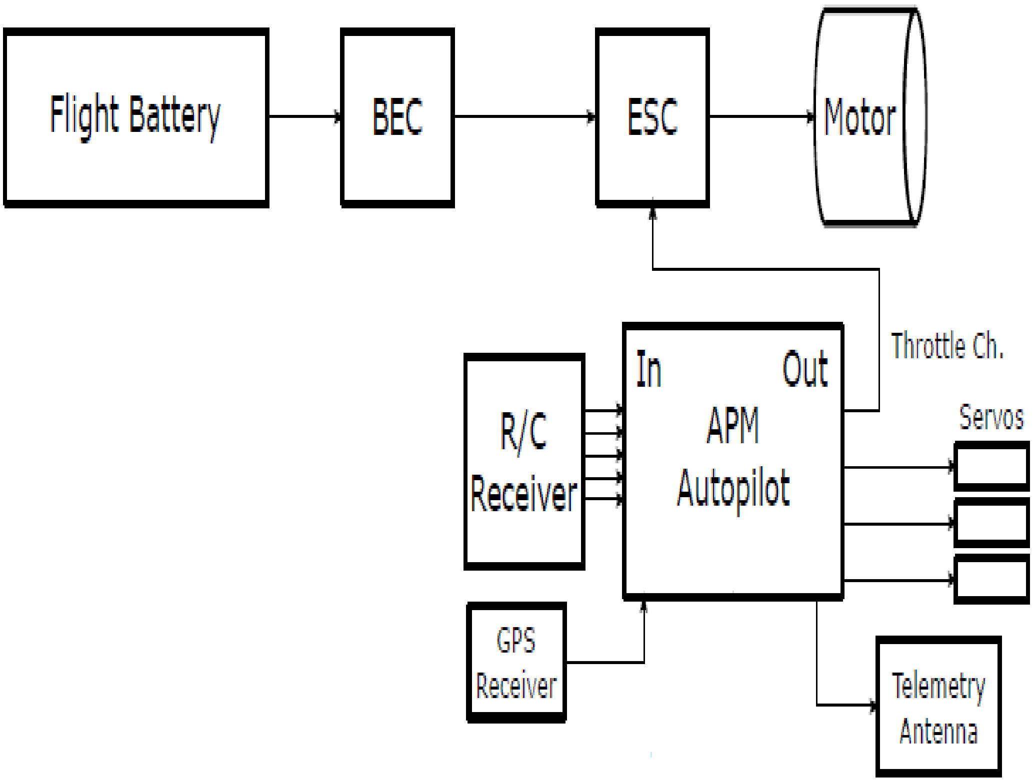


Figure 3-19: Block Diagram of our project

3.3 SCHEMATIC/WIRING DIAGRAM:

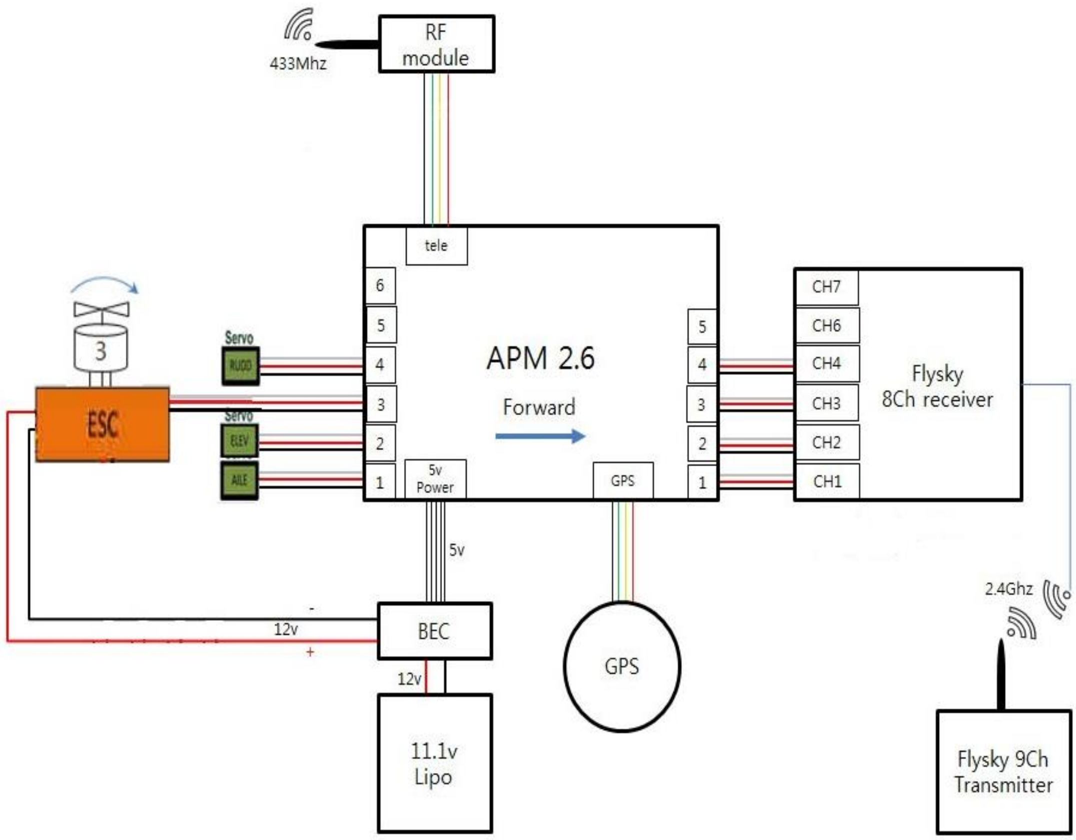


Figure 3-20: Schematic/Wiring Diagram of our project

3.4 FLOW CHART:

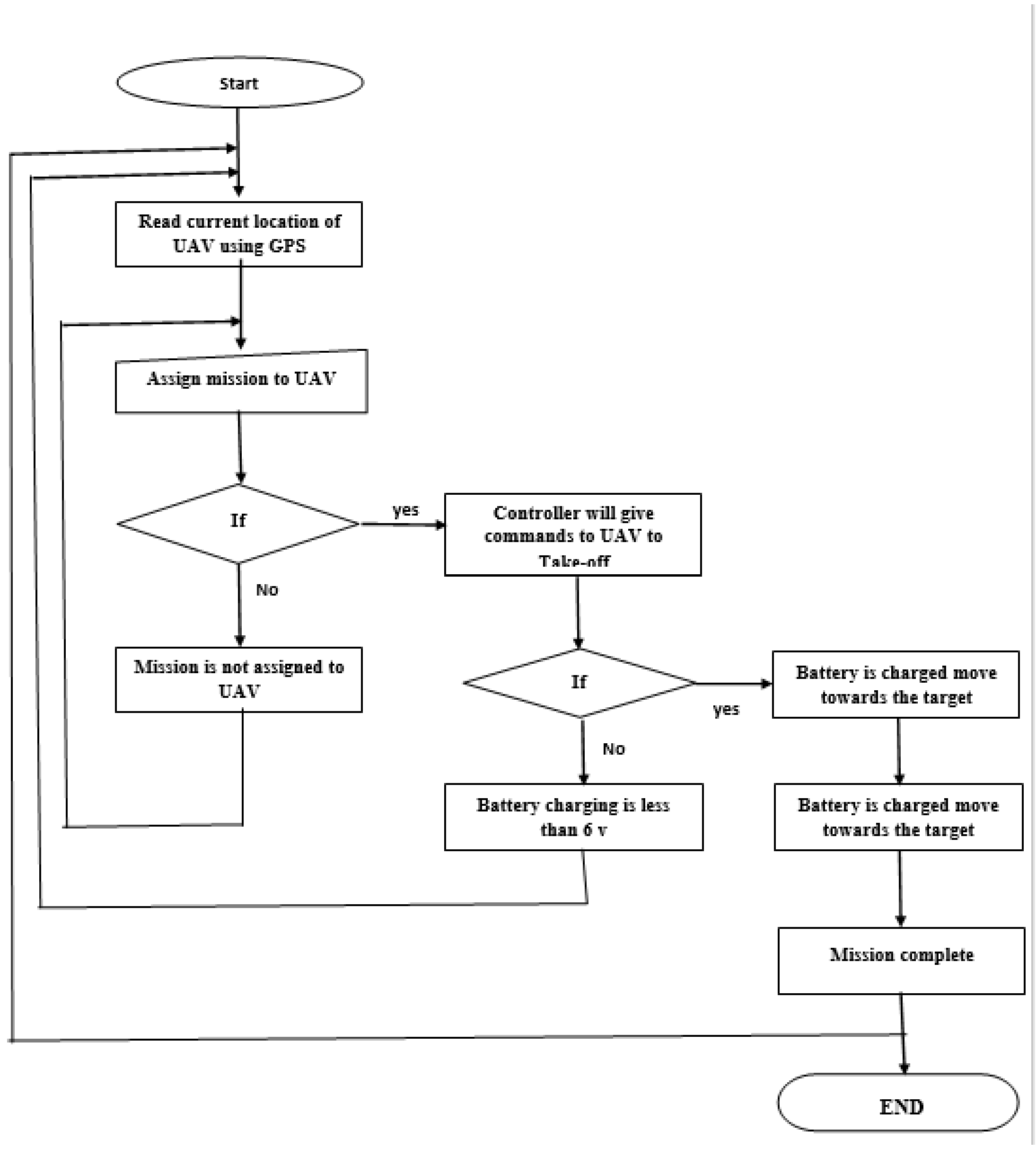


Figure 3-21: Flow Chart of our project

3.5 ALGORITHM:

3.5.1 Control Algorithm:

The control algorithm consists of two layers. The first upper layer is waypoint sequencer. The second layer is sets of PID (proportional, integrative, and derivative) controller. The waypoint sequencer reads the waypoints given to the autopilot control system by the operator. Each waypoint basically consists of 3D world coordinate which are latitude, longitude and altitude. Based on this waypoint information and current position, attitude and ground speed, the waypoint sequencer will output several objectives: attitude (roll, pitch and yaw/heading objective) and ground speed objectives. These objectives will be read by PID controller as its setting point and will be compared with actual value using PID algorithm to produce servo command value that will actuate the airframe's surface control (aileron, elevator and rudder) and throttle.

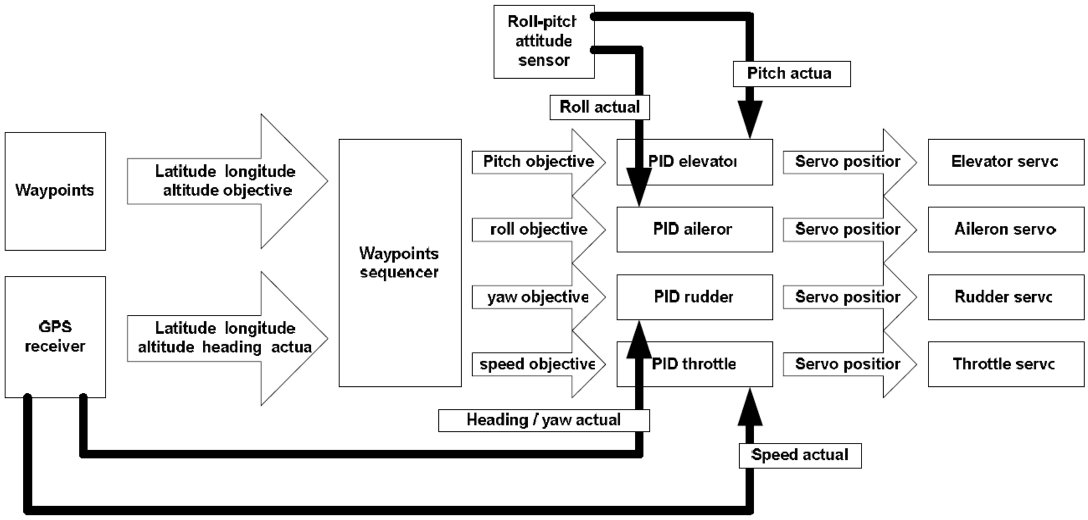


Figure 3-22: Block diagram of control algorithm

3.6 SIMULATIONS:

3.6.1 Hardware In the Loop (HIL) Simulation

Field trial is one of the most critical steps in UAV development. UAV usually consists of relatively high priced airframe, engine, actuator / servo, and payload system, so when there is failure in control system field trial, the risk is airframe crash, and usually only minor part of the crashed UAV that can be used for the next research and development. This step proved to be one of the main problems in UAV research and development.

One of the solutions for minimizing the effect of control system failure in field trial is Hardware in the Loop (HIL) Simulation.

3.6.1.1 HIL General Description

Hardware in the loop (HIL) simulator simulates a process such that the input and ou put signals show the same time-dependent values as the real dynamically operating components. This makes it possible to test the final embedded system under real working conditions, with different working loads and in critical/dangerous situations.

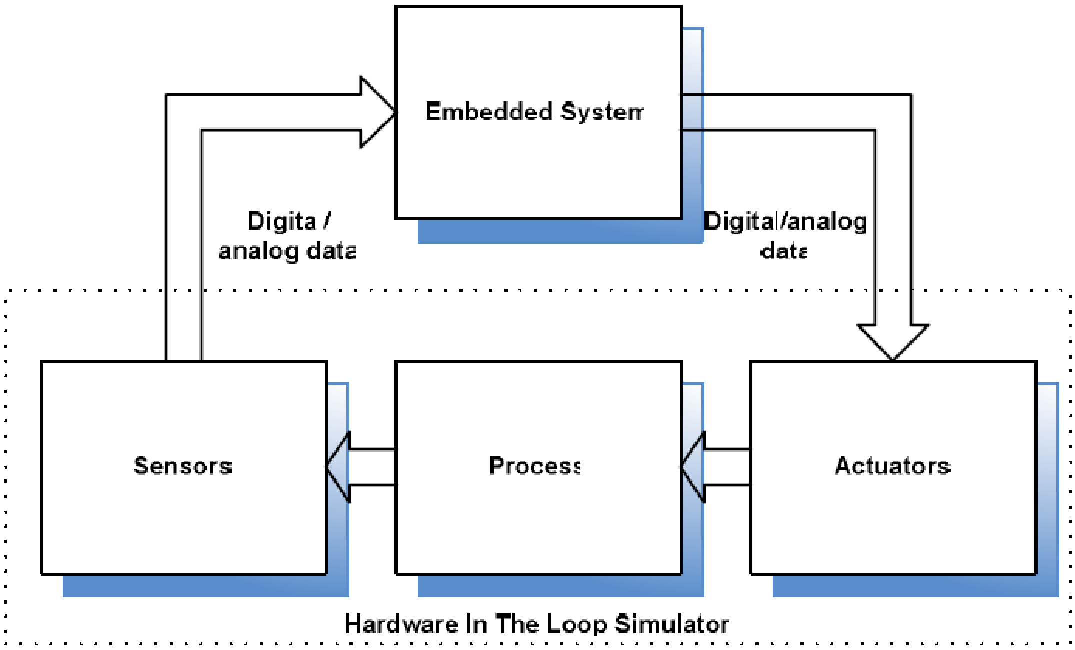


Figure 3-23: Autopilot hardware block diagram

In the case of UAV autopilot system development, A HIL simulator can be developed to simulate the flight characteristic of the airframe including the sensor output and the control input signal. The UAV autopilot system can be installed with the HIL simulator to see how the overall system works as a closed loop system. Here we can tune the PID gain parameter as well as the other system parameter and watch the effect to the airframe in the HIL simulator.

36.1.2 HIL Simulator Development

This writer develop HIL simulator based on commercially available simulation software. By using this approach, the basic simulation feature doesn't have to be implemented from scratch. Only specific functionality needed by HIL simulator need to be added. This specific functionality usually relates with interfacing between simulation software and autopilot hardware (sensor measurement and servo actuation simulation).

The chosen simulation software for HIL simulator development is X-Plane, because these reason:

- X-Plane is very interesting for non-aerodynamicist developer, because we can make an airframe based only on its geometric dimension. The physics model is based on a process called Blade Element Theory. This set of principles breaks an airframe down by geometric shape and determines the number of stress points along its hull and airfoils. Factors such as drag coefficients are then calculated at each one of these areas to ensure the entire plane is being affected in some way by external forces. This system produces figures that are far more accurate than those achieved by taking averages of an entire airfoil, for example. It also results in extremely precise physical properties that can be computed very quickly during flight, ultimately resulting in a much more realistic flight model. The X-Plane accuracy of the flight model is already approved by FAA, for full motion simulator to train commercial airline pilot.
- X-Plane's functionality can be customized using a plugin. A plug in is executable code that runs inside X-Plane, extending what X-Plane does. Plugins are modular, allowing developers to extend the simulator without having to have the source code to the simulator. Plug ins allow the extension of the flight simulator's capabilities or gain access to the simulator's data. For HIL simulator purposes we need to make plug in that
- Reads attitude and position data to simulate sensor measurement
- writes surface control deflection values to simulate servo command
- has ability to communicate with autopilot hardware with some kind of hardware interface (to give sensor measurement and accept servo command).

3.6.1.3 X-Plane as HIL Simulator Platform

The HIL simulator consists of 3 main parts:

• sensors,
• process, and
• actuators.

The Sensors part simulates the sensor's output data in the airframe. This data will be processed by the UAV autopilot hardware as input. The sensor output data that should be produced by HIL simulator are position data (speed, altitude, latitude and longitude) and attitude data (roll, pitch and yaw). This can be accomplished by reading data from the simulator. The Actuators part simulates how the UAV autopilot hardware can change the surface control of the airframe (aileron, elevator and rudder) and throttle position. In real world application this will be done by controlling the hobby servos put in the corresponding control surface or throttle engine. In HIL simulator this is done by writing data to the X-Plane that will affect the control surface of the simulated airframe.

The Process part simulates how the airframe will react to the input given by the UAV autopilot hardware. So basically this part is where we should put the system dynamic model (transfer function). Generally, this is the most complex part of the HIL simulator, but fortunately this part is already provided by the X-Plane (using its blade element approach). The HIL simulator plug in communicates with the UAV autopilot hardware through RS232 serial communication.

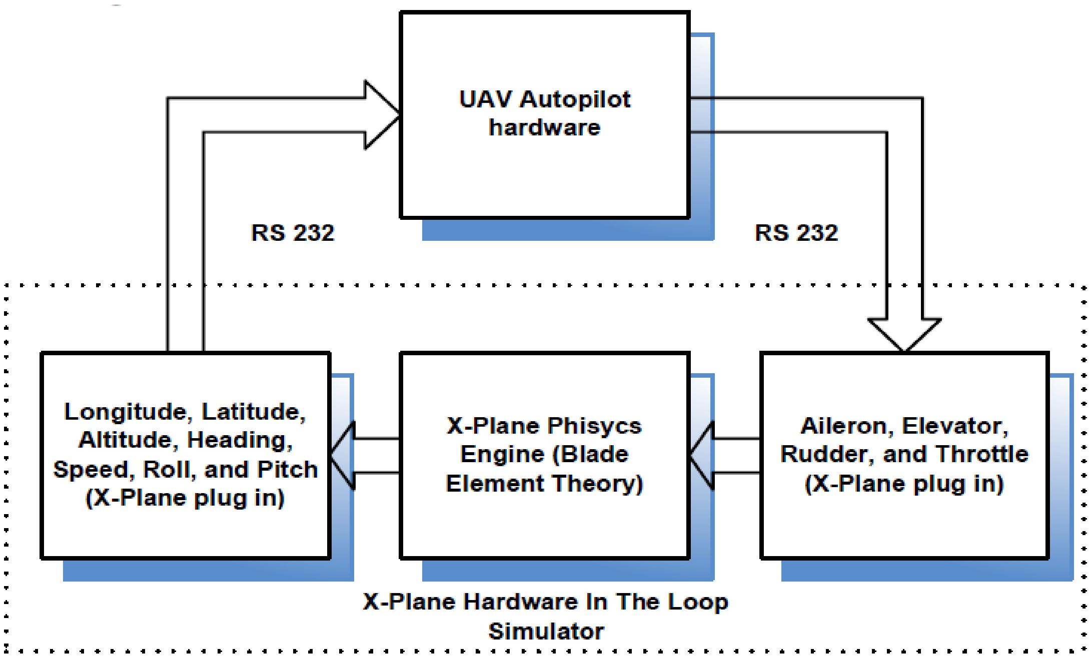


Figure 3-24: UAV autopilot hardware

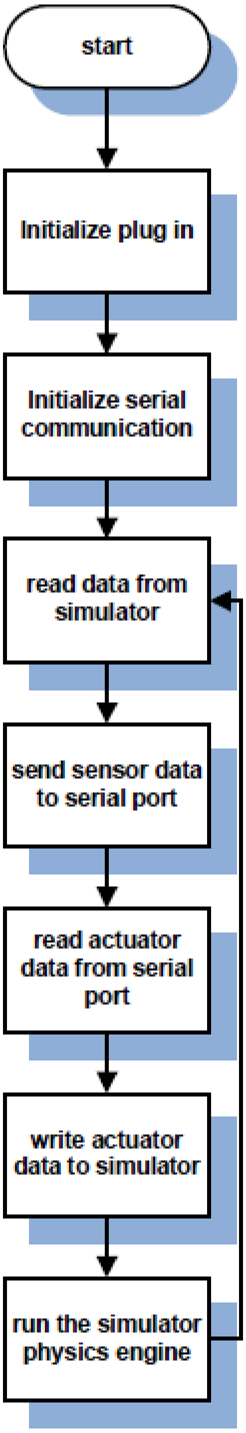


Figure 3-25: HIL simulator flow chart

3.6.1.4 HIL Simulator Utilization

The HIL simulator is utilized to:

• develop the Ground Control Station Software,

• refine the firmware implementation through simulated closed loop tests,

• refine the hardware implementation through UAV autopilot long run reliability test, and

• PID gain tuning

There was one finding when testing the UAV autopilot reliability. The power supply regulator was not stable, and it can be seen from the overall system performance in the HIL simulator. This failure results in airframe crash in its worst. Since this test is conducted in HIL simulator no financial lost occurred. This is one example how HIL simulator can prevent airframe crash in real world field trial. The HIL simulator enables the PID gain tuning based on trial and error basis. Analytical method of PID gain tuning is much more difficult since we have to have the mathematical model of the plant (airframe transfer function). It's considered easier for this writer to tune the PID gain on trial and error basis since airframe crash is not a problem in HIL simulator.

Figure 3-26: Hardware in the loop simulator 3D visualization

Figure 3-27: HIL complete simulation on both softwares MP & X-plane

Figure 3-28: HIL simulation curves of servos for control surfaces by giving some input

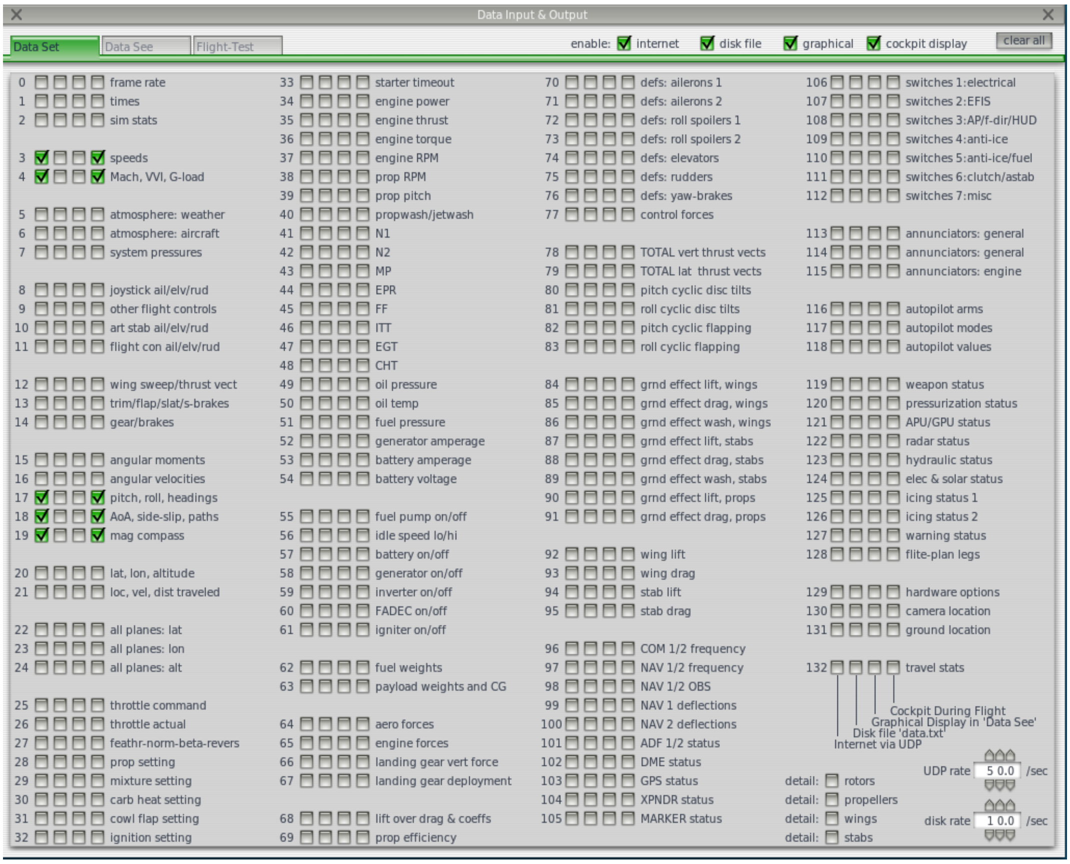


Figure 3-29: X-plane DATA SET values for the HIL simulation

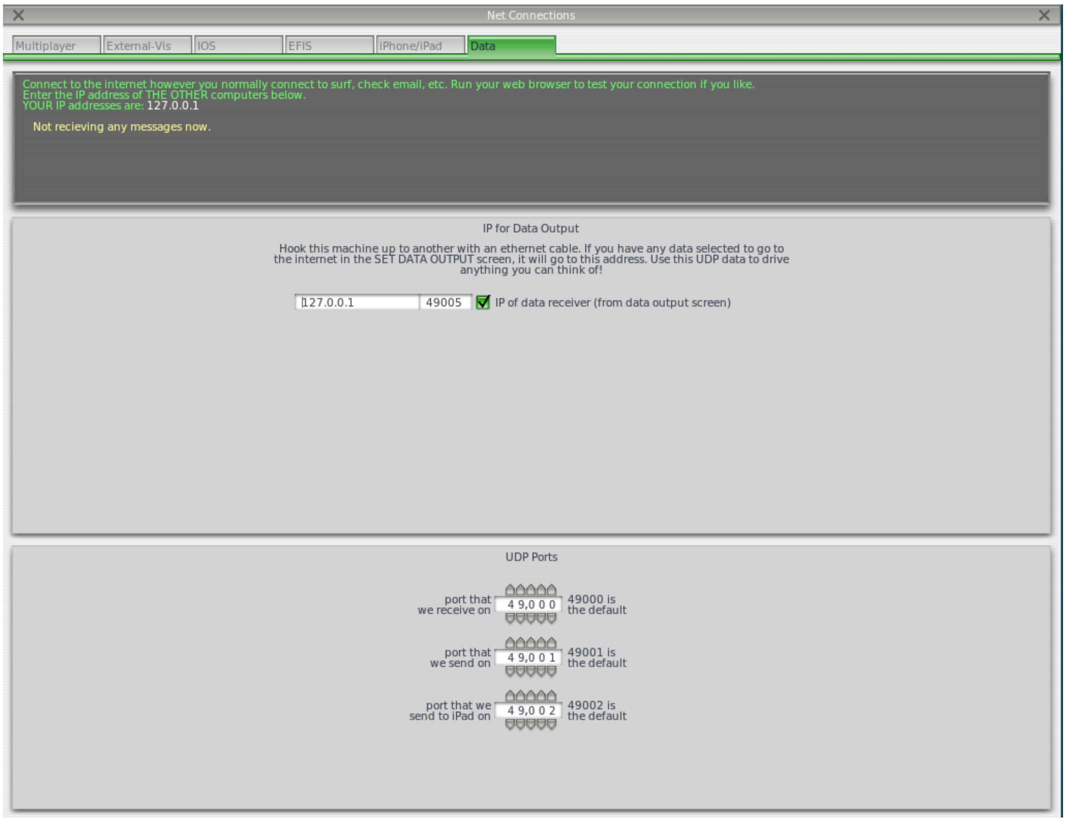


Figure 3-30: X-plane net connections with MP by giving unique IP Address and COM PORT number

3.7 SAFETY AND PRECAUTIONS:

- Ensure that operating environment is safe.
- Do not fly near and over the infra structure /property i.e. power stations, road ways etc.
- Do not fly in high winds and low visibility.
- Before flying over private properties, follow the rules and ordinance.
- Contact the control tower before flying with in the 5 miles of airport.
- It is prohibited to fly under the influence of drugs.
- Remain 25 feet away from public and moving vehicles.
- Avoid obstacles and do not fly near to manned aircraft and try to avoid all obstacles and keep an eye around UAVs surrounding.
- In case of disturbance of frequencies in telemetry radio or any errors occur during a flight the UAV return to its home coordinates or return to its initial launch.
- In case of any battery loss or battery issues occur during a flight the UAV return to its home coordinates or return to its initial launch.

3.7.1 Safety:

There are many inherent risks with the use of unmanned aircraft including: complexity of the system, use of airspace, component failure, and negligence. Precautions have been identified to reduce these risks. To avoid any electronic short-circuiting at most care has been taken to insulate single wire and bind multiple wires using heat shrink sleeve. Any unnecessary sharp edges are avoided. Every flight test is confirmed with Faculty advisor. Risks can be mitigated most with focus on two identified criteria: failsafe and pre-mission tests.

3.7.2 Fail-safe:

Ardupilot has been programmed to conduct two type of fail-safe mechanism.
The Ardu-fail-safe is a fail-safe mechanism used in case of any failure except loss of the radio link. In this case the control of the plane is given to the safety pilot through the radio link. An example is in case the GPS module fails then the Ardu-fail-safe acts. In case of a Radio-Link Loss the Ardupilot takes over and cuts the throttle and vary the control surface such that the plane spirals down and lands. The fail-safe has been tested and works fine.

3.7.3 Pre-Mission Tests:

In order to reduce any failure caused due to negligence the team before every mission conducts a test which involves a series of ratification steps for important components. The first few test is to conclude any hardware glitch in the plane and the power supply (the input current is within the safe range). The next series correspond to the autopilot and its sensor. If any sink effect is realized the component is replaced. The camera power supply is independent and is verified.

CHAPTER # 04

TEST RESULTS AND THEIR ANALYSIS

4.1 TESTING PROCEDURE

When trying to decide the best way to test the APM autopilot system, a full range of options was assessed as to how to validate whether or not this system would work in an aerospace educational environment. A great deal of thought went into what programs to use to validate the autopilot, what aerodynamics model-building processes to use, what wind tunnel data would be pertinent, what flight dynamics engine would be best suited, and what optimization methods could be used. After much indecision, it was decided to go back and look at the mission of this thesis . . . to find a suitable autopilot system to teach undergraduate aerospace students how to design and build autonomous aircraft. What better way to do this than to design and build a prototype capable of flying fully autonomous missions while using APM, all the while keeping detailed steps of how to accomplish this task. Afterwards a full review of all the data collected was done in order to decide how much benefit students would get from designing with this product.

After reviewing past studies on the APM autopilot, it was decided to go with flight testing rather than theoretical analysis to provide a unique view into the autopilot's capabilities. Detailed information on the theory behind the APM autopilot code has been published, but most flight test information available is scattered and incomplete. Learning from past experience with designing and building remote controlled airplanes, there is a large leap from theory to the real world, and integrating RC equipment into an aircraft mixed with unpredictable flight conditions can spell disaster.

In order to validate the APM autopilot, an aircraft initially must be designed to act as a test-bed for the autopilot. At first it was thought that it might be beneficial to use a pre-built commercial RC model as the test aircraft, but since the autopilot will eventually be installed on student-designed and -built airplanes, what better way to test the autopilot than on a self-designed and -built aircraft. This will also enable us to tailor the aircraft to best fit flight-testing conditions.

The next step is to run some simulations on the aircraft. This seems contradictory to what was decided earlier, but there is a need to simulate the aircraft and autopilot system before flight testing in order to resolve any problems before the airplane is in the air. The purpose of the simulations in this project is that there will not be any answers derived from the simulations themselves. Instead, the simulations will be used to support the flight testing, which is where the results of the thesis will be derived. Not to run simulation flights first would be foolish and possibly even dangerous. The makers of APM have developed a way to easily test the autopilot system in a flight simulator, such as X-Plane or Flight Gear, with full hardware-in the-loop. This means that the airplane can be flown with a transmitter, receiver, and APM all interacting with the flight simulator, giving a scenario that is as close to real flight as possible.

Next, flight testing will begin. During flight testing, a large array of tests will be done to evaluate nearly every aspect of the autopilot system. At this point, most of the data will be collected and examined to determine the fidelity of the APM autopilot. Five main areas will be focused on during these tests:

- **Gain Tuning -**

Simulations will be done first to try to determine the initial gains. This will provide a good starting point. Flight tests will then be conducted in order to fine tune the gains more precisely for the actual aircraft. This will be an iterative process, going from simulation to flight test and back again. Results from the flight test may even be used to review the simulation model and, if need be, make changes so that it better represents the actual aircraft. This process should allow convergence to a simulation model and a flight test model that have identical aerodynamic and propulsion characteristics, and near-identical tuned gains.

- **Mission Scripting -**

Once tuned, different mission capabilities will be tested. Every aspect will be tested including automatic takeoff, hitting waypoints, automatic landing, etc.

- **Hardware Performance -**

Performance will be monitored on how well the instruments communicating with the autopilot are working. Components such as airspeed sensor, current sensor, telemetry, altimeter, GPS, gyros, accelerometers, magnetometer, etc., play a vital role in the unmanned aerial system. All of them are vital to the fidelity of the autopilot, and without some of them, it is impossible to achieve autonomous flight.

- **Ability to Handle Changing Flight Conditions –**

During flight testing, there is a likelihood of changing parameters and flight conditions, both planned and unplanned. A good example of this would be a center of gravity shift during flight due to a payload drop, or a shift in wind direction while on approach. Comments will be made on what parameter changes the APM can handle and how well.

- **Data Acquisition -**

Possibly the most important part of the autopilot system as a learning tool is that the acquisition of flight data be consistent. It will be determined what flight data can be recorded and to what degree of accuracy. Most likely this will be taken care of while testing the other four parameters.

Once the five parameters are complete, a comprehensive review of the APM autopilot system will be done in terms of incorporating it into aerospace academe. Strengths and weaknesses of the autopilot will be reiterated, and suggestions for implementation into an aerospace learning environment will be made.

4.2 FLIGHT TESTING (VALIDATION)

Now that a full range of simulations has been performed to help tune the aircraft, flight testing can begin. Before starting, it is important to note the anticipated differences between flight testing and simulation. First, the simulation realm consists of perfect flight conditions with perfect sensors, which is not the case in real flight testing. Granted, wind and turbulence can be simulated in X-Plane, but this is not a perfect representation of real flight conditions. Second, X-Plane is a linear-based software and does not account for factors like separation of flow over surfaces. These issues will most likely lead to the need for further tuning during flight testing, but the simulation results are “in the ball park.” Aside from this, it should still be possible to obtain good data that will give a decent view of how the autopilot performs. It should also be noted that many of these flight tests were simulated with different wind conditions. It is important to ensure that the limits of the mission with respect to wind are known before the flight test. Special effort will be made in the flight test results to emphasize the weather conditions at the time of the flight.

4.2.1 Servo PID Test:

The most important gains will be tested first. Without an accurate servo PID gain set, the autopilot will not be able to control the aircraft. The testing/tuning of the servo PID gains was done with the same process as the simulation. On the day of testing, there was a 10 mph wind out of the south, so for all the tests, the aircraft was flown into the wind and kept at an airspeed of around 12.5 m/s. The aircraft was taken off in manual mode and then placed in FBW-A. The first axis tuned was the roll axis. A full right aileron input was given, causing the aircraft to produce a 55-degree bank angle. The stick was then released, allowing the autopilot to level out the aircraft. Figure 4-1 shows the response of the roll to the stick input. A few things must be noted from this graph. The rise time is about 1 second, compared to 0.6 second in the simulation. Notice that there is a rounding effect of the roll as it reaches the 55-degree bank angle and back to level, which did not appear in the simulation. Also, hardly any overshoot occurs when traveling to the new desired state.

The aircraft's roll performance is not as optimized as in the simulations, but it appears to be quite capable of performing autonomous missions. The only change made to the roll PID gain set was tuning the proportional gain up from 0.7 to 0.9. This provided slightly more aggressive maneuvers without adding undesirable overshoot or oscillations. Figure 4-2 shows the roll response with the new gain, this time with a left-hand turn.

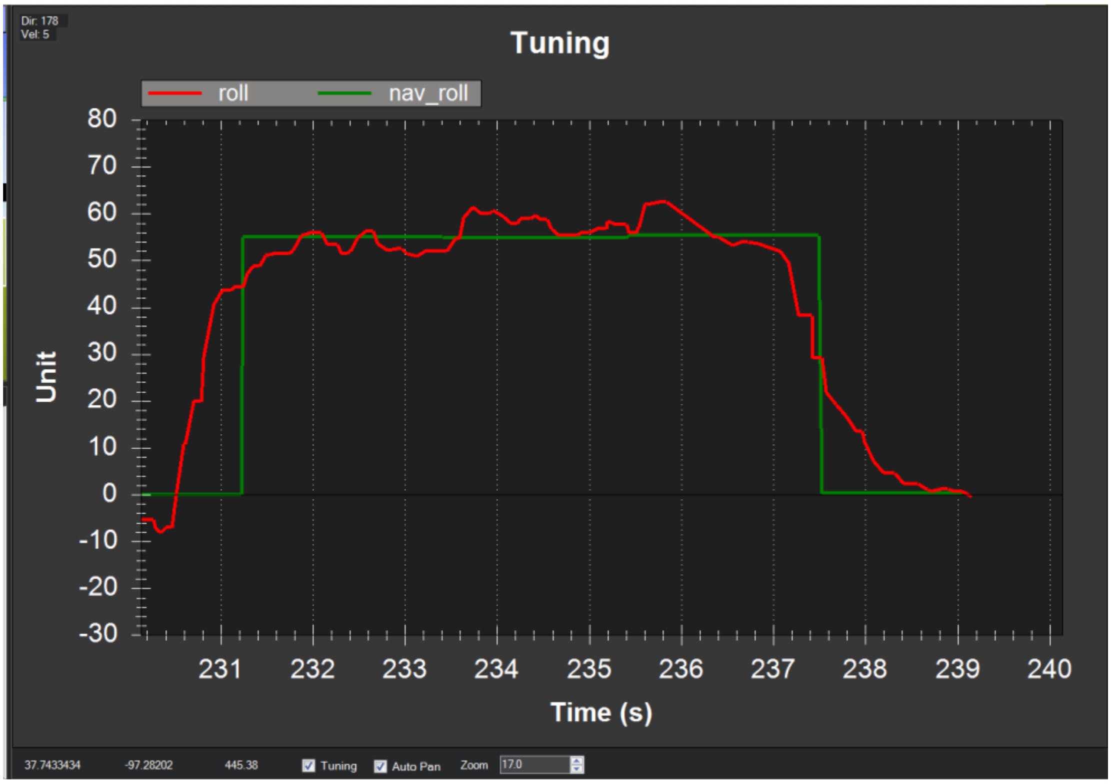


Figure 4-1: Servo roll gain set of P = 0.7, I = 0.4, D = 0.12 performing roll of 55° during flight testing.

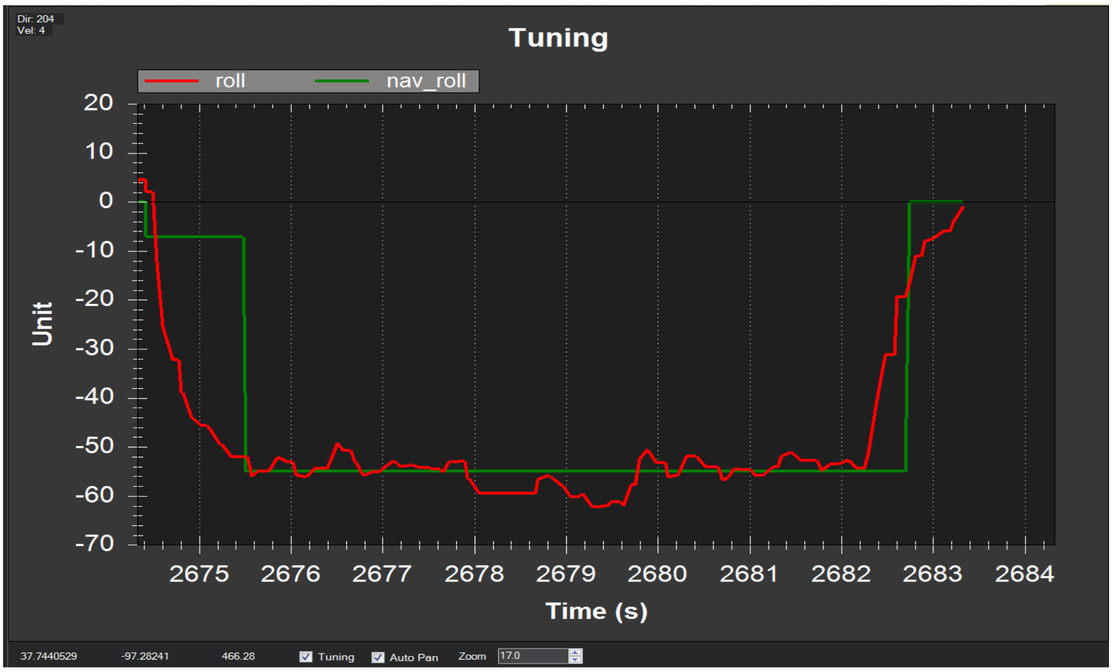


Figure 4-2: Servo roll gain set of P = 0.9, I = 0.4, D = 0.12 performing 55° roll during flight testing.

The same process was carried out for the pitch axis. An input of 25 degrees, which is the maximum negative pitch angle allowable, was given by the pilot and then released. Figure 4-3 shows the aircraft's reaction.

Figure 4-3: Servo pitch gain set of P = 0.7, I = 0.25, D = 0.05 performing pitch of -25° during flight testing.

Rise time, or in this case decline time, is about one second. The pitch never truly hits the desired 25 degrees, but rather settles around 22. This is due to the elevator setting for trim flight being about 3 degrees, which subtracted from 25, gives the difference that is shown. This is similar to what was seen in the simulation. The rise time is dreadfully slow at more than 2 seconds. There does not seem to be any over shoot either. Both of these characteristics lend themselves to achieving flight improvements by tuning up the proportional pitch servo gain.

By turning up the pitch proportional gain from 0.7 to 1.2, as shown in Figure 4-4, the aircraft gives pitch characteristics similar to what was observed in the simulations. Both the roll and pitch tests show a trend of the real aircraft performing slower maneuvers than what was seen in the simulation. This is most likely due to the aircraft's control surfaces being not as efficient as the simulation. This would make sense because the simulation is a linear process and not able to predict factors like separation.

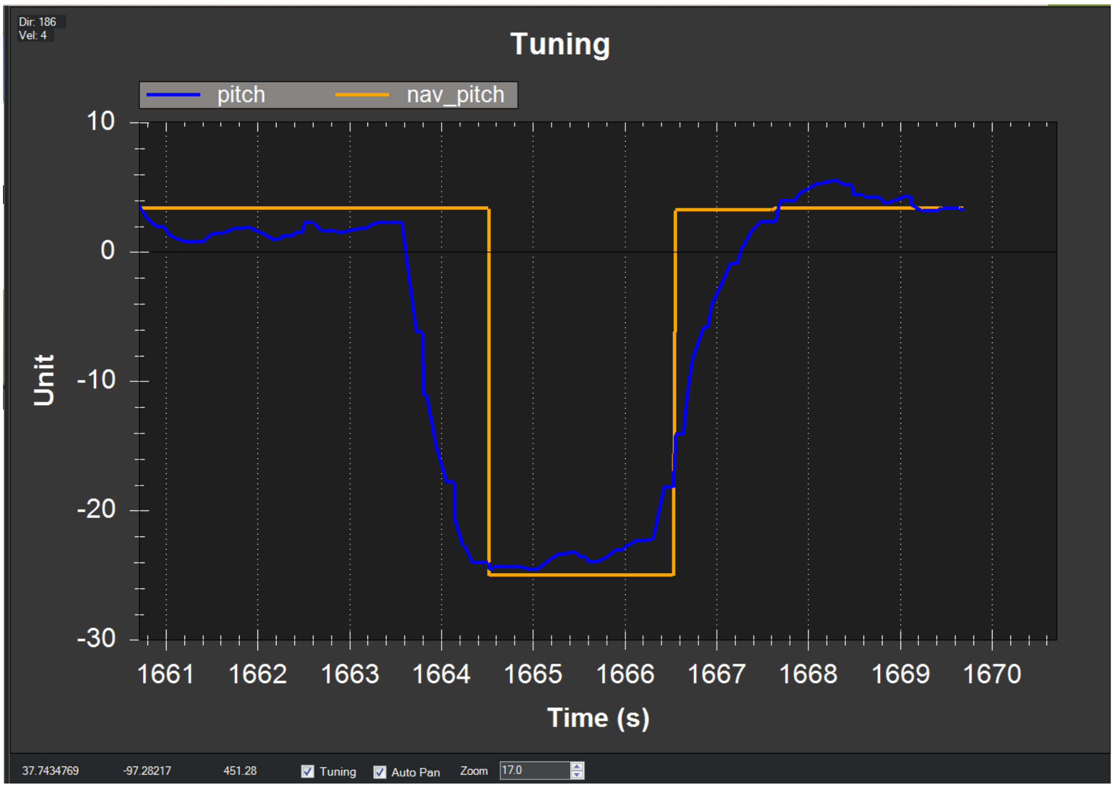


Figure 4-4: Servo pitch gain set of P = 1.2, I = 0.15, D = 0.05 performing pitch of-25° during flight testing.

The yaw is more difficult to analyze than the roll or pitch. The only real role it will play in the autopilot is if the rudder mix parameter is turned up. The actual PID gains that are being used for yaw are zero. Coincidentally, it is not as significant to the flight mission success as the other two parameters. For this reason, the yaw was judged by viewing it from the ground, instead of analyzing graphs, to see how affective it was at turning the aircraft. The rudder, with its current throws, seemed to do a good job of turning the aircraft. The pilot was able to keep the aircraft flying into the wind by using only the rudder. The next step will be to test different rudder mixes to see what impact on the turn the rudder will have while performing a coordinated turn with the ailerons.

4.3 RESULTS:

Figure 4-5: Servo roll gain set of P = 0.4, I = 0, D = 0 performing roll of 45°.

Figure 4-6: Servo roll gain set of P = 0.6, I = 0, D = 0 performing roll of 45°.

Figure 4-7: Servo roll gain set of P = 0.6, I = 0.1, D = 0 performing roll of 45°.

Figure 4-8: Servo roll gain set of P = 0.6, I = 0.1, D = 0 showing removal of steady-state error.

Figure 4-9: Servo roll gain set of P = 0.6, I = 0.2, D = 0 performing roll of 45°.

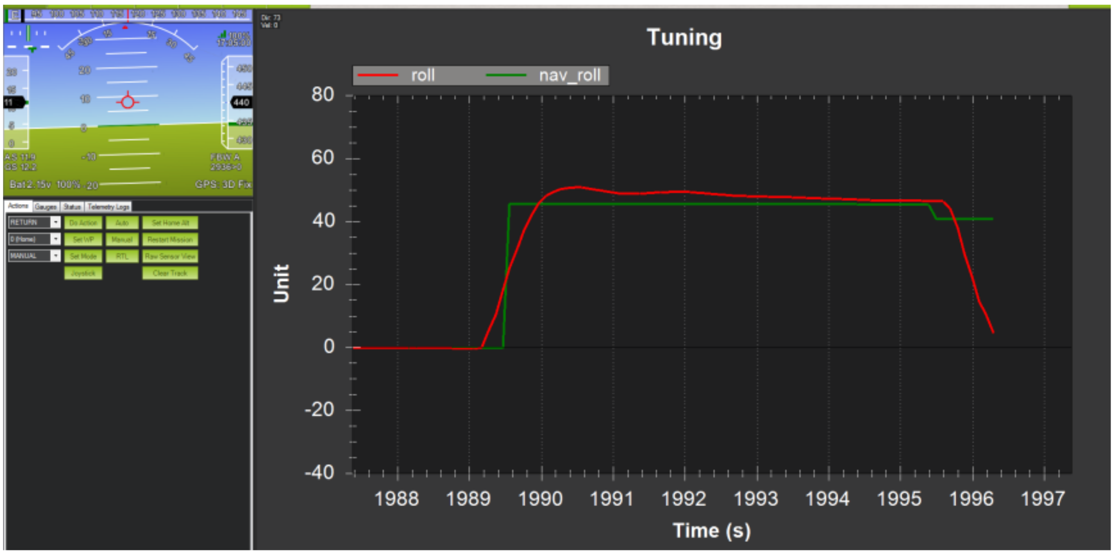


Figure 4-10: Servo roll gain set of P = 0.6, I = 0.2, D = 0.1 performing roll of 45°.

	Servo Roll PID	**Servo Pitch PID**	**Servo Yaw PID**
P	0.7	0.7	0
I	0.4	0.25	0
D	0.12	0.05	0

Table 4-1: Optimized Servo Motor PID Gains Sets

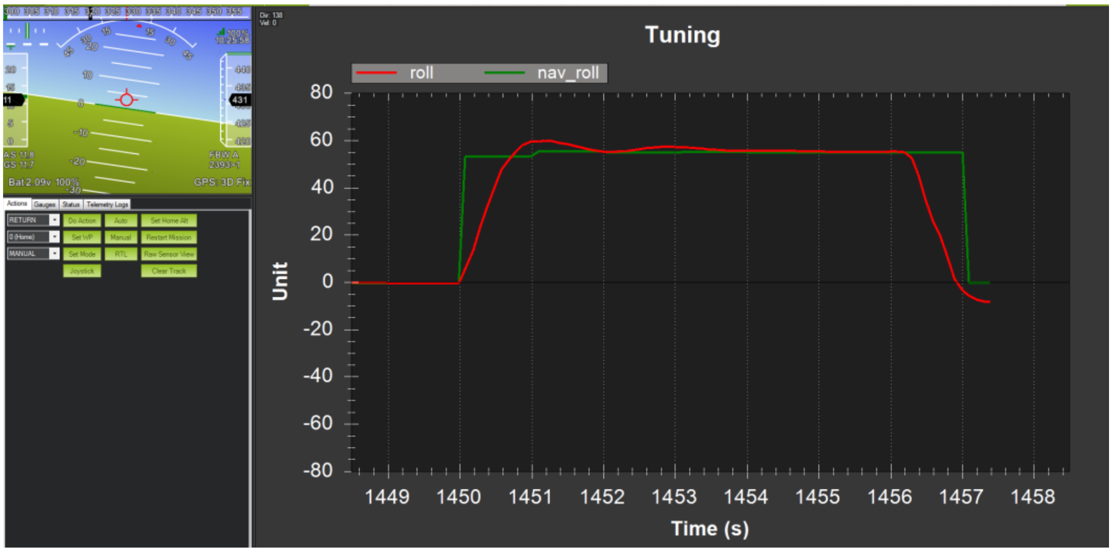


Figure 4-11: Servo roll gain set P = 0.7, I = 0.4, D = 0 performing roll of 55°.

CHAPTER # 05

ECONOMIC ANALYSIS

Figure below shows a chart that displays the items used for the project, the cost of each item individually, and the overall cost of all of the components. It also shows a rough estimate of the cost of the project if the RC aircraft and the spare parts required for it were purchased, as well as an estimate of the complete total cost.

5.1 BUDGET OF OUR PROJECT:

CATEGORY	ESTIMATED (IN PKR)
CONTROLLER	4500/-
SERVOS	4800/-
RADIO TRANSMITTER/RECEIVER	7000/-
LI-PO BATTERY	4000/-
POWER MODULE	1000/-
CHARGER	2300/-
CONNECTORS	70/-
TELEMETRY RADIO	2800/-
GPS+COMPASS MODULE	2780/-
UBEC	1000/-
CELLS	230/-
BELSA WOOD	5900/-
GLUE	570/-
NOSE GEAR	2500/-
MONOCOT(COVERING)	1500/-
OTHERS	3000/-
TOTAL EXPENSES	**44000/-**

Table 5-1: Budget table of our project in Pakistani Rupees

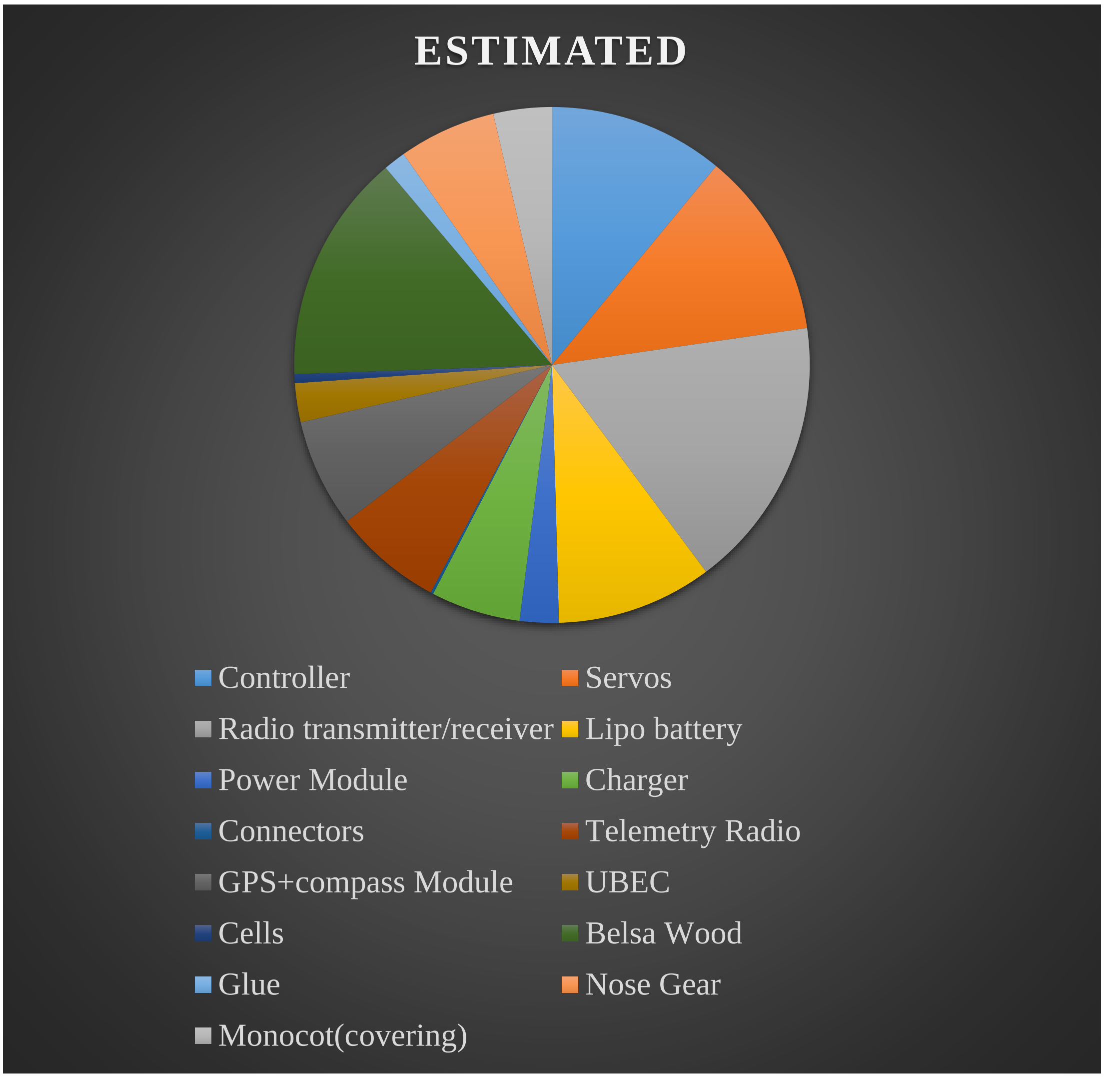


FIGURE 5-1: ESTIMATED COMPARISON CIRCLE OF HARDWARE OF OUR PROJECT

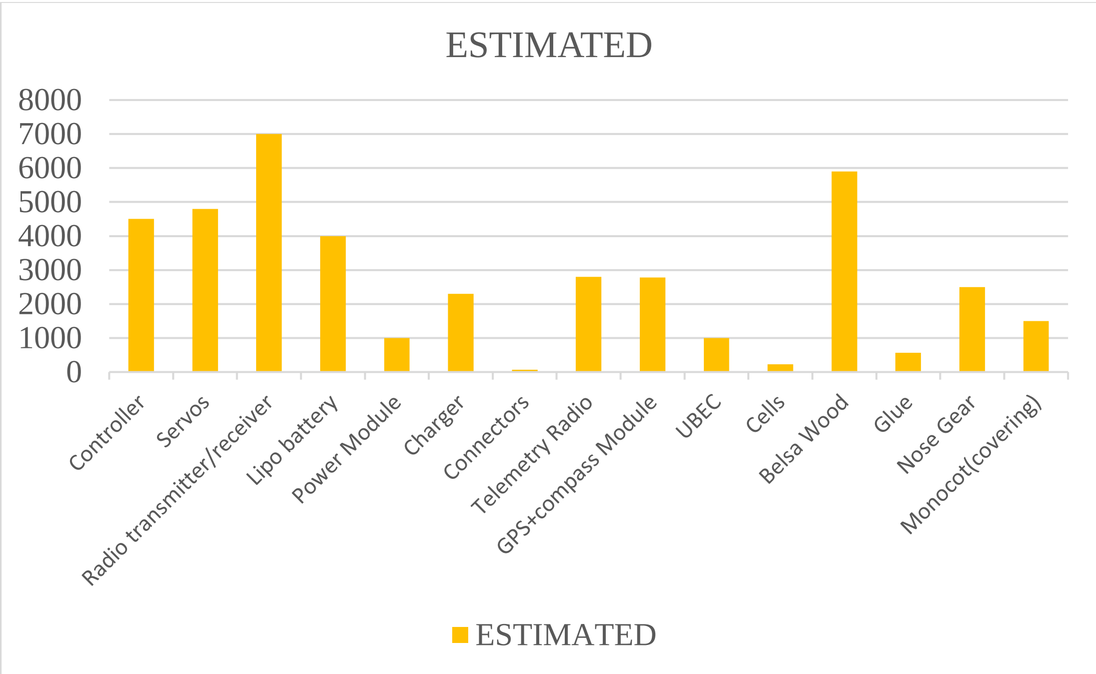


FIGURE 5-2: ESTIMATED GRAPH OF HARDWARE OF PROJECT

CHAPTER # 06

CONCLUSION

The UAV that was developed has fully autonomous flight capabilities. It has also been successfully integrated with urban security systems. It can navigate its waypoints successfully as well as maintain its height. The UAV can be hand launched and maintains a sufficient height to fly safely. All the relevant information necessary for monitoring the flight is relayed to the operator.

The UAV that was developed has fully autonomous flight capabilities. It has also been successfully integrated with security systems. It can navigate its waypoints successfully as well as maintain its height. The UAV can be hand-launched and maintains a sufficient height to fly safely. All the relevant information necessary for monitoring the flight is relayed to the operator.

The UAV is also small enough for car transport. It has a flight range long enough to monitor perimeters and the endurance of the UAV is 15 min. It is concluded that the UAV is effectively integrated with a security system. One of the drawbacks of the system is that it is difficult to operate since it does not yet have autonomous take-off and landing capabilities. Lastly, the height it is capable of flying at is not high enough to avoid detection.

CHAPTER # 07

FUTURE RECOMMENDATIONS

7.1 Future Works and Recommendations

- It is recommended that the autopilot be built into a delta-wing airframe. This will give the UAV increased stability at high speeds.
- The UAV needs autonomous take-off and landing capabilities which would make controlling the UAV simpler for less educated operators.
- Software for the analysis of the video feed needs to be acquired or developed which would allow the system to function without human operators.
- The video feed telemetry can be integrated into the autopilot telemetry which would simplify the system and save production cost.
- Test the UAS with real security operators which could give further insight into integration requirements.
- Research objects detection and collision avoidance systems which could include in -flight collision avoidance with other airplanes, UAVs and birds as well as stationary objects like buildings and masts.
- Research how multiple UAVs should be positioned to give the optimal view of an area.
- Testing the UAV with disturbances such as wind.
- A backup navigation system — that uses ground based equipment — needs to be created for when the UAV does not have GPS lock.
- A UAS system needs to be developed that not only incorporates multiple UAVs, but can also be controlled from more than one GCS.
- Alter the code to maintain a preset height above ground level, rather than launch altitude.
- Wind tunnel testing must be done to accurately determine the stall speed.
- Install a camera that can pan and tilt.

Implement a system that can sweep an entire environment. With this, an UAV can have total control on objects around it, improving the decisions and response behaviors of “Avoid and Continue” mode.

Furthermore, in order to increase the performance of the guidance and control system the parameters in the low-level PID controller in APM: Plane used in the experiments at Agdenes should be tuned further. The parameter values used in the experiments are a result of the APM: Plane mode autotune. For better performance, manual tuning is a described as a must in the autotune documentation. When the final mathematical model of the X8 is fully developed, the analytical tuning expressions developed in this thesis should be tested in real flights, potentially saving several hours and days of tuning compared to manual tuning.

During this project, a few aspects can be improved further. These are highlighted in the following points:

- Modeling techniques will be improved to model a high speed UAVs.
- Control strategy will be modified to design an aircraft with heavy loads.
- Using advanced embedded systems with 32-bits with achieving real time operating systems concepts.
- The need for the cooperation with an establishment interest in our work to construct our proposed system and aerospace labs to have a real results specially the coefficients of most advanced aircrafts from their wind tunnels to aid us in developing our design.

CHAPTER # 08

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CHAPTER # 09

APPENDIX

9.1 LIST OF FLIGHT MODES OF CORE APM AUTOPILOT FIRMWARE

Manual –

While in this mode, the pilot has complete control of the aircraft. The autopilot system has no influence on the control of the aircraft.

Stability Mode – This is the mode that every other auto-piloted mode uses, incorp-orating the main servo PID gain controller. The pilot still has overall say of what the aircraft does, but the controller will always try to bring the aircraft back to zero pitch and zero roll. For the pilot, the controls may feel “mushy,” since the controller will want any movement away from center in pitch and roll to come back to center. If the pilot lets go of the stick, the plane should go back to center. The controller has no influence over the throttle.

Fly-by-Wire-A (FBW-A) –

This mode is similar to stability mode, except the controller has more say over navigational control. Throwing the aileron stick full right will cause the aircraft to continuously roll to the maximum roll limit inputted by the user, where normally the aircraft would do barrel rolls. Flying in this mode has been described as similar to driving a car. This is a very good mode to test the servo PID gains. The throttle is controlled manually

Fly-by Wire-B (FBW-B) –

This mode is similar to FBW-A, except the throttle is controlled by the controller. The airspeed sensor must be enabled, or the mode will revert back to FBW-A. There is no direct control over the elevator in this mode. Instead, if an elevator-down control is given by the pilot, the logic of the controller will understand the command as wanting to lower altitude and therefore lower the throttle. This flight mode is not recommended for testing.

Autopilot –

In this mode, the controller has complete control over the aircraft. The aircraft will use a pre-programmed mission to fly to waypoints. The pilot is still able to give sugg-estions to the aircraft, which is equivalent to nudging the aircraft in the right direction, but the autopilot still has the overall say.

Return-to-Launch –

Similar to autopilot mode, instead of following a course of GPS waypoints, the controller will tell the aircraft to return to the home GPS waypoint and loiter until given further instruction.

Loiter –

Similar to autopilot mode, instead of navigating through a course of waypoints, the aircraft will loiter around a specific GPS point until given another command.

9.2 LAYOUT OF FRAME/BODY OF PLANE (MECHENICAL STRUCTURE) WITH COMPLETE DIMENSIONS: