FEBRUARY 2019 M.Sc. in Aircraft and Aerospace Engineering ENES ÖZEN

UNIVERSITY OF GAZİANTEP

GRADUATE SCHOOL OF

NATURAL & APPLIED SCIENCES

DESIGN OF UNMANNED AERIAL VEHICLE

AND

GROUND TERMINAL

M.Sc. THESIS

IN

AIRCRAFT AND AEROSPACE ENGINEERING

BY

ENES ÖZEN

FEBRUARY 2019

Design Of Unmanned Aerial Vehicle And Ground Terminal

M.Sc. Thesis

In

Aicraft and Aerospace Engineering

University Of Gaziantep

Supervisor

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By

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February 2019

REPUBLIC OF TURKEY

UNIVERSITY OF GAZİANTEP

GRADUATE SCHOOL OF

NATURAL & APPLIED SCIENCES

AIRCRAFT AND AEROSPACE ENGINEERING

Name of the thesis: Design of Unmanned Aerial Vehicle and Ground Therminal

Name of the student: Enes ÖZEN

Exam date: 15/3/2019

Approval of the Graduate School of Natural and Applied Sciences

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This is to certify that we have read this thesis and that in our opinion it is fully adequate, in scope and quality, as a thesis for the degree of Master of Science.

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Enes ÖZEN

ABSTRACT

DESIGN OF UNMANNED AERIAL VEHICLE AND GROUND TERMINAL

ÖZEN, Enes

M.Sc. in Aircraft and Aerospace Engineering

Supervisor: Prof. Dr. İbrahim Halil Güzelbey

February 2019

103 Pages

The aim of this thesis is to design and manufacture a full autonomous unmanned aerial vehicle. Previous studies have been examined, according to the needs of the type of air-vehicle was determined. The most suitable avionics and propulsion elements were chosen as a result of the mathematical calculations based on the approximate capacity of the air-vehicle. The design of the air-vehicle was performed in CATIA V5 according to the elements decided to be used. Production of prototype work was done by 3D printing method. After the revision works, electronic equipment for integration was prepared to the level of sub-assembly. The system was mounted in accordance with the complete designation of the flight controller used. According to the flight controller APM instructions, the required short tests and software downloads to the air-vehicle have been completed. Ground tests and flight tests were completed successfully.

Camera and rocket systems were added after the successful flight of the air-vehicle except for the payload. Pre-flight plan required for autonomous flight was prepared. Flight plan was transferred to the air-vehicle flight controller. Images and rocket studies were examined during the given task.

Keywords: UAV, Quadrotor, Rocket Launcher, Design, Combat UAV

ÖZET

İNSANSIZ HAVA ARACI VE YER İSTASYONU TASARIMI

ÖZEN, Enes

Yüksek Lisans Tezi, Uçak ve Uzay Mühendisliği

Tez Yöneticisi: Prof. Dr. İbrahim Halil GÜZELBEY

Şubat 2019

103 Sayfa

Bu tezin amacı, tam otonom insansız hava aracı tasarımı ve imalatını gerçekteştirmektir. Hava aracının yaklaşık kapasitesine göre yapılan matematiksel hesaplamalar neticesinde en uygun aviyonik ve itki elemanları seçildi. Kullanılmasına karar verilen elemanlara göre CATIA V5 de hava aracının tasarımı yapıldı. Prototip çalışmanın imalatı 3D baskı yöntemiyle yapıldı. Revizyon çalışmalarının ardından integrasyon için elektronik ekipmanlar alt montaj seviyesine hazırlandı. System, kullanılan uçuş kontrolcüsünün talimatnamesi doğrultusunda monte edildi. Kullanılan uçuş kontrolcüsü APM talimatnamesine göre, hava aracına gerekli short testleri ve yazılım yüklemeleri tamamlandı. Yer testleri ve hava testleri başarı ile sonuçlandırıldı.

Hava aracının faydalı yük hariç uçuş testlerinin başarı ile sonuçlanmasından sonra, kamera ve roket sistemleri eklendi. Otonom uçuş için gerekli olan uçuş öncesi planı hazırlandı. Uçuş planı hava aracına aktarıldı. Verilen görev süresince alınan görüntüler ve roket çalışmaları incelendi.

Anahtar Kelimeler: İHA, Quadrotor, Roket Fırlatma, Tasarım, Savaş İHA’sı

ACKNOWLEDGEMENTS

I would like to thank Professor Halil Ibrahim GUZELBEY for all his supports and feedbacks during my entire study. I prepared this thesis in company whose name is Lapis Aviation Technologies Corporation and CANAERO Aviation Corporation. I would like to extend many thanks to my colleagues. Moreover My mother and father also deserve many thanks, because of their endless support to my studies throughout my educational life. Furthermore I would like to thank to my instructors at YAGEM who supported me in determining the subject of my thesis at the very outset.

I hope the results of my thesis would be beneficial for the economy of my country. I also hope that my thesis would help enlighten those who are and will be studying on UAVs.

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LIST OF ABBREVIATIONS

ABS	Acrylonitrile butadiene styrene,
ADF	Automatic Direction Finder,
AMM	Quadrotor Maintenance Manual,
AGL	Altutide Ground Level,
ALS	Altutide Ground Level,
ACC	Air Control Center,
AFIS	Aerodrome Flight Information Service,
AIA	Asian Institude Aviation,
AIP	Aeronautical Information Publication,
ATC	Air Traffic Control,
BLDC	Brushless Direct Current
CTR	Control Zone,
CAA	Civil Aviation Authority,
CW	Clock Wise,
CCW	Counter Clock Wise,
CPU	Central Processing Unit,
DA	DecisionAltitude,

DH	Decision Height,
DGCA	Directorate General of Civil Aviation,
EASA	Europen Aviation Safety Agency,
ESC	Electronic Speed Controller,
FC	Flight Controller,
FL	Flight Level,
Flip	Flight Information Publication,
FIR	Flight Information Region
FPV	Fisrt Person View
GPS	Global Position System,
GNSS	Global Navigation Satellite System
GLONASS	Global Orbiting Navigation Satellite System
GUUM	Gaziantep Ucak ve Uzay Muhendisligi,
LIDAR	Light Detection and Ranging,
Li-Po	Lithium-ion Polymer,
ICAO	International Civil Aviation Organization,
ILS	Instrument Landing System,
IFR	Instrument Flight Rules,
IMC	Instrument Landing Meteorological Conditions,
IMU	Inertial Measurement Unit,

IR	Instrument Rating,
I/O	Input/Output,
MEMS	MicroElectroMechanical System,
MPD	Maintenance Programme Document,
MLS	Microwave Landing System,
NOTAM	Notice to Airmen,
NDB	Non Directional Beacons,
NTSC	National Television Standard Committee
OSD	On Screen Display,
PAL	Phase Alternate Lines
PID	Proportional Integral Derivative,
PPL	Private Pilot License,
PPM	Pulse Position Modulation,
PWM	Pulse Width Modulation
RC	Remote Control,
RTK	Real Time Kinematic,
RF	Radio Frequency,
R&D	Research and Develop,
Rx/Tx	Reciever / Transmitter,
TMA	Terminal Control Area,

WP	Waypoint,
VFR	Visual Flight Rules,
VMC	Visual Meteorological Condition,
VHF	Very High Frequency,
VOR	VHF Omni-directional Radio Range,
V-TOL	Vertical Take Off and Landing,
USB	Universal Serial Bus
UAV	Unmanned Aerial Vehicle,
UHF	Ultra High Frequency,
UASID	The United States Agency for International Development,

LIST OF SYMBOLS

b	Thrust Factor
O_B	Body Fixed Frame
O_E	Earth Fixed Frame
d	Drag Factor
g	Acceleration of Gravity
Ix,y,z	Inertia moments
Jm	Motor Inertia
Jr	Rotor Inertia
Ke	Motor Electrical Constant
Km:	Motor Torque Constant
l	Horizontal Distance
R:	Rotation Matrix
U:	Control Inputs
ρ:	Density of Air
τ:	Torque
x,y,z:	Position in body coordinate frame
ϕ	Roll Angle

θ	Pitch Angle
ψ:	Yaw Angle
ω	Angular Rate
g	Gravitational acceleration g =9.81m/s^2

CHAPTER 1

INTRODUCTION

1.1 INTRODUCTION

The utilization of unmanned aerial vehicles (UAV) is constantly expanding due to the ever decreasing cost of electronic components such as microcontrollers, sensors, lithium based batteries, and the availability of huge open sources. UAV's application are arranged from civil or military target track in identification, search and rescue in dangerous area sand disaster control, agricultural spraying, traffic control, through to mapping.

Eventhough many UAVs are able to operate fully autonomously, they are mostly controlled via remote control stations in different forms such as laptops, ground control shelters, tablet PCs, or smartphones. Besides many currently existing UAVs which still requires humanitarian effort and intelligence for controlling purposes, there are already UAVs being deployed on the a forementioned are as which do not require any human intervention at all, and these UAVs are able to take-off, cruise, land on specified areas, and perform the requested mission fully autonomously [2], [31].

Another important factor which leads to the widespread usage of UAVs, is the availability of many commercial or open source based autopilot systems, which different the usage of their microcontrollers and sensors. Whereas most commercial systems do not offer the possibility for modifications on the hardware and/or software, open source based systems provide the ability to do additional research and development. These open source based systems are in addition very cheap and are therefore preferred by universities and hobbyists all around the world [31].

Another technological aspect of UAVs is the integration and development of the control algorithms used in the autopilot software. The theory and techniques behind the autopilot control software can be as varied as the application area of the UAVs itself. Nowadays, anyone who is involved in UAV development and research, might easily come across terms and definitions such as classical PID, adaptive control, Fuzzylogic, neural networks, LQG (LinearQuadraticGaussian). With the deployment of such advanced control software a quadcopter, for example, will be able to do aggressive maneuvering when required, or hover in very windy conditions, or land on very tricky and tiny landings pots [3], [23], [31].

Developments in the manufacturing, 3D printer, composite manufacturing methods and the development of manufacturing industry have accelerated the development of unmanned aerial vehicles. Previously, working on these issues was very costly and ready to use kits. It became even easier for students and amateur inventors to realize their ideas. Any ideas can be modeled on the computer and produced as prototypes. In this way, many different designs were created.

The aim of this thesis is to realize an original work by using the mentioned developments. The study will be carried out in the light of previous studies and calculations.

1.2 UAVs HISTORY

The first flying experiments began in 1452 with Leonardo da vinci. After this work, the inventors made significant contributions to the development of aviation by constantly adding ideas. These contributions were multidisciplinary with the developments in other systems. Aviation has set a different road map with the development of vehicles that can take off without the need for people. Nowadays these systems have become a very popular research and development science [1], [19], [25].

After the Second World War, the interest and investment in American unmanned systems increased. The largest work on the subject is the Black Widow unmanned aerial vehicle developed by an American company, Norhrop Grumman Corp [2], [19].

In 1986 - Gnat 70, supposed to be a complement to the larger UAV, has begun to be produced. This project is also the basis of the Predator [19].

In 1998 – The RQ-4 Global Hawk realized its first flight [19].

In 2006 - The Baykar Mini UAV was included in the military inventory [19].

In 2014 – TB2 tactical UAV, began to be used by the army [19].

2.2 UAVs APPLICATION

They can be classified according to their application for military or civil use [2], [10], [11].

2.2.1 Civilian Unmanned Systems

Unmanned aerial vehicles are used to protect people's benefit, animals and forests. In Africa, drug and aid supplies are delivered to hard-to-reach places with the help of developed UAVs. Unmanned aerial vehicles were used in Japan in the nuclear accident. In this way, people's exposure to radiation was prevented. For such applications, unmanned aerial vehicles are used for the benefit of humans and others[2], [3]. Civil aplications are;

- Transportation
- Research
- Scientifistic
- Observation
- Mapping

2.2.2 Military Classifications

Unmanned aerial vehicles are seen as a branch of robot wars, which are war technology in the future. An Army Base in America, it is possible to neutralize terrorist groups in Africa easily. The same applies also to observe illegal border crossings in Turkey and ground units can intervene informed. The same applies for the safety of petrol transfer pipes. To prevent terrorist attacks, hundreds of kilometers of pipelines can be controlled. The attacks can be prevented without being harmed [2], [3]. Military applications such as;

- Discovery / Observation
- Diversion

- Defense
- Destruction.

Classifications determined by NATO unmanned aerial vehicles are given in Table 1.1. [7].

Table 1.1 NATO UAS Classification Guide. September 2009 JCGUAV meeting

Class	Category	Normal employment	Normal Operating Altitude	Normal Mission Radius	Primary Supported Commander	Example platform
CLASS I (less than 150 kg)	SMALL >20 KG	Tactical Unit (employs launch system)	Up to 5K ft AGL	50 km (LOS)	BN/Regt, BG	Hermes 90 Luna
	MINI 2-20 kg	Tactical Sub-unit (manual launch)	Up to 3K ft AGL	25 km (LOS)	Coy/Sqn	Aladin DH3 DRAC Eagle Raven Scan Skylark Strix T-Hawk
	MICRO<2 kg	Tactical PI, Sect, Individual (single operator)	Up to 200 ft AGL	5 km (LOS)	PI, Sect	Black Widow
CLASS II (150 kg to 600 kg)	TACTICAL	Tactical Formation	Up to 10,000 ft AGL	200 km (LOS)	Bde Comd	Aerostar Hermes 450 iView 250 Ranger Sperwer
CLASS III (more than 600 kg)	Strike/ Combat	Strategic/ National	Up to 65,000 ft	Unlimited (BLOS)	Theater COM	
	HALE	Strategic/ National	Up to 65,000 ft	Unlimited (BLOS)	Theater COM	Global Hawk
	MALE	Operational/ theater	Up to 45,000 ft MSL	Unlimited (BLOS)	JTF COM	Predator B Predator A Harfang Heron Heron TP Hermes 900

CHAPTER 2

LITERATURE SURVEY

2.1 INTRODUCTION

A literature study was performed in this section about design, manufacture and flying principle of UAV. Previous studies, hardware and software used were examined. The studies on the type of mini UAVs platform for this project were examined.

2.2. THE LITTLE DIPPER 300

This study mentions the installation of mini unmanned aerial vehicles by Terry Kilby. The theoretical information about unmanned aerial vehicles is the way of designing air-vehicle in many different sizes. The Little Dipper 300 class autonomous quadcopter as a reference air-vehicle gives an example of how to build an air-vehicle by showing how to do it. This resource allows us to anticipate any errors that may occur while performing the project. Very important information on design, manufacturing and material selection was prepared with reference to this source [17].

Table 2.1 The Little Dipper 300 Specifications

Type of UAV	Multi-rotor
Take off Weight	0.6 kg
Diagonal Length	30 cm
Flight Time	10 minutes
Maximum Payload Mass	onboard
Maximum Speed	55 km/h
Range	1 km
Altitude	-

2.3 AEROVIROMENT – SHRIKE VTOL

Shrike VTOL is an air-vehicle that was designed for military purposes. The air-vehicle was developed by Aeroviroment. The main field of operation of this company is military systems and it manufactures many various and interoperable systems. The specifications of Shrike Vtol are given in Table 2.2. The features of the air-vehicle were taken from https://avinc.com/. Thanks to the advanced communication systems used in air-vehicle, it can perform tasks like swarm. It is completely autonomous and does not have structural intelligence modules. According to the laws of war, the last fire order is the verb of a person, allowing the ability to make limited decisions.

Table 2.2 Shrike Vtol Specifications

Type of UAV	Multi-rotor
Take off Weight	2.5 kg
Diagonal Length	90 cm
Flight Time	40 minutes
Maximum Payload Mass	500 gr
Maximum Speed	55 km/h
Range	5 km
Altitude	-

2.4 MODELLING AND CONTROL OF QUADCOPTER

This study is releated mathematical modeling and control of quadcopter. The mathematical model of the quadcopter is due to its different flight dynamics. Conventional fixed-wing air-vehicle are based on Bernoulli principles, quadcopters based on newton principles. Quadcopters have 6 degrees of freedom. Air-vehicle control is provided by four commands. This imbalance is eliminated through the flight controller. In order to create flight controller, it is necessary to understand the dynamics of quadcopter and develop the system according to the equivalents to be formed. In this study, PD controller which is the most popular controller was used. PD and other control algorithms are added to the controllers so that the air-vehicle is able to manage its esponses to incoming commands in a balanced way [21], [23].

2.5 ADDITIVE MANUFACTURING

In this study, the benefits of additive manufacturing and the problems to be encountered were discussed. Rapidly developing technology has increased the availability of 3D printers, a variant of AM. A prototype can be produced in a fast and cost-effective way with 3d printers. With improved material technology, it has increased the production capabilities of 3D printers with different methods and materials. 3D Printers have the ability to offer fast and cheap solutions for Automotive, aviation, medical and construction applications.

The rapid prototype has some disadvantages. The problems that occurred during the manufacturing process and the problems caused by the inclusion of unexpected errors in the materials and the inclusion of additional additives were prevented. This article contains a general overview of the benefits and challenges of AM and 3D printers [22].

2.6 CONCLUSION OF LITERATURE SURVEY

The level of multi-rotor systems in aviation are increasing day by day. Information obtained from previous studies, the necessary conceptual design for this thesis was obtained. The Little Dipper is a micro-quadcopter class that does not require landing gear. The motor and other components are mounted on the bottom plate and the image is transferred via a fixed camera. Shrike is a professional multi-rotor developed by aeroviroment. Shrike quadcopter has many similar features as a reference for this thesis study. Considering weight and flight time, similar avionics may be preferred. Another example of this study is the DJI Phantom model. This system is preferred for plastic shell structure, diagonal length is 400 mm. This quadcopter which is very popular in the world. This thesis will be mentioned in terms of both manufacturing and ease of installation. The design of new systems increases both costs and causes time loss. For this reason, using general measures of a working system will minimize these losses.

Follow-up of previous studies provides benefits in many ways. Quadcopters can be controlled easily by flight controllers. As seen in the studies examined, there are 6 dof and 4 inputs. Thanks to flight control software, the air-vehicle can be controlled easily. These control softwares are prepared using Euler-Lagrange equations. The most well-known of them is the open source code and it is preferred because control algorithim is not the main target of this thesis. Generally, it is necessary to examine these principles in order to understand mechanics of flight and calibration.

Weight for air-vehicle is a very important parameter. When we want to reduce weight of quadcopter, it falls below the safety factor. These should be taken into consideration and the design should be shaped. In this thesis, air-vehicle will be ground tested. It will also be subject to flight tests. Since the product design for the mass-production was not frozen, additive manufacturing method which is the most suitable and fast manufacturing method was preferred. The studies for this were examined and the production was seen suitable with the 3D printer.

CHAPTER 3

IDENTIFY PROJECT REQUIREMENTS

3.1 CLASSIFICATION of UAV

According to the instructions of DGCA, UAVs is categorized four class with reference to maximum take-off weights [6]. They are:

3.1.1 Very Small UAVs – UAV 0

UAV 0 is air vehicles with take-off weight below 500gr (payload and battery included). It is within the scope of DGCA-UAV [6].

Very Small Unmanned Air Vehicles can be basically categorized into four main groups which are [4], [30];

3.1.1.1 Fixed-wing UAVs

The carrier surfaces do not move, vehicles in the air are called fixed-wing UAV [30].

Figure 3.1 IAI mosquito Fixed-Wing

3.1.1.2 Rotary-Wing UAVs

In aviation, a general name given to vehicles that can turn their wings, that is helicopters. It is light air vehicles with the ability to swing their wings to receive the full or substantial part of the lift force from the rotor shaft system [2], [30].

Figure 3.2 Black Hornet Rotary Wing

3.1.1.3 Multi-Rotor UAVs

Multi-Rotor UAV is the air-vehicle that can fly with the lifting force generated by more than one rotating wing. They do not need tail to be fixed on the z axis as they are in the rotary wing. The opposite rotation of the motors compensates the moments [30]. The Tello model developed by DJI is an example for these UAVs. It is the most up-to-date product of DJI with 60 g flight weight and 12 minutes flight time. The features of the air-vehicle was taken from https://www.dji.com/.

Figure 3.4 Dji Tello

3.1.1.4 Flapping-wing UAVs

They are the structures developed using biomimetic science. Flapping-wing UAVs are developed from the results of the examination of animals with wings.

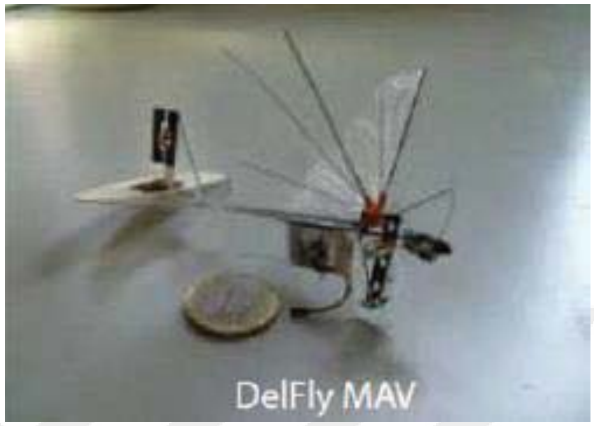


Figure 3.5 Flapping Wing

3.1.2 Small UAVs – UAV 1

UAV-1 have a take off weight of between 4 kg and 25 kg. Many of the designs in this category are based on the fixed-wing model, and most are hand-launched by throwing them in the air. Electric Vtol models are usually in this class [2], [24].

Vtol is a type of fixed wing capable of vertical landing and departure. It uses the structure of the quadrotor for vertical landing and take off, after a certain altitude, it behaves like a fixed wing. It is widely preferred in recent times. UAV 1 has more features than UAV 0 quadrotor such as longer flight times and wider area scanning [2], [24].

3.1.2.1 RQ-11 Raven

Raven UAV was Developed by Aeroviroment. It is a fixed-wing UAV that has successfully carried out surveillance tasks thanks to its long flight time and advanced electronic systems. It has been working day and night thanks to his electro-optic camera and thermal camera. Main features are given table 3.3. These features of the air-vehicle was taken from https://www.avinc.com/

Table 3.3 RQ-11 Specifications

Type of UAV	Fixed Wing
Take off Weight	Around 2 kg
Wing Span	1.4 meters
Flight Time	-
Maximum Payload Mass	500 gr
Maximum Speed	-
Range	Up to 10 km
Altitude	6000 ft

Figure 3.6 RQ-11

3.1.2.2 The Turkish Bayraktar

Bayraktar mini was developed by baykar machine. Thanks to camera systems which have been used by over Turkish Army. Its main task is surveillance. There are no landing gear as they are launched by hand-throw. Air-vehicle is landing with parachute system. Main features are given Table 3.4. These features of the air-vehicle were taken from http://baykarmakina.com/

Table 3.4 Bayraktar Mini

Type of UAV	Fixed-Wing
Take off Weight	3.5 kg
Wing Span	1.6 m
Flight Time	50 minutes
Maximum Payload Mass	900 gr
Maximum Speed	-
Range	Up to 10 km
Altitude	6000 ft

Figure 3.7 Baykar Mini UAV

3.1.2.3 DeltaQuad One

The general characteristics of unmanned aerial vehicles in this class are flying by electric motor. DeltaQuadone is a type of Vtol. Vtol is a fixed-wing air-vehicle that can make vertical take-off and landing. It has 5 motors, horizontal and vertical. Main features are given Table 3.5. These features of the air-vehicle were taken from verticaltechnologies.com/

Table 3.5 DeltaQuad One

Type of UAV	Fixed-Wing VTOL
Take off Weight	Around 6 kg
Wing Span	235 cm
Flight Time	-
Maximum Payload Mass	900 gr

Maximum Speed	20 m/s
Range	100 km
Altitude	6500 ft

Figure 3.8 DELTAQUAD ONE

3.1.2.4 Lapis VTL-02 ULAK

The benefit of VTOL air-vehicle was examined in other vehicles. Ulak UAV, which is an indigenous construction, is in the same class but can perform more extensive tasks than others. Main features are given Table 3.6. These features of air-vehicle were taken from http://lapishavacilik.com.tr

Table 3.6 ULAK VTOL

Type of UAV	Fixed-Wing VTol
Take off Weight	Around 20 kg
Wing Span	3 m
Flight Time	-
Maximum Payload Mass	900 gr
Maximum Speed	-
Range	Up to 10 km
Altitude	13000 ft

Figure3.9 ULAK VTOL

3.1.3 UAV 2

UAV 2 is air vehicles with take-off weight between 25 kg and 150 kg. Many of the designs in this category are based on the fixed-wing model or VTOL [14], [24].

UAVs in this class are accepted as intermediate class. Lift force is generated by internal combustion engine for UAV 2. The most suitable example for ÇAĞATAY Vtol UAV is developed by ivme aviation. Main features are given Table 3.7. These features of air-vehicle were taken from https://ivmeihs.com/

Table 3.7 CGT45

Type of UAV	Fixed-Wing VTol
Take off Weight	Around 45 kg
Wing Span	4.5 m
Flight Time	9 hour
Maximum Payload Mass	4000 gr
Maximum Speed	120 km/h
Range	-
Altitude	18000 ft

Figure 3.10 CGT45

3.1.4 UAV 3

UAV 3 is air vehicles with take-off weight 150 kg and above [2], [14], [24].

3.1.4.1 Tactical UAV

Medium Range or Tactical UAV with range between 100 and 300 km. These air vehicles are smaller and operated within simpler systems than HALE or MALE . They are operated also by land and naval forces [2], [14].

TB2 UAV was developed by Bayraktar Machine. Turkey is also used effectively in the realization of military operations. Exports started this year. Main features are Table 3.8. These features of the air-vehicle were taken from http://baykarmakina.com/

Table 3.8 Bayraktar TB2

Type of UAV	Fixed-Wing VTol
Take off Weight	650 kg
Wing Span	12 m
Flight Time	24 hour
Maximum Payload Mass	55 kg
Maximum Speed	220 km/h
Range	150 km
Altitude	18000 ft

Figure 3.11 TB2

3.1.4.2 Medium UAVs - Medium-Altitude Long-Endurance (MALE)

Male UAV is an effective duty air vehicle with flight time of more than 18 hours and flight heights of 30000ft. Payload capacities can find tons of weight. Therefore, it has the ability to carry advanced imaging systems and weapons systems[2], [14], [19].

ANKA and ANKA S drones developed by TAI are in this class. Main features are given Table 3.9. These features of the air-vehicle were taken from https://www.tai.com.tr/

Table 3.9 TAI Anka

Type of UAV	Fixed-Wing
Take off Weight	1600 kg
Wing Span	17 m
Flight Time	24 hour
Maximum Payload Mass	-
Maximum Speed	220 km/h
Range	4896 km
Altitude	30000 ft

Figure 3.12 TB2

3.1.4.3 High-Altitude Long-Endurance (HALE)

HALE UAV is considered the largest UAV class. It is considered the largest UAV class. They cannot be detected from the ground. They have very advanced imaging systems to perform their tasks from this height. They are guided by satellite control because they are used for overseas missions. They have the ability to carry weapons and nuclear missiles [2], [14], [19].

Global Hawk is the most advanced unmanned aerial vehicle developed by Northop Grumman Corp for the US. Since 2001, it has been actively used by the US military [2], [14], [19]. Main features are given Table 3.10.

Table 3.10 Global Hawk

Type of UAV	Fixed-Wing
Take off Weight	14000 kg
Wing Span	39 m
Flight Time	34 hour
Maximum Payload Mass	1500 kg
Maximum Speed	574 km/h
Range	12000 km
Altitude	60000 ft

Figure 3.13 Global Hawk

3.2 MATHEMATICAL MODELLING

In this chapter, the objective of this work to understand how the system works, to identify the physical parameters correctly. The mathematical model of DJI 450 has been accepted as referance.

In the Quadrotor Model there are 4 rotors on a solid body. Each rotor produces thrust to lift force. Propeller creates lift force by driving motor. The rotation of the propellers produces torque. The torque is equaled by turning 4 motors opposite each other. Quadcopter is very unstable. Flight controllers compensate for this.[8], [31].

An other important point is the quadrotor frames are two types: Cross or plus. In this thesis the cross configuration is being used. During mathematical modelling Cross Configuration Frame type will be used.

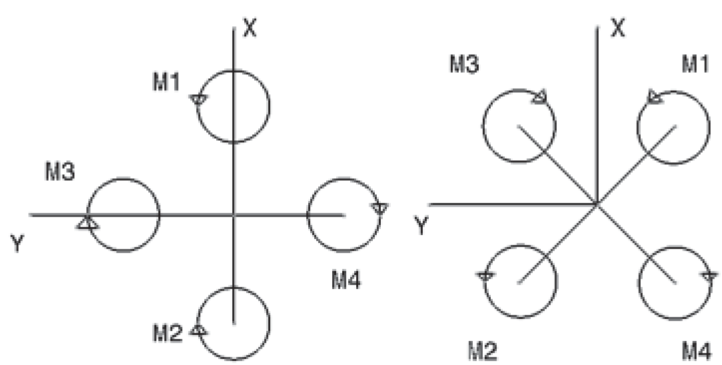


Figure 3.14 Plus Configuration and Cross Configuration Frame

The advantages of Cross configuration frame [27];

- High maneuverability
- Quad arms can not be an obstacle when taking a picture

The disadvantages of Cross configuration frame;

- Complicated control parameters

The preferred multirotor for this project is quadrotor, with four motors. Commands sent to the quadrotor during manual or autonom flight are processed by the flight controller and transmitted to the motors via ESC. Summoment created by the motors must be balanced. Therefore, as shown in Figure 2.1, the directions of rotation of the motors are arranged to balance each other. Motor 1-2 move in CCW direction and 3-4 motor move in CW direction. Because the total moment is balanced, the quadrotor does not rotate around its Z axis [24], [27].

3.2.1 Basic Flight Dynamics

Quadrotor's propeller rpm is changed to move in three-dimensional space. As shown in figure 3.15, front, yaw, pitch and roll orientations are obtained by commands are given Table 3.1 [4], [15], [16], [31].

Table 3.11 The Range of Angles

Case	Orientation	θ	Ψ	X	Y	Z
1	Hovering	$\theta = 0^o$	$\Psi = 0^o$	0	0	$\pm T_z$
2	Forward	$0^o < \theta < 90^o$	$\Psi = 0^o$	T_X	0	$\pm T_z$
	Backward	$-90^o < \theta < 0^o$	$\Psi = 0^o$	$-T_X$	0	$\pm T_z$
3	Left	$\theta = 0^o$	$0^o < \Psi < 90^o$	0	T_y	$\pm T_z$
	Right	$\theta = 0^o$	$-90^o < \Psi < 0^o$	0	$-T_y$	$\pm T_z$
4	Pitch + Roll	$0^o < \theta < 90^o$	$0^o < \Psi < 90^o$	T_X	T_y	$\pm T_z$
	Pitch + Roll	$-90^o < \theta < 0^o$	$-90^o < \Psi < 0^o$	$-T_X$	$-T_y$	$\pm T_z$

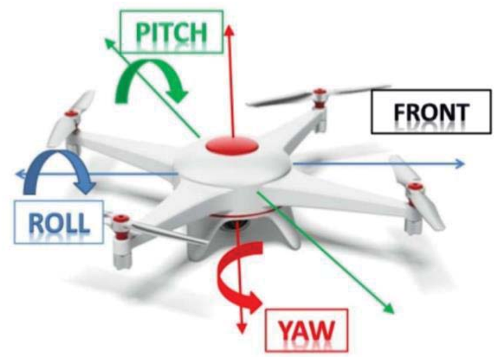


Figure 3.15 Euler Angles

3.2.1.1 Roll

The moment that occurs in the X axis allows these movements to occur. With the acceleration of the motors to the right of the axis, a rolling movement to the left occurs [5], [16], [27].

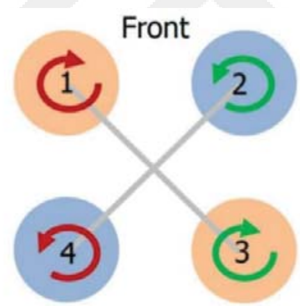


Figure 3.16 Roll

3.2.1.2 Pitch

It is the movement of the air vehicle around the axle with the moment that occurs around the Z axis [5], [16], [27].

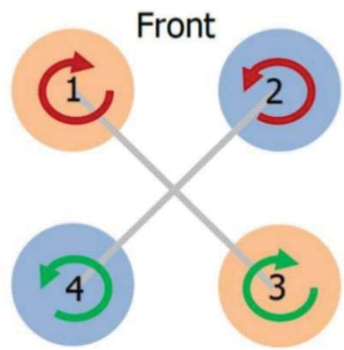


Figure 3.17 Pitch

3.2.1.3 Yaw

It is the movement of the air vehicle around the axle with the moment that occurs around the Y axis [5], [16], [27].

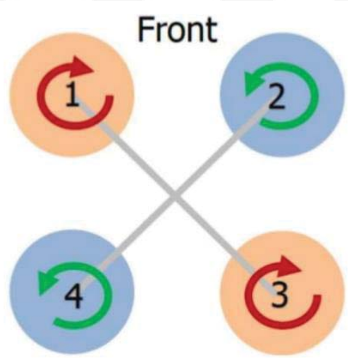


Figure 3.18 Yaw

3.2.1.4 Throttle

Throttle command gives the propellers on quadcopter enough power to get airbone. When flying, you will have the throttle engaged constantly. Take off and landing, forward and backward movements are realized with 4 motors rotating in a balanced manner. The forward motion command sent from the flight controller increases the rotation speed of motors 3 and 4. Thus, the air-vehicle moves forward. The command sent for backward movement is processed by the flight controller and forwarded to motors 1 and 2. The rotation speed of motors 1 and 2 is increased. The air-vehicle moves backwards [5], [16], [27].

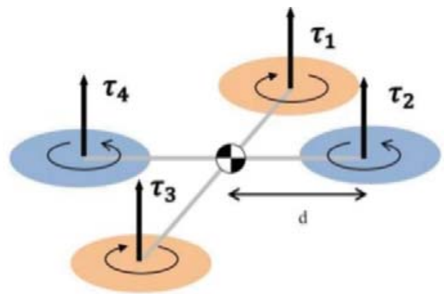


Figure 3.19 Throttle

In this thesis The Flight Controller Design does not take place. The widely used Flight Card APM 2.6 has been preferred. Frame Design and Manufacture have been performed within the scope of this thesis.

When an Air-vehicle has to be designed and manufactured, some dynamics are supposed to be taken into consideration. These are Inertia, Lift, Drag Forces, momentum [16]. In this Chapter these terms are being calculated, and the required parameters are obtained. During calculation F450 system model. In this way the coefficients can be taken directly from the manufacturer [27].

3.2.2 Quadcopter Frame Configuration

Multirotor systems are named according to motors and frame structure, i.e. Tricopter, Quadcopter, Hexacopter, octocopter. 4 rotor system has been choosen for easy calculation and low cost . Before starting the calculation of the dynamic principles of a Quadrotor, we need to identify the coordinate axis: inertial (earth) Frame ve body-fixed frame [8], [23], [27], [31].

The first one will be the Body-fixed coordinate system, and it is going to be symbolized as O_B. O_B is fixed on the gravity center of the quadrotor and it can move, rotate along the vehicle. The second coordinate system, inertial coordinate system will be symbollized with O_E. O_E will be used to determine the direction of the vehicle and to define the location of the vehicle on earth. The rotation speed of the earth is much lower with respect to other far stars. Therefore O_E will be assumed as inertial frame. Figure 3.20 yields the details about both frames [8], [23], [31].

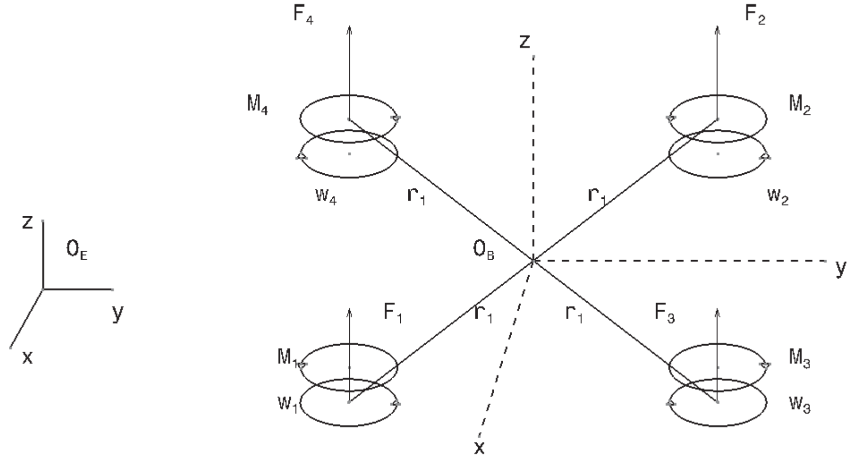


Figure 3.20 Inertial Frame and Body-Fixed Frame

In aviation systems generally the frame is defined as following: Z as downwards, Y as East, X as North. More often the NED (North, East, Down) frame is used [8], [27], [31].

3.2.3 Dynamic Equations

The physical properties are taken into account and dynamic equations of the quadcopter are simplified. When it is compared to real platform, the results can vary. This work is done to get the insight and pre-information about the concept [8], [9], [23], [27], [31].

The assumptions:

1- Quadcopter is a rigid body, it helped to reduce number of dynamic equations

2- Quadcopter is a symmetric structure,

3- The mass is constant, therefore the derivative of it is zero.

Classical Mechanics is valid in the O_E frame. X ,Y and Z are linked with earth frame. As it is seen among situations the derivative of time is mentioned, but they are not present in the same coordinate axis. This is the reason why we have to use an other operation in order to link them. Rotation matrices will be helpful in this procedure.

More precisely to say the relation between states depend on derivative of time as well as Rotation Matrices [8], [23], [27], [28], [31].

- Ψ angle around Z axis is yaw angle of the quadrotor body
- θ around the intermediate Y axis is pitch angle of the quadrotor body
- ϕ around the intermediate X axis is roll angle of the quadrotor body

$$R(\phi) = \begin{bmatrix} 1 & 0 & 0 \\ 0 & \cos\phi & \sin\phi \\ 0 & -\sin\phi & \cos\phi \end{bmatrix} \tag{1}$$

$$R(\theta) = \begin{bmatrix} \cos\theta & 0 & -\sin\theta \\ 0 & 1 & 0 \\ \sin\theta & 0 & \cos\theta \end{bmatrix} \tag{2}$$

$$R(\Psi) = \begin{bmatrix} \cos\phi & \sin\phi & 0 \\ -\sin\phi & \cos\phi & 0 \\ 0 & 0 & 1 \end{bmatrix} \tag{3}$$

Multiplication of Rotation Matrices yields Rotation equations [6], [14].

$$R = R(\phi)R(\theta)R(\Psi) \tag{4}$$

In our system there are 6 degree of freedom (DOF) and 12 states. These variables (roll, pitch, yaw) are the euler angles between the earth frame and the body frame. In addition, the angular velocities p, q and r associated with these euler angles and derivatives are on the body frame. The other 6 state variables are the x, y, and z coordinate axes, which are the position variables that we can get fixed on the earth [8], [27], [31].

$\begin{bmatrix} x \\ y \\ z \end{bmatrix}$ position in the earth frame

$\begin{bmatrix} u \\ v \\ w \end{bmatrix}$ linear velocity in the body fixed frame to earth frame

$\begin{bmatrix} \emptyset \\ \theta \\ \psi \end{bmatrix}$ euler angles

$\begin{bmatrix} p \\ q \\ r \end{bmatrix}$ angular velocity in the body fixed frame to earth frame

3.2.4 Force Equations

In this project, The four-rotor quadcopter control used is achieved by adjusting the angular velocities of the four rotors (propeller) appropriately. Angular velocity was shown in relation to moment and force [8], [16], [28], [31].

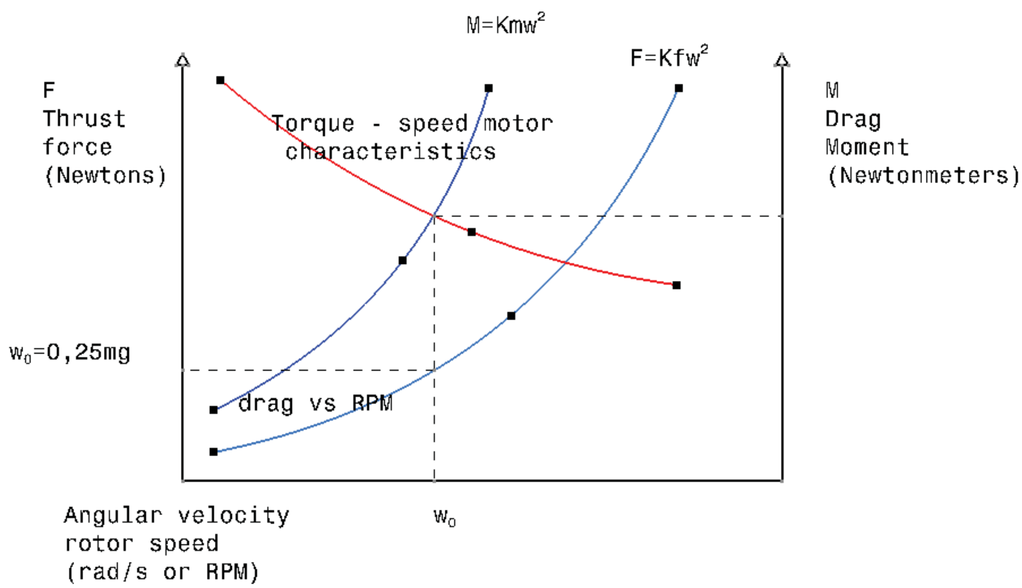


Figure 3.21 Moment and Force

Each propeller creates an aerodynamic force. These forces moves the body upwards. When the body is parallel to the earth, the rolla and pitch angles are "0", those aerodynamic forces overcome to the gravity force and Quadcopter flies. The relationship between the angular velocities of the rotors and the force and torque produced by the rotors F_i, M_i and ω_i represent the force, torque and rotor angular velocity produced by the rotor i, respectively k_n and k_m are the constant coefficients obtained for F450. k_n, thrust coefficient (Ns^2) and k_m, torque coefficient (Nms^2). F_i and M_i vectors are given in Figure 2.9 [27], [31].

$$F_i=\omega_i^2 k_n \text{ for } i =1,2,3,4 \quad (5)$$

$$M_i = F_i k_m \text{ for } i =1,2,3,4 \quad (6)$$

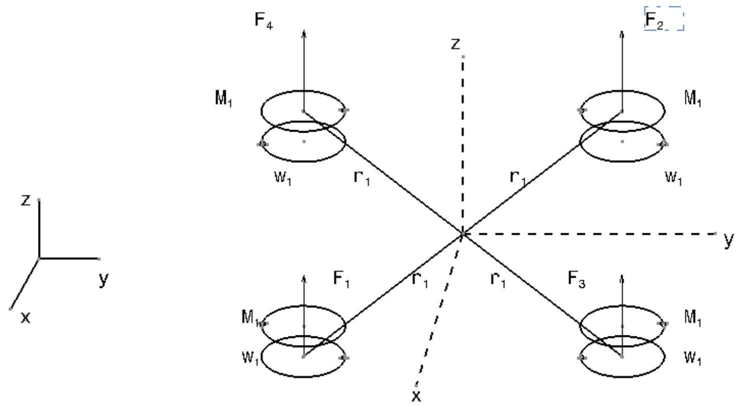


Figure 3.22 Thurst and Moment

F_1, F_2, F_3, F_4 are the forces applied on the rigid body [27].

$U_1 = F_1+F_2+F_3+ F_4$ Throttle (7)

$U_2 = (F_2 - F_4)l$ Roll (8)

$U_3 = (F_3 - F_4)l$ Pitch (9)

$U_4 = M_1 + M_2 - M_3 - M_4$ Yaw (10)

F and M are the lifting force and torques produced by the motors. l is the distance of the motor from the center of gravity. All motors create a thrust along z-axis [21], [27].

$$\sum F_i = \begin{pmatrix} 0 \\ 0 \\ k_n \quad (\omega_1^2 + \omega_2^2 + \omega_3^2 + \omega_4^2) \end{pmatrix} \tag{11}$$

3.2.5 Momentum Equations

These equations determine the quadcopter return dynamics. As seen in the linear and rotational dynamic equations, the U1 control input, along with the roll (ϕ) and pitch (θ), linear motion, in other words, the movement in x, y, z direction. U2, U3, U4 control inputs provide rotational motion, in other words, roll (ϕ), pitch (θ), and deviation (ψ) motion [8], [16], [27].

Angular momentum theory;

$$\sum M = \dot{h} \tag{12}$$

h represents the angular momentum around the center of gravity. Momentum equations are easier to calculate in the body-fixed frame.

$$\sum M = j_{\omega+\omega}J \tag{13}$$

Here, J represents the quadcopter inertia matrix.

$$\mathbf{J} = \begin{vmatrix} I_{xx} & -I_{xy} & -I_{xz} \\ -I_{xy} & I_{yy} & -I_{yz} \\ -I_{xz} & -I_{yz} & I_{zz} \end{vmatrix} \tag{14}$$

Quadcopter is symmetric, so all cross terms of the inertial matrix equals 0 [14].

$$\mathbf{J} = \begin{vmatrix} I_{xx} & 0 & 0 \\ 0 & I_{yy} & 0 \\ 0 & 0 & I_{zz} \end{vmatrix} \tag{15}$$

$$\begin{bmatrix} \dot{p} \\ \dot{q} \\ \dot{r} \end{bmatrix} = (J)^{-1} \left(\begin{bmatrix} M_x \\ My \\ M_z \end{bmatrix} - \begin{bmatrix} p \\ q \\ r \end{bmatrix} \text{ x } J \begin{bmatrix} p \\ q \\ r \end{bmatrix} \right) \tag{16}$$

Relationship between finite state equations ω and Euler angles;

$$\begin{bmatrix} p \\ q \\ r \end{bmatrix} = \begin{bmatrix} 1 & 0 & -sin\Theta \\ 0 & cos\,\phi & sin\,\phi\,cos\Theta \\ 0 & -sin\,\phi & cos\,\phi\,cos\Theta \end{bmatrix} \begin{bmatrix} \dot{\Phi} \\ \theta \\ \dot{\psi} \end{bmatrix} \tag{17}$$

The state vector is isolated by the inverse relationship [14].

$$\begin{bmatrix} \dot{\Phi} \\ \theta \\ \dot{\psi} \end{bmatrix} = \begin{bmatrix} 1 & sin\O tan\Theta & cos\O tan\Theta \\ 0 & cos\,\phi & -sin\,\phi \\ 0 & sin\,\phi\,/cos\Theta & cos\,\phi\,/cos\Theta \end{bmatrix} \begin{bmatrix} p \\ q \\ r \end{bmatrix} \text{ for } \Theta \neq \pi/2 \tag{18}$$

In order to calibrate the total momentum generated in the quadrotor system, it is necessary to add the rotation direction of each motor to the account [27].

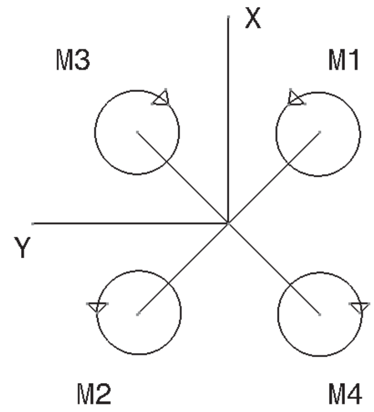


Figure 3.23 Rotation Direction Of Each Motor

Momentum expression;

$$M = \sum_{i=1}^{4} P_i x F_i + \sum_{i=1}^{4} Ti \tag{19}$$

P_i represents the position of each motor in the body. T_i represents the moment I created for the motor in the quadcap. According to Newton's Law 3, an engine rotates in a certain direction and exhibits a quadcopter tendency against the angular momentum that occurs due to the conservation of angular momentum.This reaction moment occurs due to the rotation of a motor [27].

d is the distance from the center of gravity to the center of the motor and the position of each motor;

$$P_1 = \begin{bmatrix} \frac{d}{\sqrt{2}} \\ -\frac{d}{\sqrt{2}} \\ 0 \end{bmatrix}, P_2 = \begin{bmatrix} -\frac{d}{\sqrt{2}} \\ -\frac{d}{\sqrt{2}} \\ 0 \end{bmatrix}, P_3 = \begin{bmatrix} -\frac{d}{\sqrt{2}} \\ \frac{d}{\sqrt{2}} \\ 0 \end{bmatrix}, P_4 = \begin{bmatrix} \frac{d}{\sqrt{2}} \\ \frac{d}{\sqrt{2}} \\ 0 \end{bmatrix} \tag{20}$$

The momentum generated by the thrust of each motor can be calculated [14].

$$\boldsymbol{P}_1^b \times \boldsymbol{F}_1^b = \begin{bmatrix} (-C_T\omega_1^2)\, d/\sqrt{2} \\ (-C_T\omega_1^2)\, d/\sqrt{2} \\ 0 \end{bmatrix} \quad \boldsymbol{P}_2^b \times \boldsymbol{F}_2^b = \begin{bmatrix} (-C_T\omega_2^2)\, d/\sqrt{2} \\ (C_T\omega_2^2)\, d/\sqrt{2} \\ 0 \end{bmatrix}$$

$$\boldsymbol{P}_3^b \times \boldsymbol{F}_3^b = \begin{bmatrix} (C_T\omega_3^2)\, d/\sqrt{2} \\ (C_T\omega_3^2)\, d/\sqrt{2} \\ 0 \end{bmatrix} \quad \boldsymbol{P}_4^b \times \boldsymbol{F}_4^b = \begin{bmatrix} (C_T\omega_4^2)\, d/\sqrt{2} \\ (-C_T\omega_4^2)\, d/\sqrt{2} \\ 0 \end{bmatrix} \tag{21}$$

Induced moments have only motion and opposite magnitude on the z axis. Due to the conservation of the angular momentum generated by each propeller, it is seen that a clockwise rotating propeller produces a moment in the opposite direction, with respect to the right hand rule when considering the axis being used (z axis pointing upwards) [23].

Total Moment;

$$\boldsymbol{M}^b = \begin{bmatrix} M_x \\ M_y \\ M_z \end{bmatrix} = \begin{bmatrix} dC_T/\sqrt{2}\left(-\omega_1^2 - \omega_2^2 + \omega_3^2 + \omega_4^2\right) \\ dC_T/\sqrt{2}\left(-\omega_1^2 + \omega_2^2 + \omega_3^2 - \omega_4^2\right) \\ C_D\left(-\omega_1^2 + \omega_2^2 - \omega_3^2 + \omega_4^2\right) \end{bmatrix} \tag{22}$$

3.2 PRE-DESIGN and CALCULATIONS

Calculations is necessary to create parameters for the unmanned aerial vehicle to be designed. Thanks to these parameters, production can be realized in shorter time in the light of mathematical formulas instead of trial-and-error method. The F450 Dji model will be used as a reference. Motor, propeller, ESC and general measurements will calculate the loads and moments that will occur on the required body design for the quadrotor that is planned. Design is expected that the quadrotor can take off and land safely [2].

The purpose of this thesis is to make a safe body design, which is a structure that will provide resistance against the forces obtained. The determination of these forces before the beginning of the design, their calculation is necessary [26].

The general information of DJI F450 quadcopter is as follows. These features of air-vehicle were taken from https://www.dji.com/

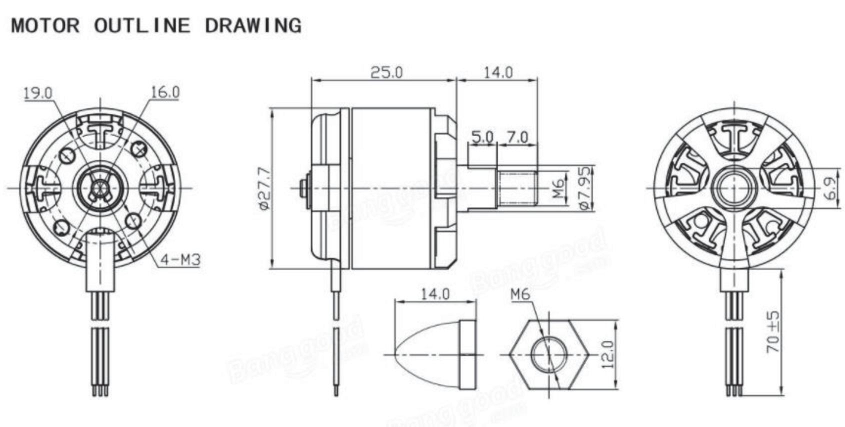
- Model Flame Wheel 450 (F450)
- Frame Weight 282g.
- Diagonal Wheelbase 450mm.
- Takeoff Weight 800g ~ 1600g.
- Recommended Propeller 10 × 4.5in ; 8 × 4.5in.
- Recommended Battery 3S~4S Li-Po.
- Recommended Motor 22 × 15mm or 22 × 12mm.
- Recommended DJI E300 15A ESC OR 30A OPTO.

With reference to Dji F450, the calculation of the forces to be generated is explained in the following steps.

3.3.1 Step 1: Forces

As the motor rotate the propellers, lifts are produced by the propellers. These forces are determined by the characteristics of the DJI F450 engine and propellers. The number of cells of battery used determines the maximum lifting force [27]. These values are given Table 3.9.

Table 3.12 Motor Specifications.



MOTOR PERFORMANCE DATA

MODEL	KV (rpm/V)	Voltage (V)	Prop	Load Current (A)	Pull (g)	Power (W)	Efficiency (g/W)	Lipo Cell	Weight (g) Approx
B2212	920	11.1	8045	7.3	465	81	5.7	2-4S	50
			1045	9.5	642	105	6.1		
	980	11.1	8045	8.1	535	90	5.9		
			1045	10.6	710	118	6.0		

During take-off and landing, 4 motors will move to create equal force. The reason of this; roll, pitch, yaw must be 0 degrees.

Given:

- Battery Cells - 3 Cells
- Motor - 2212/ 920 kV
- Propeller - 8045

Lifting force for each motor to be obtained in full throttle;

$F_L = 4.65$ kN

$F_L = F_1 = F_2 = F_3 = F_4$ and Euler angles are assumed to be 0 degrees, total lift force;

$F_T = 18.6$ kN

3.3.2 Step 2: Moments

The propeller is rotated by the drive of the motor axis in the z-axis. This rotational motion creates a moment at these centers. The body of the quadcopter is considered rigid. The forces created by the moments in the structure of the body disrupt the balance of the system, at the same time causing cracks and fractures in the structure. These moment movements also occur in the yaw motion. The X configuration type determines the direction of rotation of the motors in the preferred quadrotor frame. During vertical landing and take-off, the motor rotation produces a moment that balances each other to keep the quadrotor in balance. This is achieved by turning the motors in the CW and CCW directions respectively [27], [28].

We can calculate moments with the following formulas.

Centrifugal force consisting of propellers [28]:

$F_C = m\,\omega^2 r$

m = 7 gr. (mass of propeller)

$\omega = 2\pi N/60 = 10000$ rad/s (angular velocity) r = 140 mm (radius of propeller)

F_C = 766 N

M = 766*0.14 = 107 Nm

CHAPTER 4

HARDWARE SPECIFICATIONS

4.1 DETERMINATION OF HARDWARE PLATFORM SPECIFICATIONS

To design new quadcopter UAV, readily available hardware components were chosen in order to reduce prototyping and production costs. The purpose is to develop a quadcopter UAV system which can be quickly and cost-effectively used for academic research and development and at the same time serve as a platform for new technology demonstrations [3], [10]. Therefore, at the hear to this new quadcopter UAV system, the open source autopilot APM 2.6 was chosen, which brings a big advantage from the software point of view, because it can be easily modified/improved [17].

Main features are:

- Automatic waypoint navigation
- Secure digital communication
- Home Return and automatic parachute landing in case of lost communication
- Smart battery management system
- Remote-range command/control and monitor
- Ground control switching
- Automatic take off
- Automatic cruising
- Joystick assisted semi-automatic control
- Real-time Google Earth integration (display of telemetry data, routes etc. in real-time)
- On-screen video display

In this section, the below listed hardware components of the newly designed quadcopter UAV are explained in detail. A quadcopter consists of the following essential parts [17], [18], [30]:

Frame - The structure that holds all the components together. They need to be designed to be strong, rigid and light-weight

Motors - brushless or brushed DC motors can be used on multirotors, they can provide the necessary thrust to lift the quadrotor

ESC - Each motor is controlled by a separate ESC

Propellers - 10x45 prop

Battery - Power Unit

FlightController - APM 2.6

RC Transmitter/Receiver - FLYSKY I6

Optional parts

4.1.1 Frame

The quadcopter body frame has a structure made out of custom 3Dprinted parts, which are designed such that the complete body frame is a slight as possible, and at the same time robust. This body frame is specifically designed to place selected UAV subcomponents in a very tight volume, but allows for sufficient cooling of embedded electronic devices, such as the ESCs which are embedded into the quadcopter arms.

The quadcopter body frame needs to be user friendly from the assembly/disassembly point of view. This way, the design brings advantages such as easy assembly/disassembly, low volume transportation requirements, quick replacement and maintenance, and minimizing user faults during plugging of sub-components [10], [17], [30].

4.1.2 Motors

The electric motors spin the propellers and generate thrust. There 2 types of electric motors for RC model multirotors: brushed and brushless motors. Brushed motors are mainly used on smaller, lower power builds, while brushless motors are usually more powerful and used on larger builds [17].

Brushed motors are basically DC motors. Those used in quadcopters are normally lighter than the brushless and they are often used in lower power builds. They are cheaper to replace, but have a much shorter lift cycle [32].

A little background of Brushless motor, they are a bit similar to normal DC motors in the way that coils and magnets are used to drive the shaft. Though the brushless motors do not have a brush on the shaft which takes care of switching the power direction in the coils, and this is why they are called brushless. Instead the brushless motors have three coils on the inner (center) of the motor, which is attached to the motor base. On the outer side it contains a number of magnets mounted to a cylinder that is attached to the rotating shaft. Generally brushless motors spinin much higher speed and use less power at the same speed than DC motors. Also brushless motors don't lose power in the brush-transition like the DC motors do, so it's more energy efficient [30], [32].

We preferred to use BLDC motors whose brand is Racestar. We use 4 motors in this project called GUUM UAV. The quadcopter used in this project is approximately 1500 gr. Two times more force is required for drones to take off. The expected lifting force from each motor was determined to be 500 gr. Motor and propeller measurements required for this were selected by examining the list of standard products.

Figure 4.1 Brushless 920 kv Motor

4.1.3 Propellers

Propellers produce the required lifting force to take-off the quadcopter. They are usually made from durable plastic and occasionally carbon fiber and even woods [10], [17].

Two propellers have different directions. This is because 2 rotors rotates in the opposite directions to the other two. The most suitable motor propeller measurements for this project are 2212 engines and 10x45 propellers [30].

Figure 4.2 Propeller

4.1.4 ESC

ESC is a device that interpret signals from flight controller, and controls the speed of brushless motors. Brushed motors doesn’t require ESC because they can be driven simply by power transistors which are normally built into the flight controllers that are designed for brushed motors. Each motor requires an ESC to work [17].

Brushless motors are multi-phased, normally 3 phases, so direct supply of DC power will not turn the motors on.The ESC generates three high frequency signals with different but controllable phases continually to keep the motor turning [30].

ESC is connected to the flight controller, and controlled by a PWM or digital signal. When selecting a suitable ESC, the most important factor is the current rating [30].

We need 11 Amp flow to get the lift force we want from the 2212 motor and the 10x45 propeller. 20 amperes ESC is preferred when it is accepted as a safety factor of 2. This value is the minimum requirement [42].

Table 4.1 ESC Specification

Cont Current	30A
Burst Current	35A
BEC Model	Linear mode
BEC Output	5V 2A
Li-ion/Li0poly	2-4S
Weight	25g
Size	32*24*7mm

Figure 4.3 ESC

4.1.5 Flight Controller

FlightController is the brain of a quadcopter. A FC contains at least a microprocessor (CPU), and a sensor which is also known as the inertial measurement unit (IMU) [30].

The IMU is an electronic sensor device that measures the velocity, orientation and gravitational forces of the quadcopter. These measurements allow the controlling electronics to calculate the changes in the motor speeds. The IMU usually contains a Gyroscope (or Gyro) and a Accelerometer (Acc) [3], [10], [30].

The accelerometer measures acceleration and also force, downwards gravity will also be sensed. As the accelerometer has three axis sensors, we can work out the orientation of the quadcopter [30].

A gyroscope measures angular velocity, in otherwords the rotational speed around the three axis [10].

In this thesis, APM was preferred as flight controller. APM 2.6 is ready to use, with no assembly required. It allows the user to turn any fixed, rotary wing or multirotor vehicle (even cars and boats) into a fully autonomous vehicle; capable of performing programmed GPS missions with waypoints [10], [17].

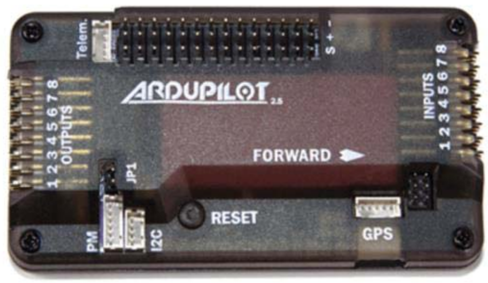


Figure 4.4 Flight Controller

The quadcopter that is designed in this thesis weighs 1.3 kg and has a maximum 20 minute endurance flight. In order for this platform to be a fully autonomous UAV, Arducopter is an autopilot/flight controller system which will be integrated into this quadcopter UAV. Compared to other autopilot systems, Arducopter includes some additional features which makes this flight controller a preferred choice.

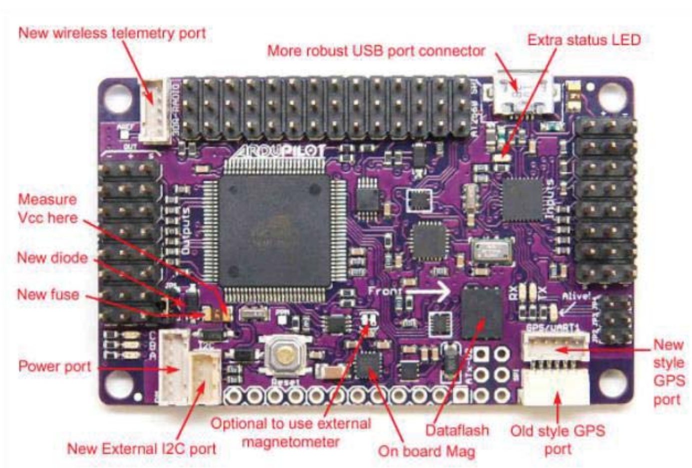


Figure 4.5 APM 2.6 Board

4.1.6 GPS

GPS is the system developed for devices to find their positions in the world. Developed by the US defense agency. It is based on communication of devices with 24 satellites placed in orbit around the Earth. Autonomous flight is divided into indoor and outdoor. Since access to GPS signals becomes more difficult in confined spaces, we cannot achieve a precise result. Sensors are therefore preferred. NEO-M8N module developed for air vehicles is used in outdoor applications [2], [10], [11], [30].

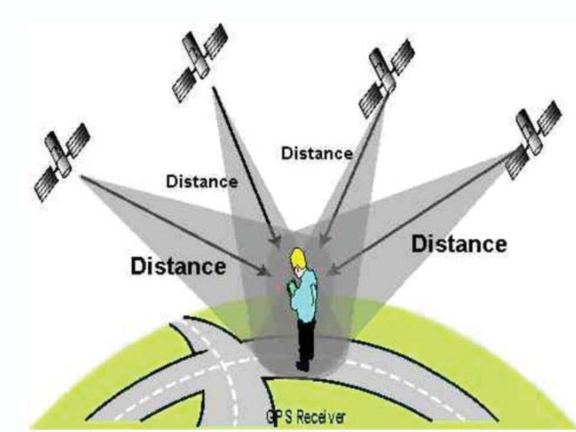


Figure 4.6 GPS

A GPS module talks to the satellite and retrieve location information. We can use this information to calculate speed and path. GPS is essential for long range out door autonomous flights. Main features of NEO-M8N GPS Modul are given Table 4.2;

Table 4.2 GPS Specifications

Update Speed	10Hz
Tracking Sensivity	-161dBm
Capture Sensivity	-148dBm
Cold Start	38sn
Warm Start	35 sn
Hot Start	1 sn
Operating Voltage	3.5~5.5V
Size	55 mm
Other feature	NEO-M8N modul
	SAW filter
	RTC Crystal
	ArduPilot Mega compatible JST connectors
	Protective housing box

Figure 4.7 GPS

4.1.7 Datalink

There are two types of data connections used for communication between unmanned aerial vehicles and the user. Telemetry and Radio (RC) data connection. Telemetry is the data path used to transfer data from unmanned aerial vehicles to unmanned aerial vehicles such as sensor and position data for communication to the ground station or job descriptions from the ground station. Radio Control is used to transfer the relevant data of the control used in the control of the unmanned aerial vehicle. In this thesis, both communication types were used [2], [10], [11], [13], [30].

4.1.7.1 Radio Control

Datalink communicates in two directions. These are Uplink and downlink. Radio TX & RX transmission is uplink direction. Flight control commands, Take off and landing etc. in this case, the communication system FlySky I6, which is used for uplink, was preferred [17], [30]. The features of this system are given in the Table 4.3.

Table 4.3 Reciever Specifications

Channels	6 Channels
Model Type	Glider/Heli/Quadrotor
RF Range	2.40-2.48GHz
Bandwidth	500KHz
Band	142
RF Power	Less Than 20dBm

2.4ghz System	AFHDS 2A and AFHDS
Code Type	GFSK
Sensitivity	1024
Low Voltage Warning	less than 4.2V
DSC Port	PS2;Output
PPM	
Charger Port	No
ANT length	26mm*2(dual antenna)
weight	392g
Power	6V 1.5AA*4
Display mode	Transflective STN positive type, 128*64 dot matrix VA73*39mm,white backlight.
Size	174x89x190mm
On-line update	yes
Color	Black
Certificate	CE0678,FCC
Model Memories	20
Channel Order	Aileron-CH1, Elevator-CH2, Throttle-CH3, Rudder-CH4,Ch 5 & 6 open to assignment to other functions.

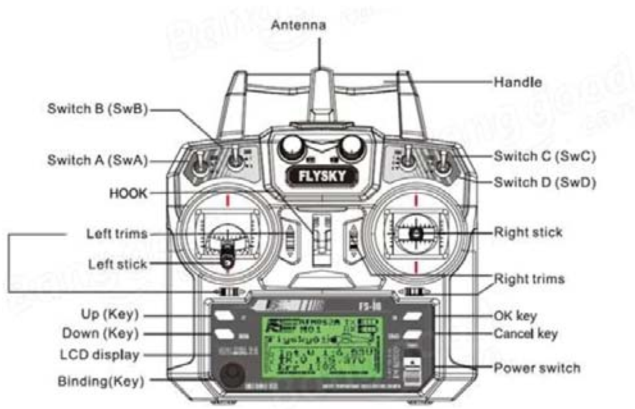


Figure 4.8 Transmitter FS-I6

Table 4.4 Reciever FS-IA6 Specifications

Channels	6 Channels
Model Type	Fixed-wing/Glider/Quadrotor
RF Range	2.40-2.48GHz
Bandwidth	500KHz
Band	142
RF power	less than 20dBm
RF.receiver sensitivity	-105dBm
2.4ghz System	AFHDS 2A
Code Type	GFSK
ANT length	26mm
Weight	6.4g
Power	4.0-6.5V
Size	40.4x21.1x7.35mm
Color	Black
Certificate	CE,FCC
i-BUS port	NO
Data Acquisition port	NO

Figure 4.9 Reciever FS-IA6

4.1.7.2 Telemetry

Telemetry is the communication unit required for autonomous flight. It provides uplink and downlink transmission. The position it receives from the air is the system that transmits the battery and image transmission to the ground control station. It transmits the autonomous flight information from the ground station to the quadrotor. Telemetry consists of 2 separate units as air and ground module. The communication band was identified as 433 Mhz. The use of this band for amateur radios was deemed appropriate [2], [10], [11], [13], [30].

Figure 4.10 Telemetry 433 Mhz TX/RX

4.1.8 Battery

Li-Po batteries are the power sources of the quadcopters. Li-Po is used because of the high energy density and high discharge [10], [17], [30]. The selected battery specifications for the GUUM unmanned aerial vehicle are given in Table 4.5.

Table 4.5 Battery Specifications

Cells Number	3
Voltage	11.1V
Minimum Capacity	3000mAh
Discharge	25C
Charge Plug	JST-XH-4P
Discharge plug	T Connector
Battery Dimension	106*35*25 mm
Battery weight	185g

4.1.9 Power Distribution

Power distribution can exist in the form of a board (PCB) or harness.The PDB contains the connectors which plug directly into the Li-Po battery and it’s responsible for distributing power the ESCs and motors, as well as providing power to other electronics with the correct voltage [10], [17], [30].

Table 4.6 Power Distribution Specifications

Dimensions	36 x 36mm
Weight	About 6g
Mounting holes	30.5mm square spacing
input voltage range	7.2 – 26VDC
spec 0	Regulated 5V and 12V outputs
spec 1	LED power indicators (5V & 12V outputs)
spec 2	4 ESC outputs
Continuous current	20A per output
Peak current	30A per output
RC Receivers, Flight controllers, OSD, and Servos, Voltage	5.0 +/- 0.1VDC
Continuous current	3 Amps Short-circuit tolerant
The battery	4S~6S Li-Po
Standard output designed to power cameras and video transmitters,etc.	
Voltage	12.0 +/- 0.2VDC
Continuous current	2 Amps (Max.3A 10s/minute)
spec 3	Short-circuit tolerant (10 seconds/minute)
spec 4	LED (indicates voltage is in regulation, within 10%)

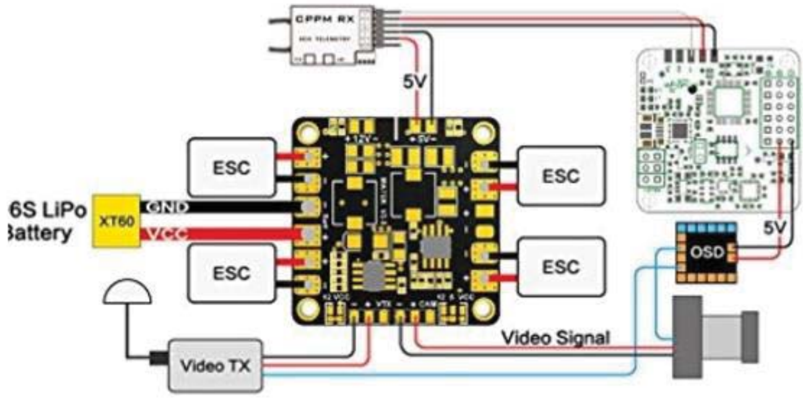


Figure 4.11 Power Distribution

4.1.10 Video Systems

The most important feature of unmanned aerial vehicles is the ability to transmit video. The location information sent by air to the ground station is sufficient for navigation. Video transmission is used for target tracking for environmental surveillance or armed unmanned aerial vehicles. It is used for vehicle control during manual flight [3], [30].

In this thesis, the FPV camera unit was approved. For this, the widely used 700 TVL camera was preferred. Camera, transmitter and receiver features were taken from www.banggood.com. The general features of the camera are given in the following table 4.7.

Table 4.7 700TVL Camera Description

Resolution	700TVL
Shell size	25mm * 25mm,
Weight	9.5 grams
Total pixels	1020H × 508V (52 million)
Effective pixels	NTSC 976H × 494V (48 million)
Signal format	NTSC
Resolution (horizontal center)	700TVL
Video output amplitude	1.0Vp-p / 75Ω
Automatic gain control	0.25 / 0.50 / 0.75 / 1.00 four levels can be adjusted up to 55dB

White Balance Mode	On / Off Selectable
Exposure mode	electronic exposure
Electronic shutter	1/50 (1/60) - 1/100000 sec
Gamma correction	0.45 / 1.0
Synchronization mode	internal synchronization
Lens	Standard 2.8mm lens
Working voltage	(wide voltage, measured can be 5-12V normal work)
Operating current	70mA (low power consumption)
Working temperature	-20 ℃ - 60 ℃
Humidity	0% ~ 98%

Figure 4.13 700TVL Camera

RC832 for ground station and TS832 for quadrotor were used to transfer the video to the location control station. Used in the 5.8 GHz frequency band.

Table 4.8 Video Reciever RX RC832 specs

Power input	12V
Working current	200mA max
Antenna impedance	50Ω
Antenna gain	2db
Rx sensitivity	-90dBm
Video impedance	75Ω
Video format	NTSC/PAL auto
Dimension	80x 65 x15mm
weight	85g

Figure 4.12 Video Reciever RX RC832

The TS832 Transmitter has 32 channels. The system with a power of 600mW performs enough video transmission for this thesis [49].

Table 4.9 Video Transmitter RX RC832 Specs

Power input	7.4-16V (3S Li-Poly suggested)
Transmitting power	600mW
Antenna gain	2dbm
Working current	220mA at 12V
Video bandwidth	8Mhz
Audio bandwidth	6.5Mhz
weight	21g
Dimension	54x 32x 10mm(excluding antenna)

Figure 4.13 TX TS832

The maximum transmission distance between TS832 and RS832 is not sufficient for this thesis. As a result of the calculations made at www.immersionrc.com, it has been determined that it has the ability to transmit images of 1.27 km. It is appropriate that we change the RX antenna to increase the view to 2 km. The 5.15-5.8GHz 6dBi Wide Band Omnidirectional outdoor antenna was added to 19 inches of antenna receiver and the transmission was increased to 2 km [13].

Figure 4.14 6 dBi Antenna

4.1.11 Ground Control Station (GCS)

For the remote control and configuration of the Quadcopter UAV, a ground control station with a human machine interface (HMI) is necessary. The purpose is to be able to configure flight parameters of the UAV during and/or before the flight, e.g. tuning of PID control parameters, uploading flight waypoints, or downloading flight log data from the UAV. Another use of ground control stations is the ability to view a live video stream from the onboard camera if one is available [2], [30].

The following section lists the individual components of the GCS. Included are the following items:

4.1.11.1 Ground Station Box

Ground control station may be a computer or tablet preference. In this thesis, a laptop was preferred. It was preferred because of the excess of connection port. Apm autopilot is compiteble with MSwindows. Telemetry ground module, image receiver computer plugged into USB port. Image transmission is also provided in FPV [2], [30].

4.1.11.2 GCS Software Features

Ground station software was preferred to mission planner. Features provided by the mission planner [17], [30];

1. 2D map
2. Video display
3. Data display for flight parameters
4. Menu system

4.2 COST ANALYSIS

Standard elements are considered the most suitable air-vehicle concept by taking into account the other projects and the useful loads. Standard elements were preferred and price / performance ratio was taken into consideration [10]. All standard parts are imported from abroad.

Table 4.10 Cost of Standard Parts

PART	QUANTITY	PRICE
Motors	4	450 TL
Propellers	4	100 TL
ESC	4	450 TL
Flight Controller	1	1000TL
GPS	1	150 TL
Radyo Reciever	1	1500 TL
Power Distribution	1	50 TL
Video Tx&Rx	1	500 TL
Camera	1	500 TL
Ground Control Station	1	2000 TL
Battery	1	500 TL
Battery charge station	1	200 TL

Battery Safe Bag	1	100 TL
Others	1	2500 TL

Pricing of all materials has been done before the present work, taking into account the sample works. The total cost is calculated as 10000 TL. The cost of the frame will be evaluated in CH 4.

CHAPTER 5

DETAILED DESIGN and MANUFACTURE OF UAV

5.1 DESIGN UAV of 3D MODEL

The main meaning of the design is calculation and construction. UAV was designed according to the general measurements and materials to be used. Strength, ductility and manufacturability are the most important criteria when selecting materials. The biggest failures in air vehicles are caused by fatigue. 90% of the fatigue consists of design and production mistakes. Other factors are material failure [10], [26], [31].

Some of the more important design parameters to consider for a frame include: strength, size, assembly, appearance, corrosion resistance, stiffness, vibration, weight, noise, production costs, maintenance costs, and sustainability. The following list of factors may be useful for assessing the beginning of a frame's design [31].

- Force to effect on connection points,
- Support elements,
- Allowable deflections of constituent machine elements,
- Cooling requirements,
- Installation infrastructure,
- Quantity required,
- Production facilities available,
- Expertise.

We have already told in detail the dynamic model of quadrotor in previous chapter. As such a quadrotor has got four arms, and a vertical motor is placed on each arm. When we give power to the system, the propellers are turned by the motors. This way, the quadrotor take off. As it is well-known, according to dynamic rules, center of gravity of quadrotor must be exactly in the center so that the quadrotor flies in a fully-balanced manner [10], [26], [31].

The GUUM UAV was designed with the above criteria and the general characteristics of the DJI F450 quadcopter, which is considered as a reference, and made usable for the first prototype. These steps are explained in detail in the following sections.

Figure 5.1 DJI F450

Our project GUUM weighs almost 1.5 kg including its payload. Therefore, the propellers was determined to be sufficient to carry the weight of our quadrotor.

5.1.1 Dimensions

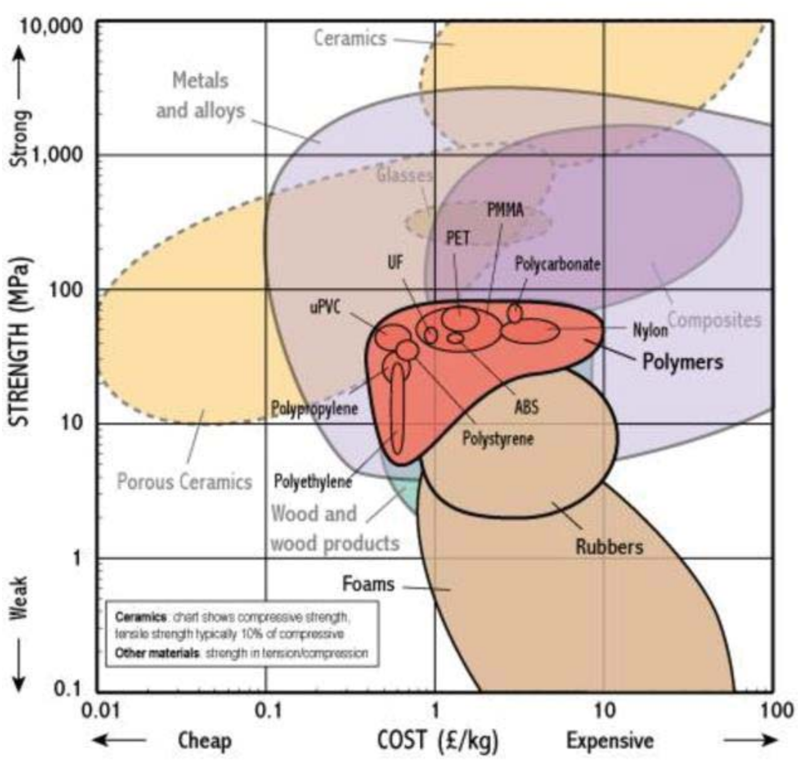
Dji F40 diagonal wheelbase 450 mm dir. GUUM UAV project was drawn in CAD environment with reference to this measure. The size of the landing is designed according to the payload to be used.

Figure 5.2 DJI F450 Cad Modelling

5.1.2 Material Selection

The body frame will manufacture of ABS material, a thermoplastic resin commonly used for injection molding and 3D printer manufacturing. ABS possesses medium strength and performance at medium cost.

Table 5.1 Material comparison about Strength per Cost



Since we wanted the mechanical design to be completely unique, a new design was deemed suitable instead of a ready-made landing gear. The carbon tube, which is the most suitable material for this, was preferred. The availability of carbon tubes in the market. Scale will be decided by the final dimension as a result of the tests. Interconnecting parts are designed according to Ø12 mm carbon tube.

5.1.3 Design Steps

Our project is designed by Catia V5 software. Especially, one point is very important which is manufacturing. GUUM is concept project. It is only design for Master Thesis. If project is successful, it may be a commercial product. Manufacturing methods can be improved and costs can be further reduced.

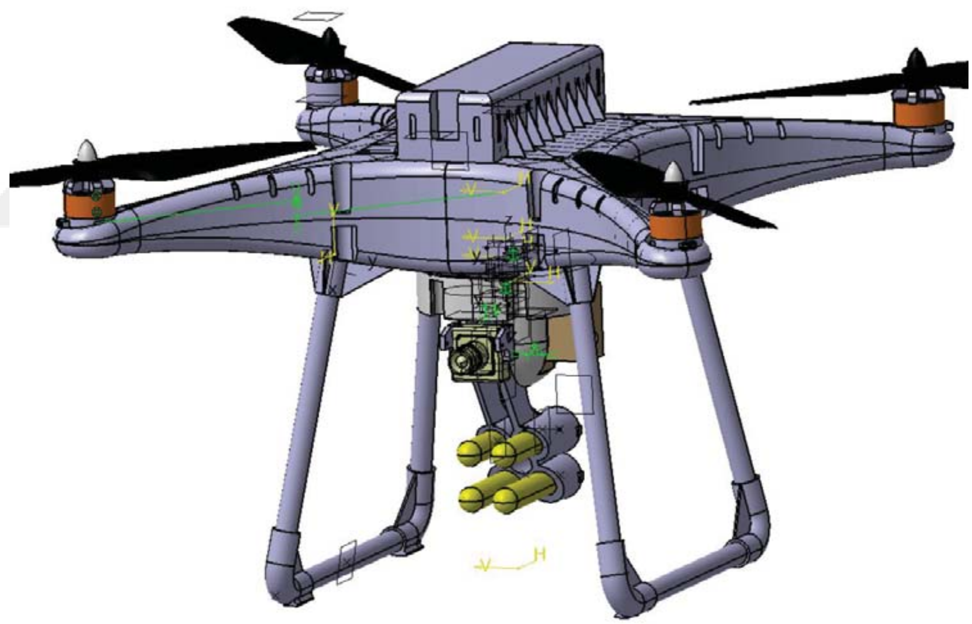


Figure 5.3 GUUM

Figure 5.4 GUUM, Anti – Suicide Quadcopter

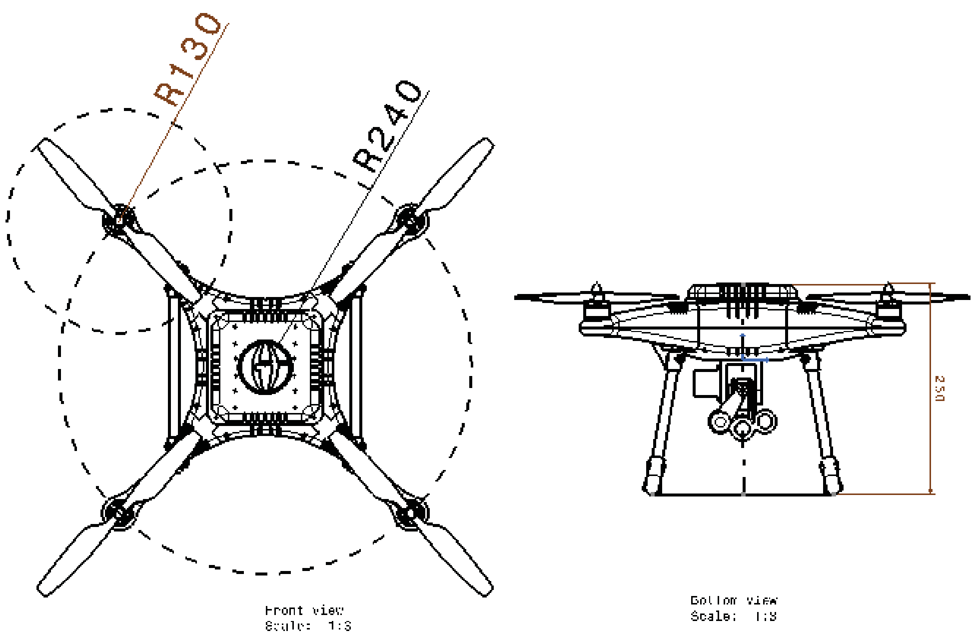


Figure 5.5 GUUM's Dimensions

Guum is concept project that GUUM can divide 4 parts which are body, landing battery case, payload. They can be seen in figure 5.5.

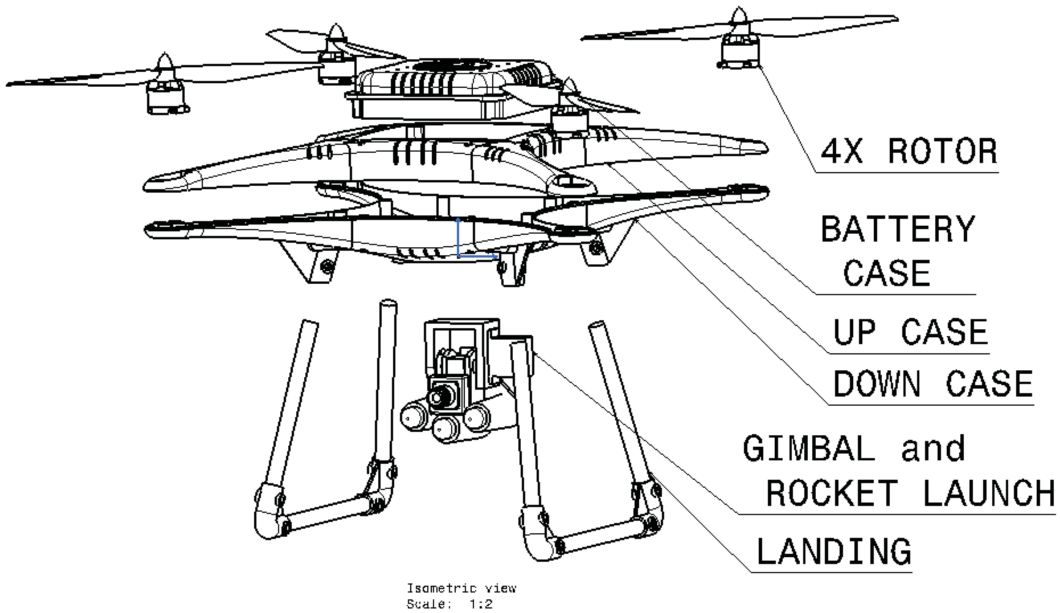


Figure 5.6 Broken View

5.1.4 Parts of GUUM

5.1.4.1 Body

Our system is assumed as rigid body and the real behavior is very close to that. Rigid Body moves as one piece. This part is the place where motors, landings and the other avionics are assemblied on it. It is very impotant that the body should be able to support all the forces, moments and vibrations, when the vehiche is in the air. Some parameters are taken into account, such as easy to manufacture and to be light as much as possible. Body was made by only 2 parts (upper and lower). The other feature that we wanted to have is to interfere easily when a breakdown happens.

5.1.4.1.1 Up Case

Up case is the section upwhere motors are connected and battery case is being carried. Air vents have been located to prevent the heating, which can occur inside the body. Motors can generate heating which could be dangerous for the connection surfaces. To avoid this phenomena so insulation has applied.

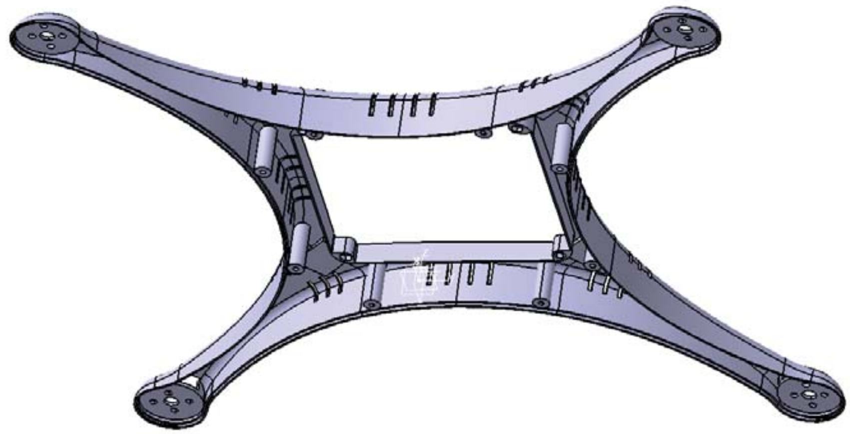


Figure 5.7 Up Case

5.1.4.1.2 Down Case

Down case is the section downwhere the avionics and the motor fasteners are linked to the body. During the flight, PDB and the Flight Card should be working without any vibration. This is essential for a stabile flight. Therefore some connection surfaces have been added and to reduce the heating some other air vents have been created. It has been designed as stiffener. This will also help to behave as rigid body.

Landing is linked where interface under the down case. During landing and take-off , landings prevent damaging the payload and also they absorb the impact forces. Interfaces have been designed, so that they inhibit any kind of failure.

Lastly, the payload assembly interface was located bottom the down case. It helps us to gain time, when we should change the payloads.

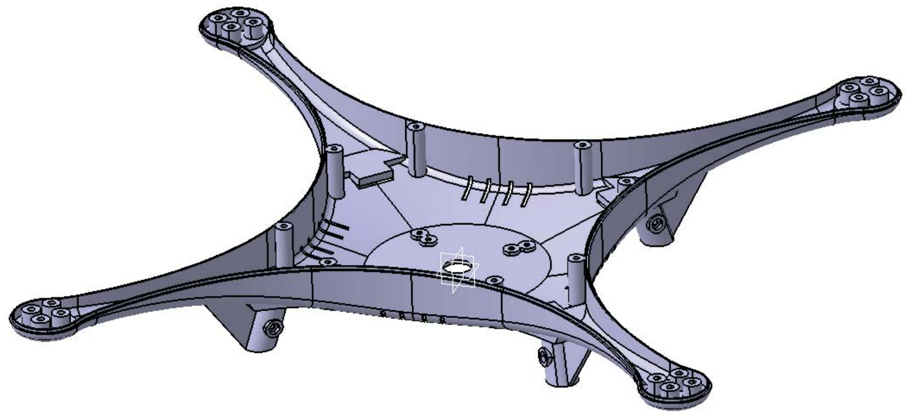


Figure 5.8 Down Case

5.1.1.2 Battery Case

The Project GUUM has been designed, so that it can be assemlied in a very pratic way. The battery which is the one of the most important parts in the quadcopter that has been attached on the upper part, and in the center of the system. It leads us to change the battery fast and independent from the payload. The battery case is a closed object and air vents are present on it. The battery will be assemblied on the up case from the 4 corners. This connection type will not create any vibrations and it is not going the spoil the stability of the drone.

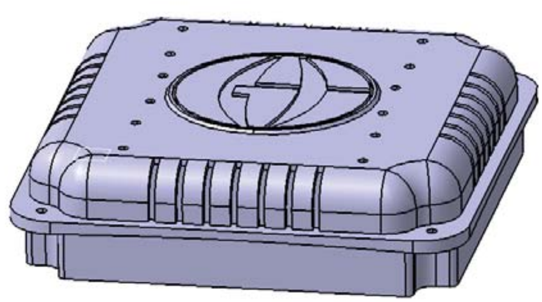


Figure 5.9 Battery Case for 2x1800 mah Li-Po

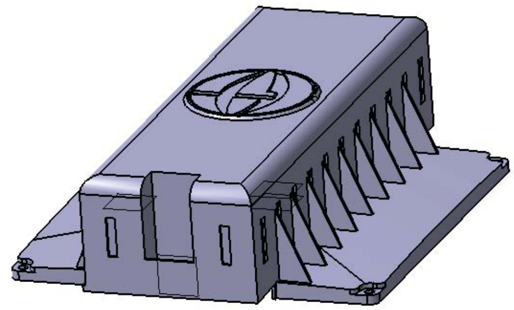


Figure 5.10 Battery Case for 4400 mah Li-Po

5.1.1.3 Landing

Air vehicles need to have landing gear to preserve the payload during landing and take-off. Landing gears should be stiff as well as they are light. For this reason carbon tubes have been used. Standard 3K carbon tubes which Diamater is 12 mm and thickness is 1 mm have been selected. In order to be linked the tubes ABS plastics have been designed.

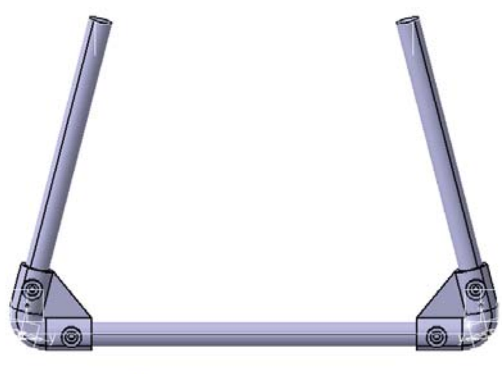


Figure 5.11 Landing Gear

5.1.1.4 Gimbal and Rocket Launcher

Unmanned air vehicles have different mission which it differs according to payload that they are carrying. vation and attack for autonomous systems are the most popular tasks. In this thesis the mission of the payload is both image transfer and attack. The movement on the Z direction will be done by air vehicle. The movement on the Y direction will be done by pitch servo. They are able to enlarge the vision angle.

Consequently when the drone is in the air, panaromic image will be able to be taken and transfered.

To assembly easily there are mounting holes on the bottom of the down case. It will give us the chance to open and close it during the breakdown. The payload is approximately 400 g. and the system was designed according to that. In thesis process the adequate work was done, and the decision was taken to build the prototype. Gimbal plastic parts are given in Table 5.2.

Table 5.2 Gimbal Plastic Parts

PART	DESCRIPTION	MATERIAL	MASS	QUANTITY
1	Gimbal inteface	abs	15 gr	1
2	Rocket and camera mount	abs	20 gr	1
3	Rocket lighter	abs	10 gr	1

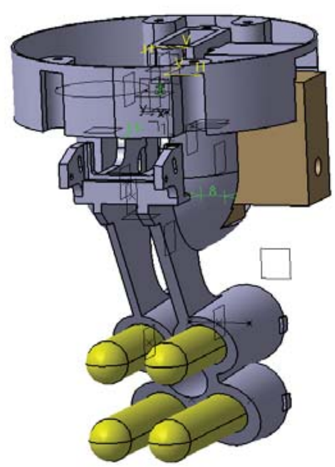


Figure 5.12 Gimbal

5.1.1.4.1 Gimbal Interface

The gimbal and rocket launcher is the part that connects to the downcase. The bearing is used as load balancer is also mounted on this part. The bearing part is a part that requires high strength because it provides balance when rotating.

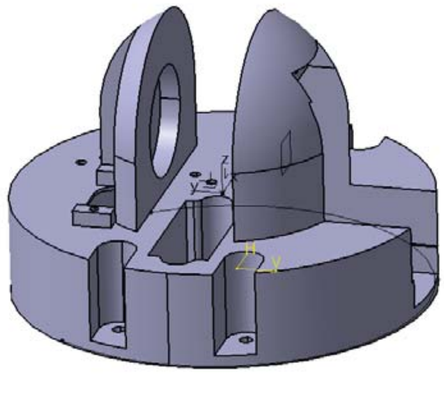


Figure 5.13 Gimbal Interface

5.1.1.4.2 Rocket and Camera Mount

This part is required for the Y axis rotation. This part carries the rockets and the camera. The servo drives this part, the pitch can move 90 °. This can also follow the target.

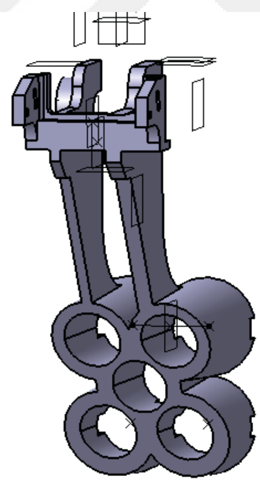


Figure 5.14 Up Case

5.2 MANUFACTURE of UAV

Manufacturing refers to achieve an industrial product by processing a raw material or a semi-finished product. The main purpose of manufacturing technology is to produce products with the lowest cost, best quality. Casting, coating, molding, forming, machining, joining, additive manufacturing etc., the methods of manufacturing methods.

5.2.1 Additive Manufacturing

The AM method is a rapid prototyping method. It is a method of manufacturing different materials by adding them in different ways. The first step is to create 3D data on computers. These data are converted into G codes which are the language the machines will understand by means of intermediate programs. Different types of raw materials are used for each production method. These materials can be powder, liquid and solid. The desired part is obtained by adding to the table. The most popular method, FDM, was chosen for this thesis study. This method is the most appropriate method between availability and AM methods [22].

5.2.2 Fused Deposition Modelling (FDM)

Our project GUUM is a type of quadrotor which is a type of UAVs. As previously mentioned, GUUM was designed by using CAD software. The designed parts were produced by Additive Manufacturing method before mass production. This method is preferred because of its economic and rapid prototyping. FDM method is type of additive manufacturing. G Code is created by the slicer which is a type of software. G Code is loaded into the 3D printer. The ABS filament is heated to 250ºC with the filament heater and melted. The molten plastic from the nozzle is converted to the desired part according to the g codes. It is cooled for about 10 minutes at ambient temperature so that the part is completely ready to use [22].

5.2.2.1 3D Printing Machine

In our project, a cubicon 3D printer, which is produced in South Korea, was used. The specifications of the printer are presented in the table 5.1. This features were taken from www.cubicon.com

Table 5.1 Cubicon 3D printer Features

Product Size	554x579x524 mm (WxDxH)
Product Weight	24 kg
Temperature Ambient	15-35℃
Temperature Operation	15-35℃
Temperature Storage	0-35℃
AC Input	220V, 60 Hz, 2.5A
Power Supply	24V DC @13 A -320W
Memory Device and Communication Environment	SD card, USB cable
Slicing Software Provided	Cubicreator
Input 3D Design file Format	.stl,.obj
Supported Operating Systems	Windows
Printing Technology	FFF- Fused Filament Fabrication
Model Size	240z190x200 mm (WxDxH)
Configure Layer Level	150-400 microns, minimım 100µm
Optimal Model wall Thickness Optimal	0.4 mm Nozzle
Filament Diameter	1.75 mm
Filament Type	ABS, PLA filaments
Basic Nozzle Diameter	Basics 0.4 mm

Figure 5.15 Cubicon Single 3D Printer

5.2.2.2 3D Printing Software

Parts are manufactured by 3D printer. The required G codes are derived by slicer. To create this by analyzing the 3D model data. In the 3D model is drawn with a CAD (Computer Aided Design) program such as AutoCAD, Solidworks, 3DsMax, or objects scanned with a 3D scanner are exported in the '.stl' extension. The 3D printer detects the file in the '.stl' extension and prints it. Stl format files need to be translated into the printer's understandable format. CURA software converts stl to G-codes.

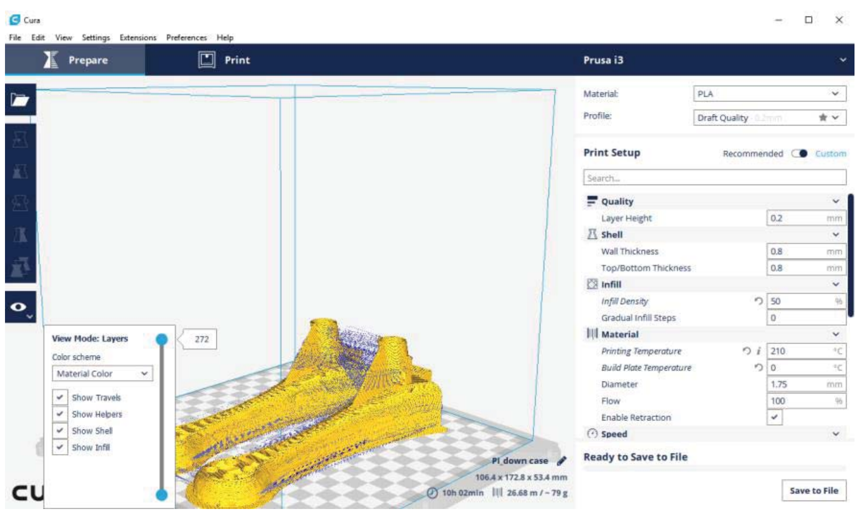


Figure 5.16 GUUM Down-Case Part on CURA

The prepared files are sent to the 3D printer software. The program that defines the 3D model begins printing. Makes the printing according to the desired options. These options are determined by the level of print quality and strength desired. Also options vary according to the raw materials used.

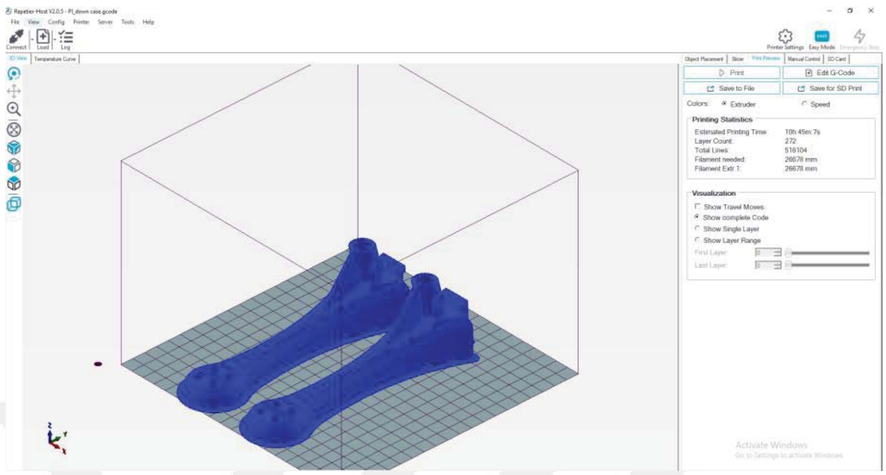


Figure 5.17 GUUM Down-Case Part on Repetier-Host

5.2.3 Plastic Parts of Manufactured by 3D printer

In this chapter the components which were manufactured by 3D printer were explained. For the places, where we can not use standart products, the parts were fabricated. See the list below for the manufactured parts.

Table 5.2 GUUM Plastic Parts

PART	DESCRIPTION	MATERIAL	Infill Denstiy	QUANTITY
1	Body Up Case	abs	%50	1
2	Body Up Arm	abs	%50	4
3	Body Down case	abs	%50	1
4	Body Down Arm	abs	%50	4
5	Battery Case	abs	%20	1
6	Landing Bracket	abs	%50	4
7	Gimbal Interface	abs	%20	1
8	Camera Mount	abs	%20	1

For the best manufacturing quality the optimal parameters were selected. See the list below for manufacturing parameters.

Table 5.3 3D printer Settings

NO	DESCRIPTION	SETTING	CURRENT-UNIT
1	Quality	Layer height	0.2 mm
2	Speed	Print Speed	30 mm/sn
3	Support	Generate Support	Everywhere
4	Built Plate Adhesion	Raft	2 mm
5	Infill	Infill Denstiy	%50

5.2.3.1 Body

The Body is designed as 2 parts. The detailed information is present in the chapter 4. The diagonal size of GUUM Quadcopter is 480 mm. The body was fabricated fragmentary, because the print table of 3D printer (20x20mm) is not enough to produce the body at once.

5.2.3.1.2 Up Case

Up Case is the part, where the motors and the battery case are connected to the body. In this graph as we can see it is not possible to manufacture the body as one piece. will not be able to Up Case.

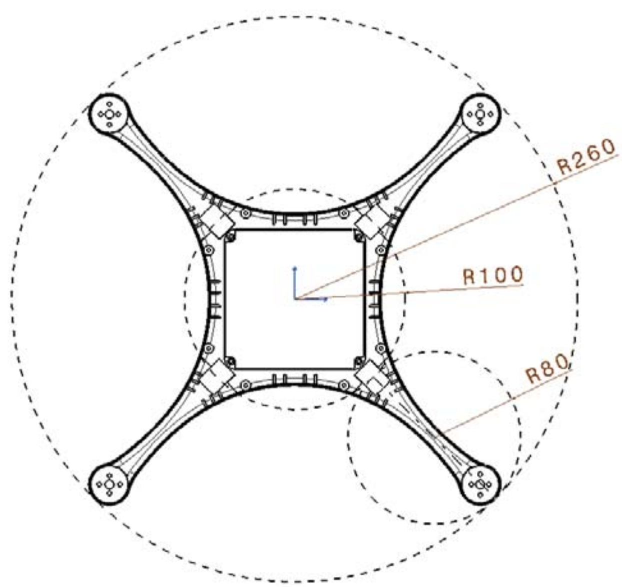


Figure 5.18 Up Case

According to print table of the 3D printer the parts of the body was divided into several pieces.

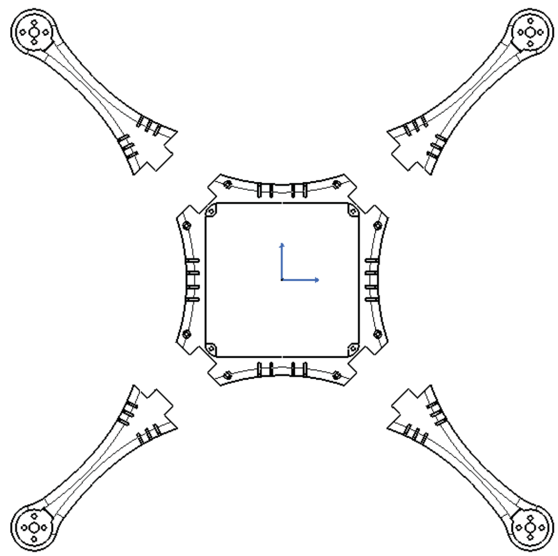


Figure 5.19 Up Case

In this configuration the parts can be manufactured within the given data of the print table.

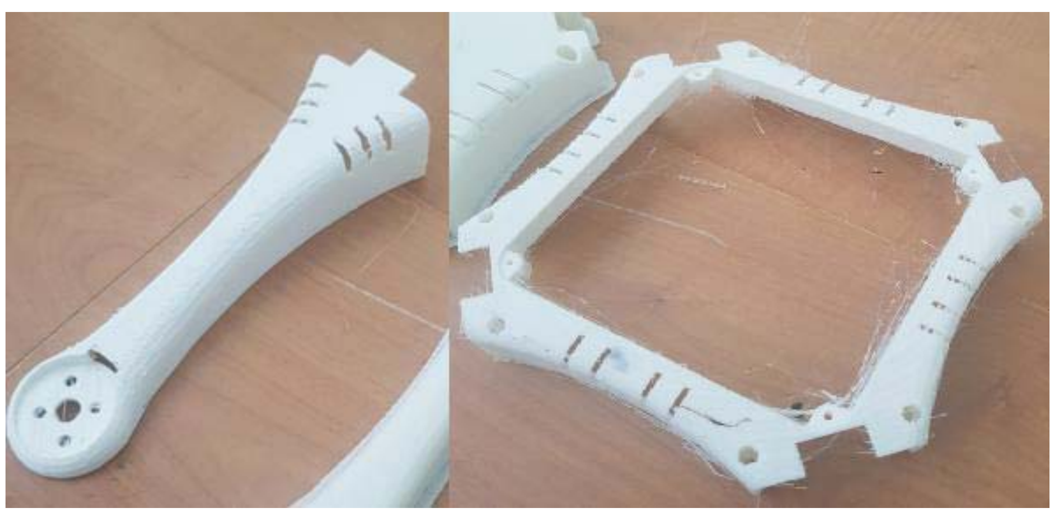


Figure 5.20 Up Case

The manufactured parts were assemblied easily thanks to the notches. Connection surfaces were sandpapered. The joints were strengthened with the some chemicals to prevent any kind of failure. The strong chemical was preferred in order to avoid any faults in the joints. Pattex was used to bind epoxy parts.

Figure 5.21 Pattex Epoxy

Figure 5.22 Up Case

5.2.3.1.3 Down Case

Down Case is the part where avionics, motor mount and the landings are connected to the body. The same procedure was followed as in Up Case. The Down Case was divided into relatively small pieces.

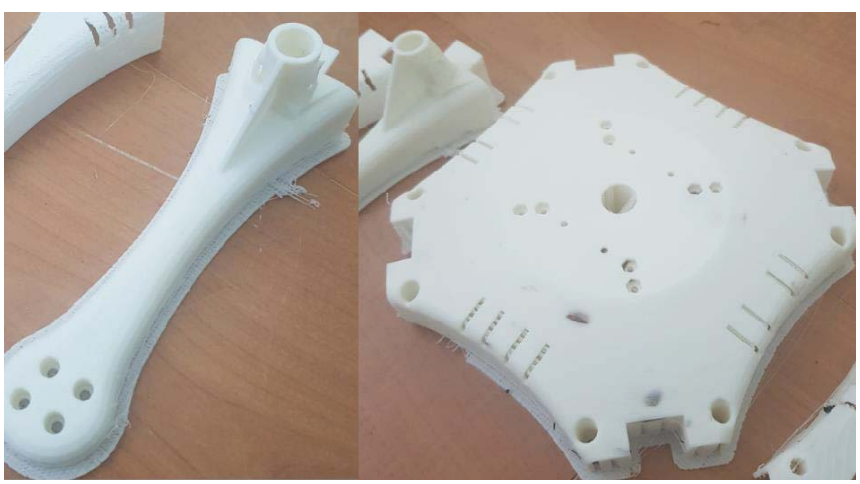


Figure 5.23 Down Case

The manufactured parts were assemblied on a plain surface thanks to the notches. Connection were sandpapered. The joints were strengthened with the some chemicals to prevent any kind of failure.

Figure 5.24 Down Case

5.2.3.2 Battery Case

GUUM Project is designed as rigid structure. The battery case can cause heating. Air vents were added. During add-drop to prevent heating the infill density was determined as 50%.

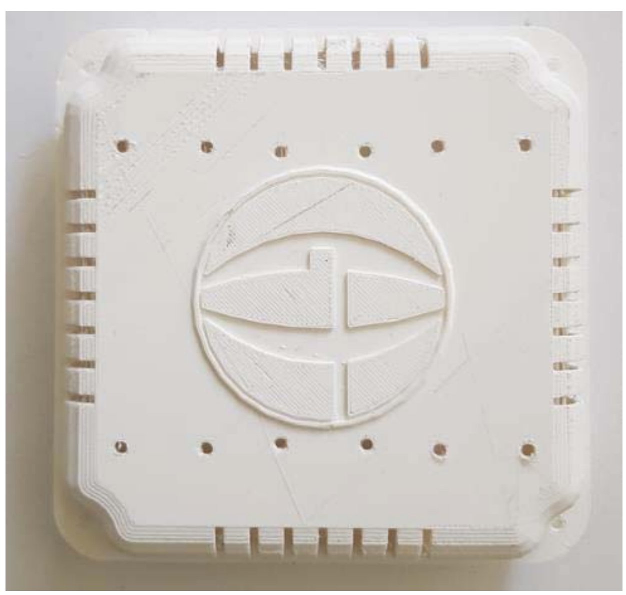


Figure 5.25 Battery Case V01

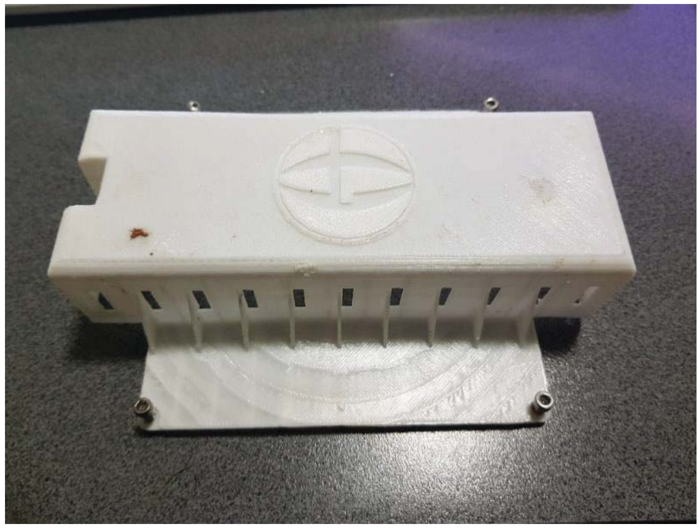


Figure 5.26 Battery Case V02

5.2.3.4 Landing

Landings are essential for protecting the payload and the body when landing and take-off occurs. For the air vehicles the extra load is undesired, for this purpose carbon pipes and abs conncections were preferred. To be able to assembly them M3 hole was added

Table 5.4 Landing Parts

PART	DESCRIPTION	MATERIAL	Infill Denstiy	QUANTITY
1	Landing Bracket	abs	%50	4
2	Vertical Carbon Tube	Carbon fiber	-	4
3	Horizontal Carbon Tube	Carbon fiber	-	2

Figure 5.27 Landing Gear

5.2.3.5 Gimbal and Rocket Launcher

Unmanned aerial vehicles undertake different tasks with payloads they carry. Tasks such as observation and assault are the most popular applications today. In this thesis, payload design was done for both image transmission and attack. Moving part prints carrying rockets and cameras were made at 20 percent. The part of the interface that connects the drone, the print quality, was printed at a rate of 50 percent when considering the stability of the moving part.

Table 5.5 Gimbal Plastic Parts

PART	DESCRIPTION	MATERIAL	MASS	QUANTITY
1	Gimbal inteface	abs	15 gr	1
2	Rocket and camera mount	abs	20 gr	1
3	Rocket lighter	abs	10 gr	1

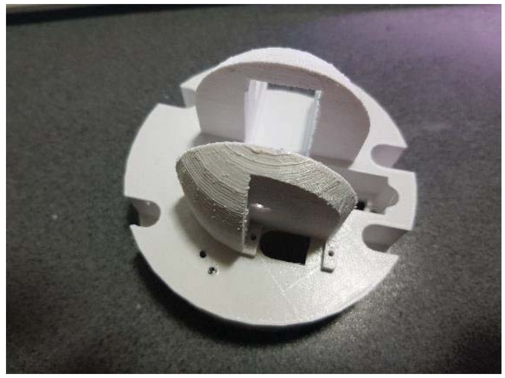


Figure 5.28 Gimbal Interface

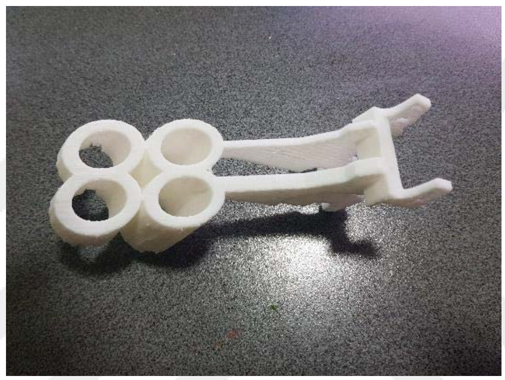


Figure 5.29 Rocket and camera mount

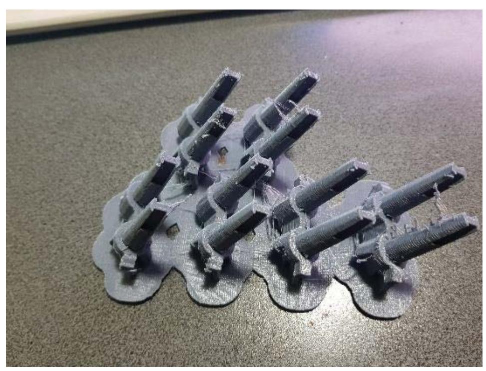


Figure 5.30 Rocket Lighter

CHAPTER 6

INTEGRATION OF UAV

6.1 INTRODUCTION

This chapter overviews the steps how to integrate all system components together to form the final quadcopter UAV system. Hardware components of this UAV system include the radio receiver, autopilot/flight controller, motor controllers, and sensors. The following picture shows the system and their connections [17].

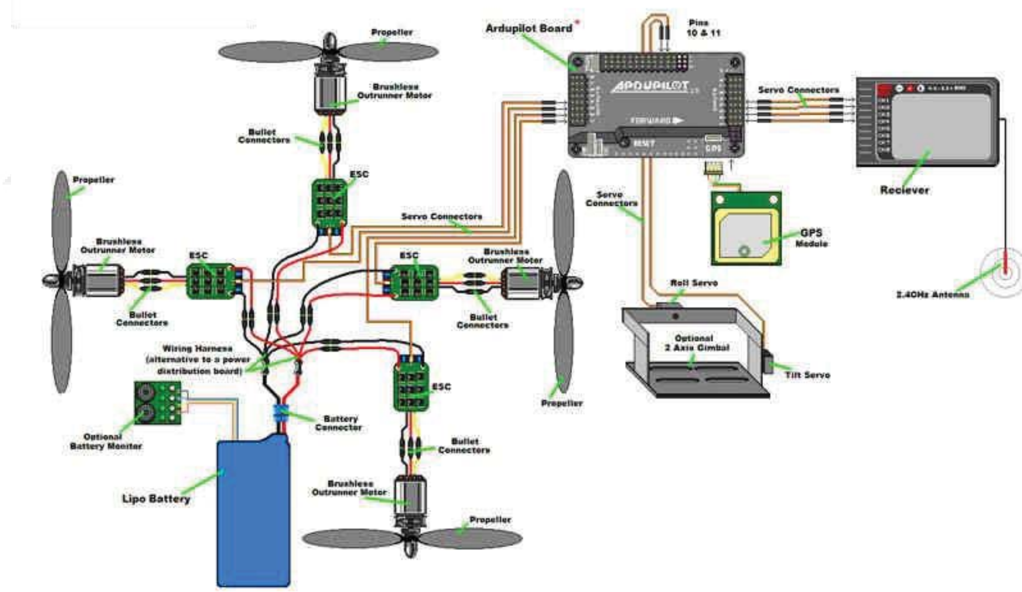


Figure 6.1 Drone Integration Layout

The body is the main part of the quadrotor. All other components; propellers, batteries, flight cards, etc. The quadrotor parts are assembled to the body.

Figure 6.2 GUUM

6.2 INTEGRATION OF AIR-VEHICLE

The quadrotor parts that are landing gear, avionic systems, batteries, camera were mounted on the main body. When the system is assembled, the quadrotor becomes ready. In this section, which describes the quadrotor of assembly phase, the main body assembly steps will be explained. The elements which are used in body assembly are given in table 4.4.

6.2.1 PDB

The PDB is the part that distributes the current from the ESC to the motor, and to other units.

6.2.1.1 Step 1: Wiring

The following steps were followed before installing plastic parts;

- ESC power cable installed
- VBAT cable was installed.
- Hot silicon coating was applied on the solders.

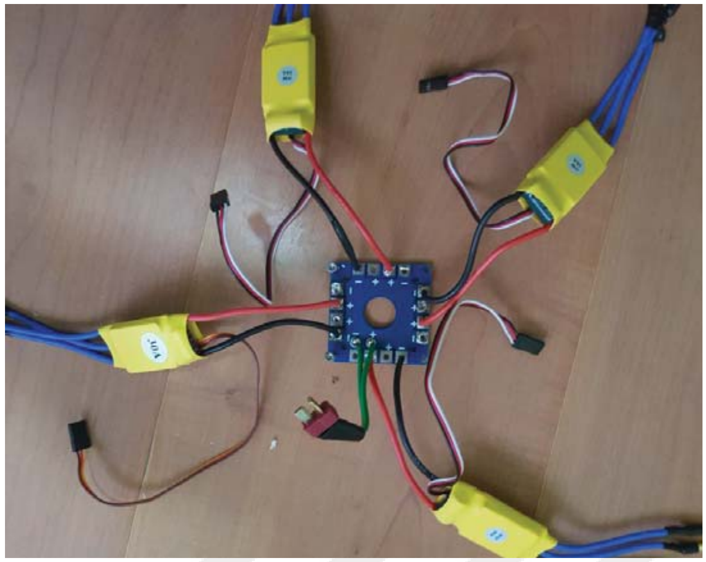


Figure 6.3 PDB wiring

The materials and cables used are given in the table below.

6.2.1.2 Step 2: PDB Integration

Soldering completed PDM sizes 50x50 mm. PDM was integrated between down case and corner holes. It was fixed by M3x4 bolts. It was covered with insulation band because short circuit can occur if this is not done.

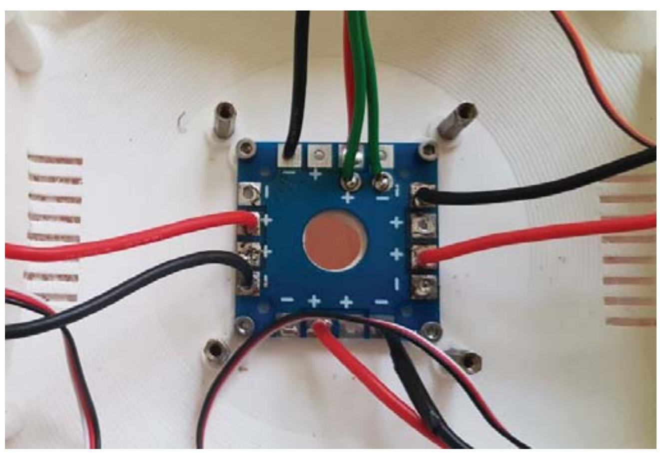


Figure 6.4 PDB Assembly

6.2.2 Flight Controller Integration

Two things are very important when installing the flight card. These are the fact that the card is in the center and the heading is gone.This is also very important in the mounting sequence of the motors.

6.2.2.1 Step 1: M3 Spacer Integration

M3x28 spacers were installed for flight card board assembly. In the down case, the distance between the PDB card and the flight card was wanted.

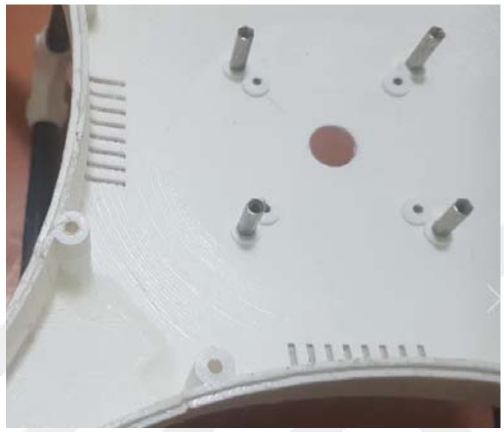


Figure 6.5 M3 Spacer Integration

6.2.2.2 Step 2: Flight Controller (APM) Integration

The flight card was placed on the spacer, mounted with M3x4 bolts. At this point, interaction with the PDB prevented short circuits from occurring.

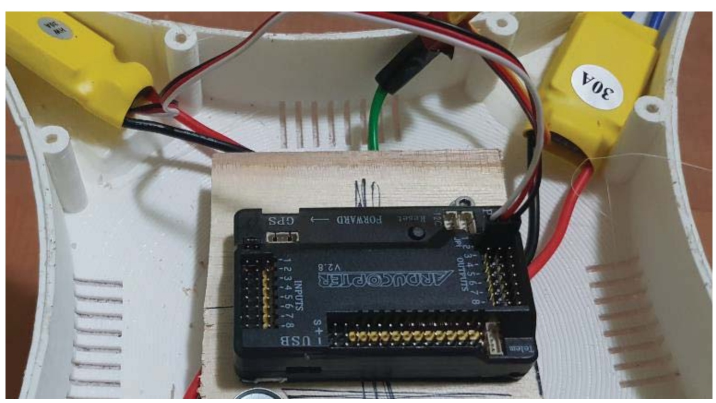


Figure 6.6 FC Integration

6.2.2.3 Step 3: Battery Monitor

The cable from VBAT, which is connected to the battery connector called PDB, is installed at the FC Power Module input. On this count, the battery status and power to the FC are provided here.

The PM is fixed between the top plate and the bottom plate by means of a cable tie. When inserting the battery, the connectors are connected without difficulty. The PM can be connected to the T connector in the PDB direction, the XT60 or T connector in the other end, depending on the package.

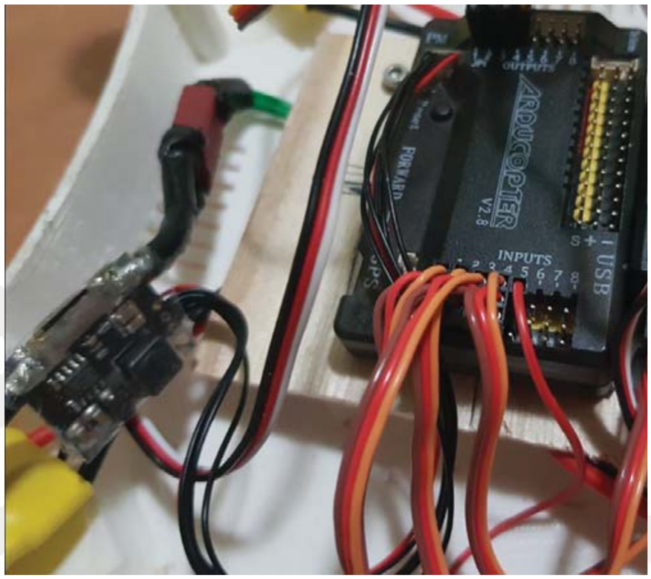


Figure 6.7 PM Assembly

6.2.2.4 Step 4: Transmitter

The FLYSKY receiver is mounted on top of the platform. The two-sided female servo cables were connected as shown in figure 6.5.

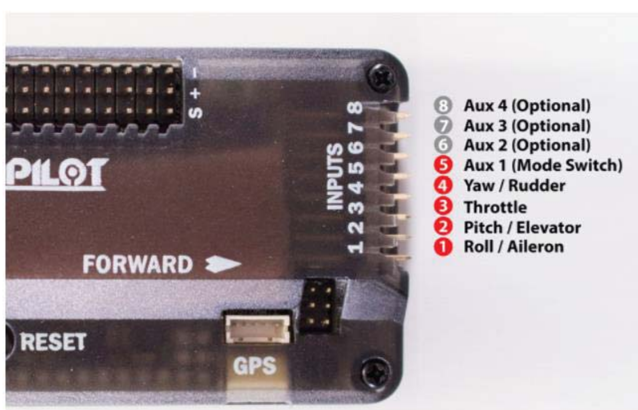


Figure 6.8 PWM wiring schematic for APM.

Reciever, receiving commands sent from the controller, transmits commands to the APM. The APM arranges the commands it receives according to the loaded settings and routes them to the output. The flight mode option is controlled by selecting the channel from the transmitter in pin number 5. The channel was preferred as autopilot mode.

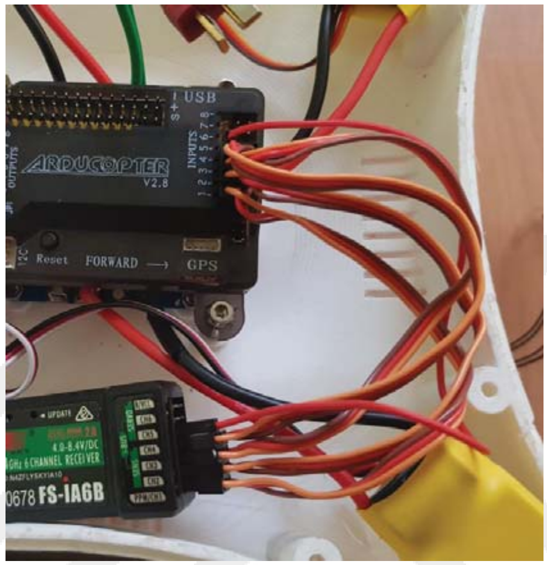


Figure 6.9 PWM wiring schematic for APM.

6.2.2.5 Step 5: GPS

GPS is the most important element in automatic flight and sensor fusion.The location information provided by the FC provides crucial information for flying in stabilized mode in the air and for correcting the flight when the mission is defined.

The GPS mounted on the top platform is mounted on the GPS. The GPS and compass cable were plugged into the GPS and I2C ports on the FC.

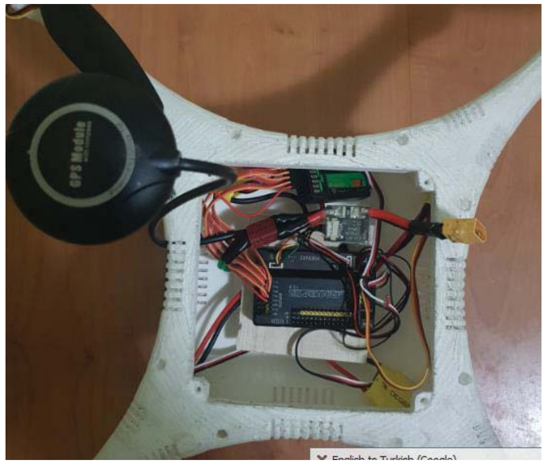


Figure 6.10 GPS Assembly

6.2.2.6 Step 6: Telemetry

Quadcopter is communicated with the ground control station via the telemetry module. The telemetry air module was mounted. One of the telemetry cables was plugged into the air module and the other was plugged into the telemetry pin of the APM.

Figure 6.11 Telemetry Assembly

6.2.3 Motor Integration

GUUM, quadrotor has got 4 arm. Quadcopter of frame was selected x configuration. To increase the angle of view of the Rocket module and camera. Since the X configuration is preferred, the order in which the ESCs are placed on the flight card is as follows Figure 6.12. After completing the first assembly, we can rearrange the directions of the wires between ESC and the motor by changing the order.

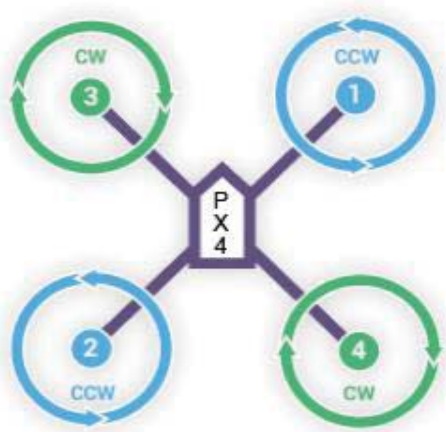


Figure 6.12 X configuration

In this step motor connection is made. The motor-esc connections were made without completely closing the top case. The motor were installed. Fixed with M3x8 screws.

Figure 6.13 Motor Integration

After the first attempt, the motor directions will be checked and the installation will be done by adding Locktite to the final state. During flight, vibrations can loosen motor connecting bolts. The most appropriate method to prevent this is the locktite application.

Figure 6.14 Locktite 243, Moderate Strength

6.2.4 Landing Gear Integration

It is the structure that protects the system during the landing and take-off of the air vehicle. It is especially necessary to be resistant to the forces that will occur during landing. In the CH4, it was explained in the detail design. Landing gear assembly was explained in 2 steps as sub system and system assembly.

6.2.4.1 Step 1 : Landing Gear Sub-Assembly

As mentioned in the design stages, lightweight and robust is the most important feature. In addition, manufacturability and ease of installation are important features. The subsystem prepared by taking these into account is combined as follows.

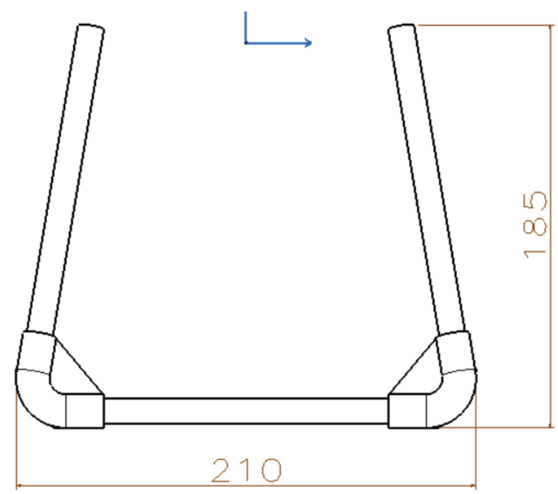


Figure 6.15 Landing Gear Sub-Assembly 2D

6.2.4.2 Step 2 : Landing Gear System Integration

The Landing Gear Sub-Assembly is mounted connection slot where it is under the arms. Landing Gear were assembled with M3x16 bolts - nuts.

Figure 6.16 Landing Gear Assembly

6.2.5 Gimbal and Rocket Integration

The quadrotor, the main objective, is to observe the environment. Quadcopter can do this by moving the yaw axis of the quadrotor and the designed gimbal pitch axis.The G1, G2, servo, bearing parts forming the gimbal were mounted.

The rocket launcher was mounted under the body. Mounted with M3x8 bolts and nuts in the connection holes in the launcher. Pitch axis servo cable was mounted receiver sixth Channel.

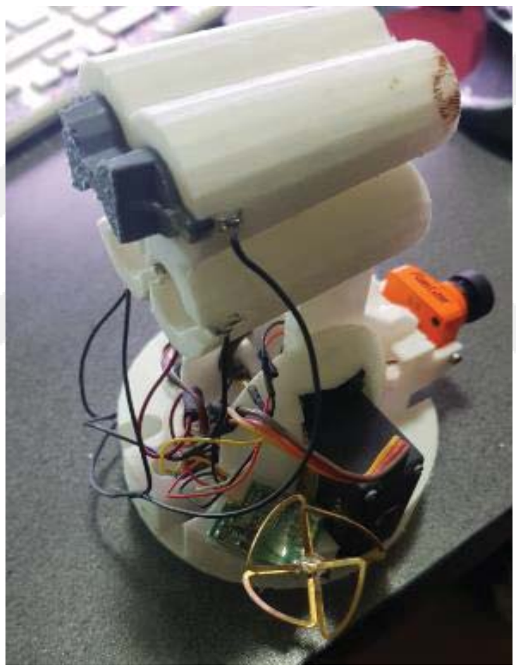


Figure 6.17 Gimbal Integration

6.2.6 Battery Case Integration

The body of the quadrotor was designed symmetrically, so the battery box was designed accordingly. 11.1 V, 4000 mAh batteries were preferred for the quadrotor, which flight time was calculated to be about 30 minutes. Two 2000 mAh batteries were connected in parallel, since battery was not available in the proper geometry [59].

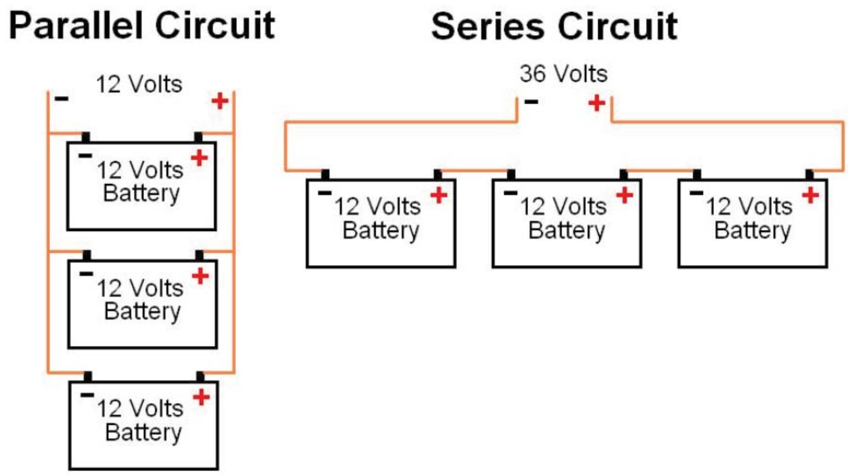


Figure 6.18 Battery Parallel Connection

Due to the parallel connection of the batteries, the total amount of battery was brought to the desired level. To position the batteries, the compartments were added to the battery case and secured in the tie holes. The single output was obtained with the prepared XT60 connector.

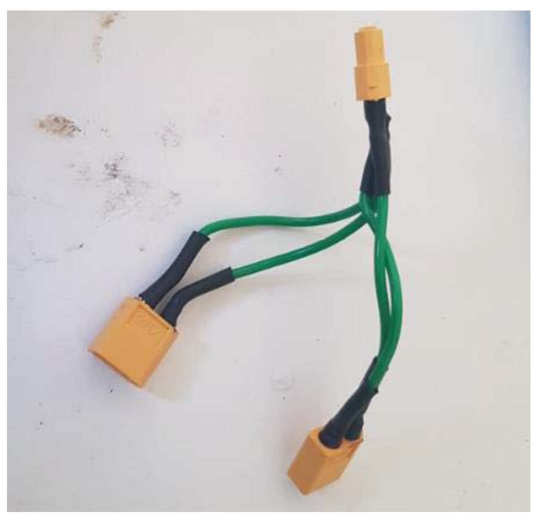


Figure 6.19 XT60 Plug Parallel Connection

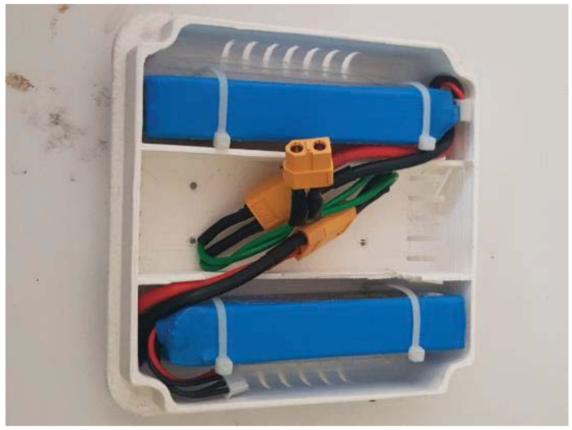


Figure 6.20 Li-Po Battery Parallel Connection

Two Li-Po batteries were fixed as shown. During the flight, it was prevented from causing vibrations that would disturb the balance.

6.3 INTEGRATION GROUND CONTROL STATION

Ground station is the unit that provides data flow with the aid of Telemetry, which provides control of the quadrotor. In includes;

- Telemetry ground unit
- CAM RX Unit
- Laptop

We can follow the information of the air vehicle, flight order through the ground station. We can define it through telemetry. These;

1. Location
2. Battery voltage
3. Mission
4. Rocket launch

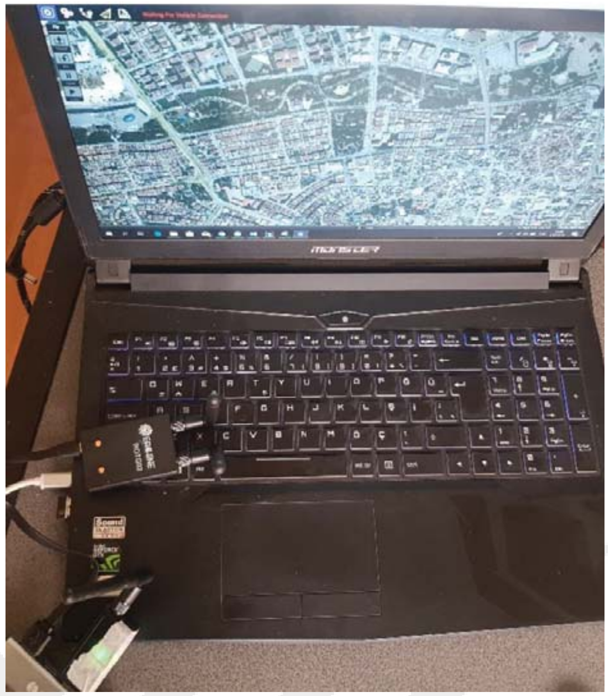


Figure 6.21 GCS

6.4 FINISH INTEGRATION AND SETUP AUTOPILOT

Quadcopters need flight controllers to fly because they are unstable. There are many different flight controllers available. The preferred flight card for this thesis is APM 2.6. The sensors on the flight card and the values they receive must be processed and balanced commands must be transmitted to the motors. At the same time it is necessary to transmit the commands from fc to the motors and to carry out all of them regularly under the control of the sensors. As previously mentioned, this was the mission planner, which is an OpenSource study in this regard. Mission Planner is a full-featured ground station application for the ArduPilot open source autopilot project [17].

Figure 6.22 Mission Planner

Mission planner is a ground station program for the control of unmanned aerial vehicles. It is open source and allows you to add different features or change existing features. Developed by Ardupilot. A similar program, Qgroundcontrol, was released by the same company.

Mission Planner is compatible with MSwindows program. It cannot be used with tablets and phones. If you want to control it with Android or IOS, Qgroundcontrol or other ground station software can be preferred.

There must be a fit between the reference axis in the air-vehicle and the ground axis. Sensors such as acc, gyro, barometer on the flight card must be calibrated properly. This is accomplished in the intermediate tabs in the mission planner that provide the calibration. This software was produced in air-vehicle in different combinations. The mission planner program can be used for fixed wing, helicopter, car, quadcopter, tricopter, hexacopter and octocopter. Commands that tell the flight card how to prepare themselves for a mission are sent from the mission planner program. Adjusts the air-vehicle structure and calibrations as a result of the choices made. Self incoming commands, the command message through a language they understand the process and the motor according to the air-vehicle frame type [17].

6.4.1 AUTOPILOT INSTALLATION and CALIBRATION

The following installation steps are necessary for the quadrotor to autonomously and manually perform a safe flight [17].

- Update Firmware
- Connect and Complete Mandatory Setup

6.4.1.1 Update Firmware

Flight controllers are constantly evolving. Errors discovered in the tests are organized and published quickly. In order not to cause similar accidents, the flight control software should be constantly updated. Twice updates were made during this study [17].

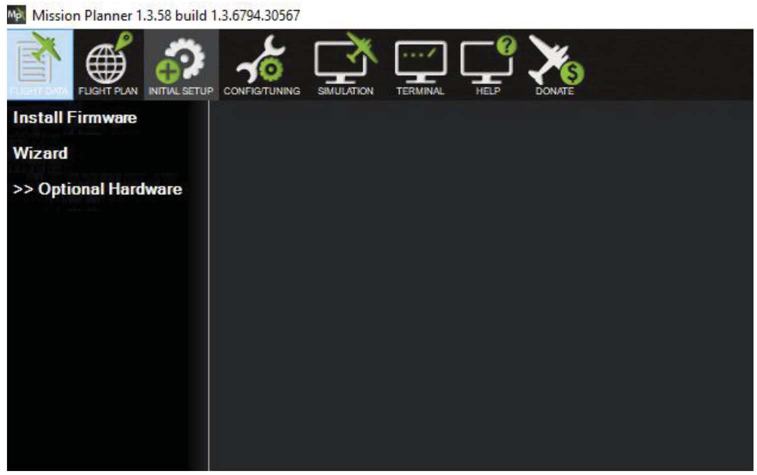


Figure 6.23 Update Firmware

6.4.1.2 Connect and Complete Mandatory Setup

Calibration process is required in order for the quadrotor to recognize the sensors and to make the necessary calculations with reference coordinates from these sensors. When doing these things, it is necessary to connect from the ground station to the quadrotor. Connection can be made via USB or Telemetry. In this thesis the connections were provided with telemetry [17].

6.4.1.2.1 Set frame type

In this project x configuration was preferred. This option was also selected in the installation to allow motor connections to work according to this scheme [17].

Figure 6.24 Select frame type.

6.4.1.2.2 Calibrate accelerometer

Accelerometer is a sensor on the APM to understand what direction is up, down, and so forth. This process was done on as flat a level as possible [17].

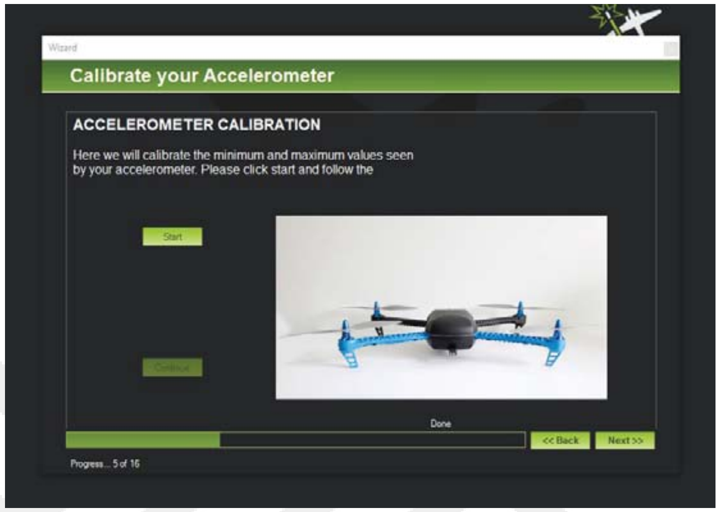


Figure 6.25 Calibrate Accelerometer.

6.4.1.2.3 Set up The Compass

Sensors on the flight controller are sufficient for manual flights. The sensor fusion method should be used for autonomous flight. Sensor fusion is the integrated operation of all sensors in the system and correcting errors according to a reference. Since internal sensors refer to the location where they are first calibrated as references, errors begin to accumulate after the flight begins. Through GPS, the system determines the north direction. Virtual dots occur. The air-vehicle was rotated around these axes with different axes [17].

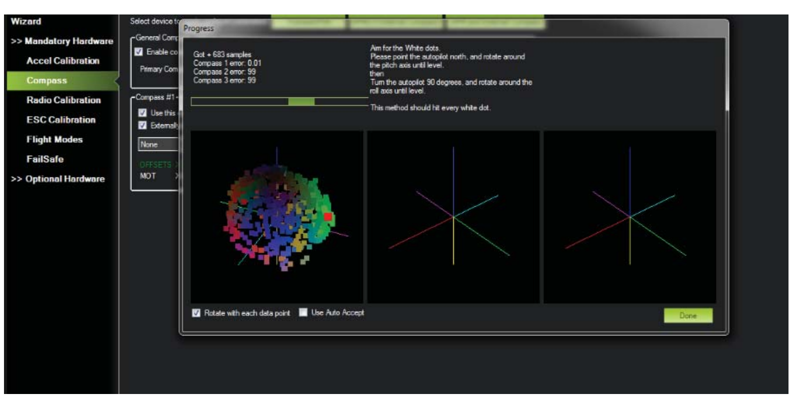


Figure 6.26 Compass Calibration.

6.4.1.2.4 Radio Calibration

Radio control is needed for manuel flight. Sometimes it is also used to prevent accident investigation in autonomous flights. Radio was calibrated [17].

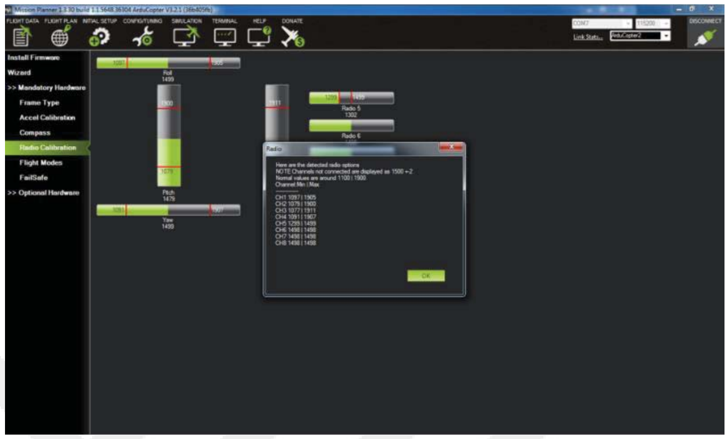


Figure 6.27 Radio Calibration.

6.4.1.2.5 Set Flight Modes

Flight modes are applied for different flight characters. Since the purpose of this project is to achieve an autonomous flight, the auto mode was preferred. Auto mode was set the 5th channel on the remote control [17].

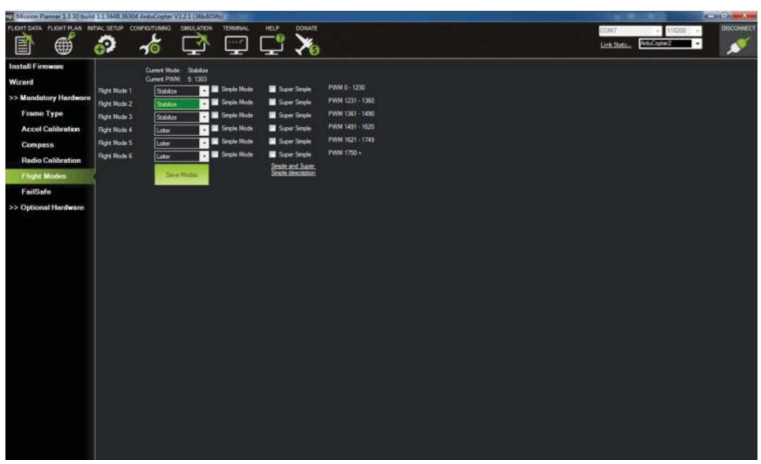


Figure 6.28 Switch Position 1 Manuel Flight Mode

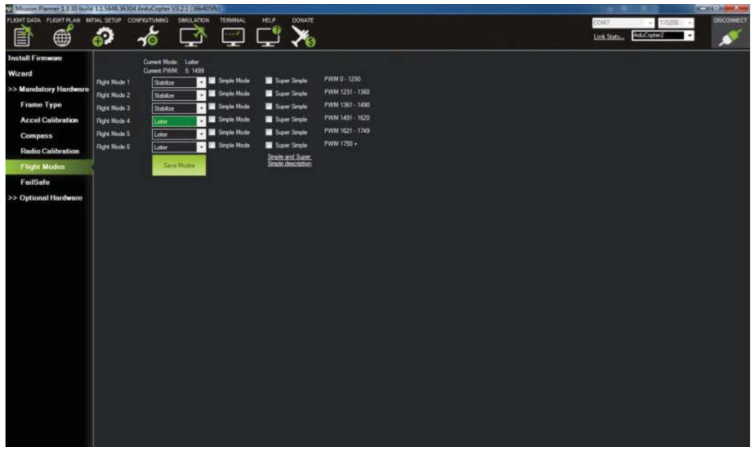


Figure 6.29 Switch Position 2 Auto Mode

Others flight mode are given table 6.1 [17];

Table 6.1 Flight Modes

Mode	Summary
Stabilize	Self-levels the roll and pitch axis
Alt Hold	Holds altitude and self-levels the roll & pitch
Loiter	Holds altitude and position, uses GPS for movements
RTL	Retruns above takeoff location, may aslo include landing
AUTO	Executes pre-defined mission
Acro	Holds attitude, no self-level
Brake	Stop Motor immadiately
Guided	Navigates to single points commanded by GCS
Land	Descend in its position
Follow Me	Follows another GPS on the ground

6.4.1.2.6 FailSafe Setup

This is set so that the quadrotor battery can return to the ground when it is weak. The battery low is set to 10 volts. When the telemetry communication was interrupted, the command return home was set in order that the air-vehicle did not cause any accidents. The most important issue that should be determined before the flight is to confirm the coordinates of the place where is home [17].

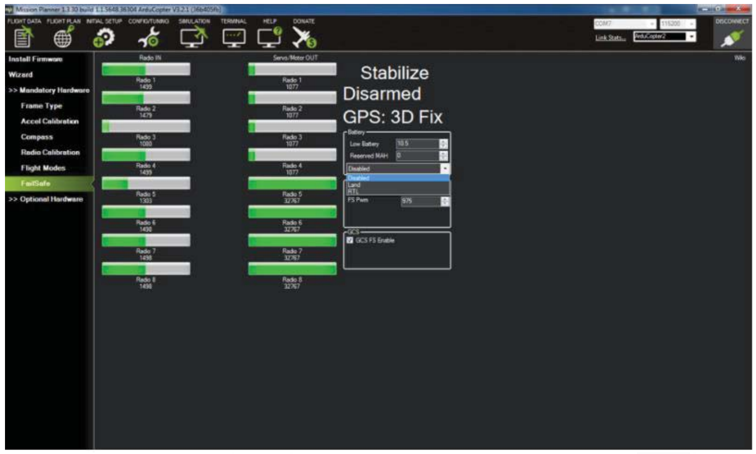


Figure 6.30 Battery FailSafe Options.

6.4.1.2.7 3DR Radio (TELEMETRY)

All calibrason and software update operations were done with telemetry. This shows that the telemetry is exchanging the correct information[17].

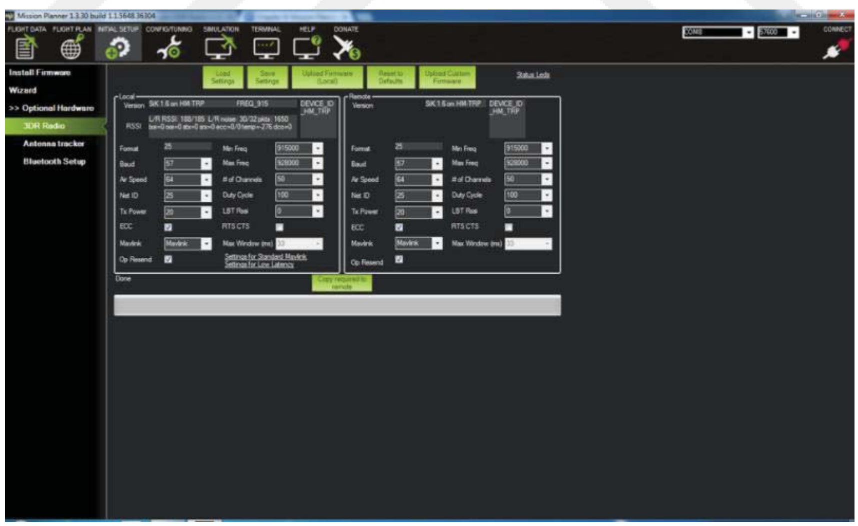


Figure 6.31 Telemetry Radio Setting

CHAPTER 7

RESULTS AND DISCUSSION

7.1 INTRODUCTION OF TEST

After the design, manufacturing and assembly of the GUUM unmanned aerial vehicle, the ground controls were made ready for flight tests. The aim of the tests is to complete the autonomous take-off, flight in the given coordinates, and follow the safe landing steps to the point of departure. Considering the available equipment and flight time, a 50% safe flight time was determined to ensure that flights were completed safely. Within this period, the task was completed, the task was accomplished successfully [30].

7.2 PRE-FLIGHT CHECKLIST and FLIGHT LOG INFORMATION

The most important rules in aviation are pre-flight checklist. This controller is vital. So air transport is considered the safest vehicle. A similar situation exists in unmanned aerial vehicles. Any malfunctions that may occur when landing, it can be cause serious damage to both the air-vehicle and the environment. Therefore, it is necessary to apply similar procedures in the flight of unmanned aerial vehicles [6], [17], [30].

1. Date and time
2. Predetermined location and safe take-off / landing zone
3. Flight crew (operator and flight operator)
4. All cable and hardware connections are intact
5. Quadrotor, radio and channel flight modes / settings
6. The propellers and the battery are in place
7. GPS: number of connected satellites
8. Weather, direction of the sun, direction and speed of the wind
9. Task
10. Potential hazards and some plans to deal with them

11. Altuitude/air speed

12. Secure vehicle load

13. Memory card withfree space and camera settings

14. Flights and observations

After reviewing the above data on the pre take off flight data screen If no problem is found, the flight is ready. The best work for this is the UAV forecast mobile application that gives information about meteorology conditions

The aviation authority has its own rules. Everything is regular. Air-vehicles failures bring great destruction. After completing the controls of the quadrotor, the DGCA asked for; the documents required to be prepared before flight are as follows [6], [17], [30].

- Special flight permit, flight availability certificates,
- Flight team licenses,
- Flight operation manual,
- UAV system manufacturer documents,
- Flight zone map,
- NOTAM and other airspace limitations affecting flight,
- Meteorological report
- Insurance
- Registration

In order to facilitate the development of unmanned aerial vehicles, some aspects are not required in R&D. The requirements for UAV 0 and UAV 1 category air vehicles produced for R & D studies are as follows [6], [30].

- Registration
- Coordinates of the zone,
- Altitude,
- Insurance,
- Flight team licenses.
- Overall, the expected actions before flight are given.

7.3 TEST

7.2.1 Flight Plan

Finally, we were planed autonomous flights for GUUM. Mission planer software also has a flight plan tab. The flight plan for this autonomous flight is prepared. On this screen, the home position, way and landing area are added respectively. The departure speed, flight height and waiting points are added in this section. Everything from an entire mission to a single waypoint can be planned from this screen. No matter what the complexity of our mission, they are all made up of a series of waypoints that direct the quadrotor to a specific latitude, longitude, and altitude [17].

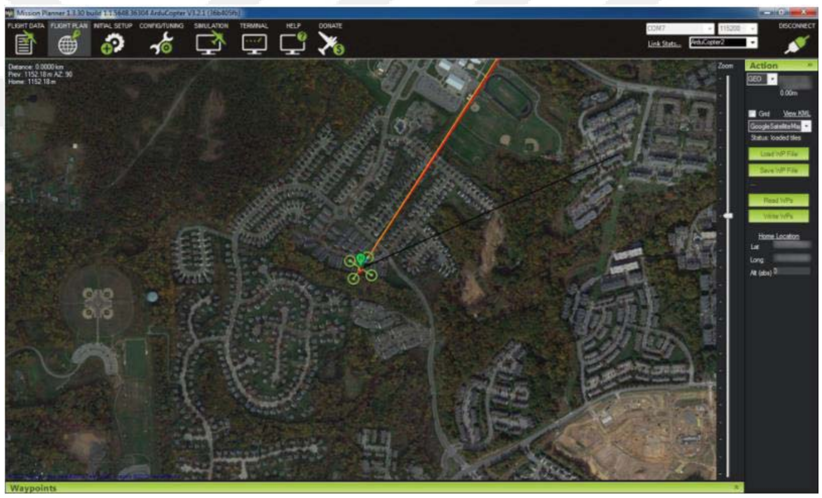


Figure 7.1 Flight Plan Screen

Prior to the flight test, the following test steps were carried out after the successful flight of the control with the platform RC control.

7.2.2 Test

For the first flight test, the preliminary preparation and control stages were completed. The appropriate test environment was selected. Flight plan prepared. Emergency landing location planned. The flight time for the first flight was 10 minutes.

Figure 7.2 Pre - Test

Figure 7.3 Flight Test

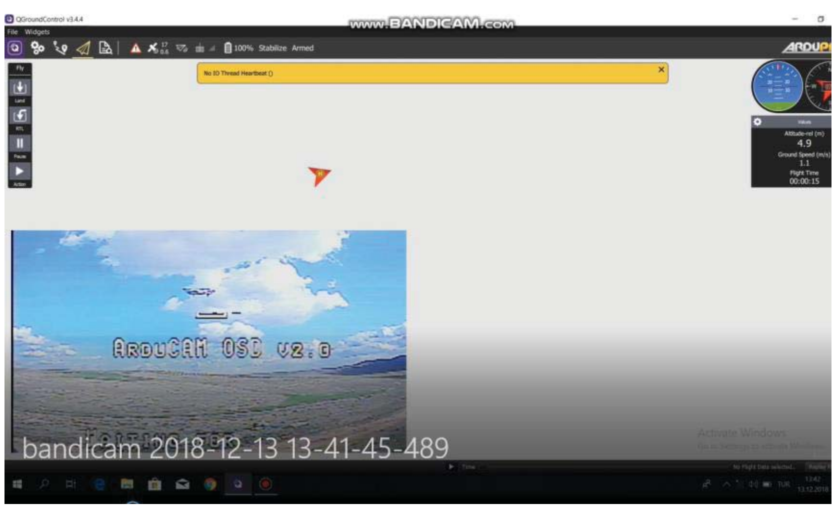


Figure 7.4 GCS.

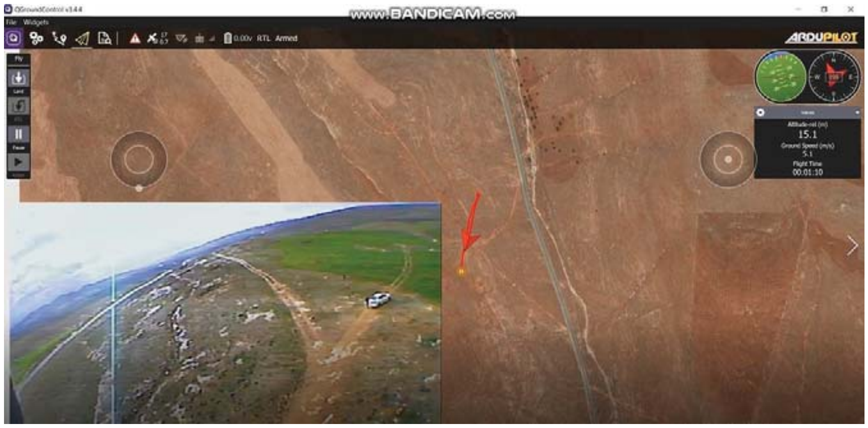


Figure 7.5 GCS.

7.4 RESULTS

The effects of air temperature and wind values were examined. 20 ºC temperature and 8 km / h wind speed were observed as the most suitable values during flight. The fact that the air-vehicle has ABS material limits the operating temperatures. This values are between 10ºC and 30ºC. The air-vehicle plastic case will occur in the stress and relaxation, rigid accepted structure may cause failure when the temperature falls below 10 degrees. When wind speeds above 20 km / h, the air-vehicle uses more energy to fly smoothly. So the flight time will be short. windy weather causes motors to overheated and break down.

CHAPTER 8

CONCLUSION

Designing and manufacturing of the quadcopter type of unmanned air-vehicle was described in this thesis. Quadcopter is a multi-rotor class air-vehicle. It designed as a closed system like DJI Phantom 4. This has provided us with limited protection from dust and water. Payloads designed for GUUM may vary in flight times according to task options. The expected flight time with module 1 which there are in rocket launcher and image transfer is approximately 25 minutes. Approximate flight time with module 2 is approximately 30 minutes. Flight times may vary according to designated tasks. These are observation, discovery and attack. The main reason for the design of the air-vehicle is its tasks. To ensure that they act in accordance with the mathematical modeling, the loads are close to the center as much as possible. In this way, the air-vehicle is prevented from exhibiting unusual behavior during the flight.

The main objective of this thesis is to design an air vehicle with a diagonal length of 45 cm to produce a system that can perform the tasks. Conceptual design was created by mathematical modeling calculations. The air-vehicle was manufactured with a 3D printer. Prepared plastic parts, electronic parts were installed according to figure 6.1. Tests were performed after assembly. These tests are visual inspection, hand inspection, electrical short test and linkage tests. As a result of these tests, the system was subjected to air tests.

Air-vehicle ground tests are vital for the system. Malfunctions that may occur in air-vehicle cause crashes. Pre- tests of ground control station should be carried out with the completion of intermediate tests. When performing this test, the propellers must be removed. All commands must be tried and the behavior of the system must be thoroughly monitored. Previously determined to the landing area with the command land. After the necessary permissions were taken and the procedures were completed before the flight test, a flight test was performed. The test was performed with payloads. During the flight test, the suitability of the air-vehicle to the mathematical model was seen. The air-vehicle was monitored in Loiter mode for 5 minutes. Total flight time was planned as 10 minutes, the net behavior of the system was observed.

Air-vehicle, safety factor is the most important factor to consider when designing. Keeping this number high will cause a decrease in efficiency. This causes undesirable conditions in air-vehicle. Therefore, we should make sure that the safety factor is not as low as 1, but the safety coefficient falls below 1. For these reasons, the forces applied to the air-vehicle causes unwanted fatigue and breaks. Mechanical strength must be calculated in advance and control schedules should be created. Since we did not prepare the control schedule of the first prototype, it would be appropriate to control the entire system completely.

In the control, the expected result from the design showed that the resistance against dust and water was successful. GUUM air-vehicle designed and manufactured as a closed system is protected against dust and water within certain limits, extra gaskets to be added to connection surfaces can further increase these values. When the wind forces increased, the aggressive behavior of the system was caused by micro cracks. These cracks can be repaired with epoxies or revised design. Third motor was also detected to be overheating. This indicates that the motor is overloaded during the yaw movement. Parts replacement may be appropriate by observing ESCs calibration and the results of other tests. All soldering control, motor-esc connections are suitable.

The conceptual design, design and fabrication stages of the system as described in this thesis and the installation of the system was successed. This system, which is produced as a result of R & D work, can be produced with different manufacturing methods. A lighter system can be achieved.

FUTURE WORK

This study emerged as a result of the role of autonomous systems in our lives. Terrorist groups can easily access this system and cause defense costs of countries to be increased. With the GUUM system, we can make ineffective Kamikaze attacks inexpensively.

High-quality image and rocket system, air-land, air-air interventions added to the GUUM unmanned air-vehicle. This capability will bring longer flight times with improved battery technology.

The further expansion of the capacities of the micro-processors will enable the air-vehicle to follow the target in a smarter way. With the developing technology, the energy needs of these processors will be further reduced and the mechanical solutions used to ignite the rocket system will evolve towards electronic systems. In this way, the most important elements, battery and rocket capacity will increase even more. This means high mobility [2], [3], [29].

Since the preferred APM flight card for this study has 8 bit processors, the response speed and capabilities are limited. The flight controller with high-capability 32-bit processor and extra sensors used in air-vehicle will provide both mobile ground control support and more balanced flights using this project. With the addition of the image identification system, the flight will be a step for both autonomous and self-deciding [3], [18].

The 3D printing technology used in mechanical manufacturing brings about practical and fast solutions and strength. With the development of printers using carbon printing technologies, more powerful and lightweight systems can be produced. In this way, solutions closer to the assumptions used in mathematical modeling will be obtained. The system considered rigid is expected to be elastic and elastic enough to absorb energy during impacts. We can solve this with different manufacturing to be used in future studies [3].

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