KARADENIZ TECHNICAL UNIVERSITY
THE GRADUATE SCHOOL OF NATURAL AND APPLIED SCIENCES

DEPARTMENT OF ELECTRICAL & ELECTRONICS ENGINEERING

DESIGN AND IMPLEMENTATION OF AN UNMANNED AIRCRAFT

MASTER’S THESIS

Electrical-Electronics Engr. Mehedi Imran HASAN

FEBRUARY 2017
TRABZON

KARADENİZ TECHNICAL UNIVERSITY
THE GRADUATE SCHOOL OF NATURAL AND APPLIED SCIENCES

DEPARTMENT OF ELECTRICAL AND ELECTRONICS ENGINEERING

DESIGN AND IMPLEMENTATION OF AN UNMANNED AIRCRAFT

Mehedi Imran HASAN

This thesis is accepted to give the degree of
"MASTER OF SCIENCE"
By
The Graduate School of Natural and Applied Sciences at
Karadeniz Technical University

The Date of Submission : 03 / 01 /2017
The Date of Examination : 21 / 02 /2017

Supervisor : Assoc. Prof. Dr. Halil İbrahim OKUMUŞ

Trabzon 2017

KARADENİZ TECHNICAL UNIVERSITY
THE GRADUATE SCHOOL OF NATURAL AND APPLIED SCIENCES

DEPARTMENT OF ELECTRICAL & ELECTRONICS ENGINEERING
Mehedi Iran HASAN

DESIGN AND IMPLEMENTATION OF AN UNMANNED AIRCRAFT

Has been accepted as a thesis of

MASTER OF SCIENCE

after the Examination by the Jury Assigned by the Administrative Board of the Graduate School of Natural and Applied Sciences with the Decision Number 1686 dated 24 / 01 / 2017

Approved By

Chairman : **Assoc. Prof. Dr. Birol SOYSAL** ……………………………………………

Member : **Assoc. Prof. Dr. Halil İbrahim OKUMUŞ** ……………………………………………

Member : **Assist. Prof. Dr. Hakan KAHVECİ** ……………………………………………

Prof. Dr. Sadettin KORKMAZ
Director of Graduate School

PREFACE

The Almighty Allah to whom I am very grateful who has given me the opportunity to study in abroad and also the strength to complete this thesis. I am very debt to my beloved parents who have brought me here and supported me all the way since my childhood.

I would like to express my profound gratitude to all my teachers who have been a source of support and inspiration throughout my life. With due respect, I would like to express my deep sense of gratitude to my honorable supervisor, Assoc. Prof. Dr. Halil İbrahim OKUMUŞ, for his guidance, and continuous support over the time. I never felt foreigner and amazed by his assistance during the education period.

Finally I am highly grateful to my friend Caner Kılıç who has been with me all the time during the construction and testing period of the aircraft. I feel thankful to all my Turkish and International friends for their cooperation warm cooperation.

I would like to acknowledge and give special thanks to Turkish Government Scholarships team (YTB) for their funding of my master program.

Mehedi Imran HASAN
Trabzon 2017

DECLARATION

I, the undersigned, declare that this study entitled “Design and Development of an Unmanned Aircraft” completed under the supervision of Assoc. Prof. Halil İbrahim OKUMUŞ is my original work and has not been presented for a degree in any other university and that all sources of materials used for the study have been duly acknowledged.
21/02/2017

Mehedi Imran HASAN

CONTENTS

Yüksek Lisans Tezi

ÖZET

İNSANSIZ HAVA ARACININ TASARIMI VE UYGULAMASI

Mehedi Imran HASAN

Karadeniz Teknik Üniversitesi
Fen Bilimleri Enstitüsü
Elektrik-Elektronik Anabilim Dalı
Danışman: Doç. Dr. Halil İbrahim OKUMUŞ
2017, 123 Sayfa

Son yıllarda İnsansız Hava Araçları askeri alanda kullanıma büyük bir katkı sağlamanın yanında, sivil kullanımda da çok popüler olmuştur. İnsansız Hava Araç uygulamalarından bu yana, UAV tasarım ve geliştirme çalışması geometrik olarak artmaktadır. İnsansız Hava Aracının aşırı basit görünüşündeki sebep, içerisindeki mürettebat çıkarılarak onun yerine bir bilgisayar sistemi ve bir telsiz bağlantısı kullanılıyor olmasıdır. Aslında bu durum daha da karmaşıktır ve İnsansız Hava Aracı, mürettebat ve konaklama yerleri olmaksızın baştan itibaren doğru bir şekilde tasarlanmalıdır. Gelişmiş ülkeler, teknik yeterliliklerinin olması ve uygun materyallere sahip bulunması nedeniyle uzun zaman önce bu tür projelere başvurmuş olabilirler. Bununla birlikte, gelişmekte olan ülkelerin öğrencileri için bu projelerde, teknik becerinin, mali desteğin ve uçak malzemelerinin satın alınması oldukça zordur. Dolayısıyla bu çalışma, özellikle gelişmekte olan ülkelerin öğrencilere, düşük maliyetli insansız hava araçları tasarımı ve geliştirilmesi konusunda ilham vermek amacıyla yapıldı.

Anahtar Kelimeleri: İnsansız Hava Aracı, Otopilot Sistemi, İnsansız Hava Aracı Tasarımı.

Master Thesis

ABSTRACT

DESIGN AND IMPLEMENTATION OF AN UNMANNED AIRCRAFT

Mehedi Imran HASAN

Karadeniz Technical University
The Graduate School of Natural and Applied Sciences
Department of Electrical & Electronics Engineering
Supervisor: Assoc. Prof. Halil İbrahim OKUMUŞ
2017, 123 Pages

In recent years Unmanned Aircrafts have come into account not only their tremendous contribution in military use but they are now very popular in civilian use also. Since their implementation, the study of design and development of UAV has been increasing in geometrical way. An over-simplistic view of an unmanned aircraft is that it is an aircraft with its aircrew removed and replaced by a computer system and a radio-link. In reality it is more complex than that, and the aircraft must be properly designed, from the beginning, without aircrew and their accommodation, etc. Developed countries may have gone for such projects longtime ago because of their technical proficiency and availability of appropriate materials. However, it is very difficult for the students of developing countries to have the support of technical skills, financial support and aircraft materials which are quiet unaffordable for these projects. Hence the study has been done to inspire the students especially from developing countries to come forward to design and build low cost unmanned aircraft.

Key Words: Unmanned Aircraft, Unmanned Aerial Vehicle, Autopilot system, Unmanned Aircraft Design.

LIST OF FIGURES

LIST OF TABLES

ABBREVIETIONS

UAV	Unmanned Aerial Vehicle
HALE	High Altitude Long Endurance
MALE	Medium Altitude Long Endurance
TUAV	Medium Range or Tactical UAV
MUAV	Mini UAV
MAV	Micro UAV
NAV	Nano Air Vehicles
DDD	Dirty Dull Dangerous
AFCS	Automatic Flight Control System
AOA	Angle of Attack
DFMA	Design for Manufacturing and Assembly
AR	Aspect Ratio
WWII	World War II
LiPo	Lithium Polymer
IR	Internal Resistance
ESC	Electronic Speed Controller
BEC	Battery Eliminator Circuit
FM	Frequency Modulation
AM	Amplitude Modulation
AGC	Automatic Gain Control
VHF	Very High Frequency
CG	Center of Gravity
RC	Radio Controlled
PIC	Pilot In Control
CIC	Computer In Control
KIAS	Knots Indicated Airspeed
GPS	Global Positioning System
PID	Proportional Integral Derivative
VTOL	Vertical Takeoff and Landing

LIST OF SYMBOLS

L	Lift
ρ	Air density
V	Velocity
A	Area
C_L	Wing lift coefficient
q	Dynamic pressure
C_T	Airfoil lift coefficient
R_e	Reynold number
μ	Dynamic viscosity of fluid
C_{D0}	Parasite drag coefficient
AR	Aspect ratio
η	Propeller efficiency
S	Wing area
W_0	Gross weight
W_1	Weight of the aircraft
Bw	Wing span
Cw	Mean chord
C_{VT}	Vertical tail volume coefficient
C_{HT}	Horizontal tail volume coefficient
X	Inertial position of the UAV along x1 north
Y	Inertial position of the UAV along y1 east
H	Altitude of the aircraft
Vp	Pressure airspeed
Φ	Roll angle
Θ	Pitch angle
Ψ	Yaw angle
P	Body fixed roll rate
Q	Body fixed pitch rate
R	Body yaw rate
Ax	X accelerometer

Yx	Y accelerometer
Zx	Z accelerometer

1. INTRODUCTION

1.1. Overview

An Unmanned Aircraft can be defined as an aerial vehicle that uses aerodynamic and propulsion forces to sustain its flight along a prescribed path without an on-board pilot. The UAV technology has the potential applications in many areas such as environmental monitoring and protection, meteorological surveillance and weather research, agriculture, mineral exploration exploitation, aerial target system, airborne surveillance for military land operations, and reconnaissance missions.

A recent progress in the supporting technologies has enabled the development of semi to fully autonomous UAV. This includes the availability of compact, lightweight, affordable motion detecting sensors essential to the flight control system and compact lightweight low-cost computing power for autonomous flight control. The common availability of Global Positioning Satellite Navigation Systems has also a direct positive impact to the navigation system development for UAVs.

Particularly, the integration of satellite navigation and inertial sensor data with flight control systems enable wider application of the UAVs. In general, the availability of global UAV knowledge-base has helped advance the frontier of this developing technology. To successfully design an autonomous UAV, core and enabling technologies have to be identified. It is well known that the core technologies for UAVs comprise airframes, propulsion systems, payloads, safety or protection systems, launch and recovery, data processor, ground control station, navigation and guidance, and autonomous flight controllers. In the ongoing research project, most of the enabling technologies are given and the effort will be centered at developing an autonomous navigation, guidance and control system for the UAV. Unmanned aircraft must not be confused with ‘drones’, as is often done by the media. A drone aircraft will be required to fly out of sight of the operator, but has zero intelligence, merely being launched into a pre-programmed mission on a pre-programmed course and a return to base. It does not communicate and the results of the mission, e.g. photographs, are usually not obtained from it until it is recovered at base.

A UAV, on the other hand, will have some greater or lesser degree of ‘automatic intelligence’. It will be able to communicate with its controller and to return payload data such as electro-optic or thermal TV images, together with its primary state information – position, airspeed, heading and altitude. It will also transmit information as to its condition, which is often referred to as ‘housekeeping data’, covering aspects such as the amount of fuel it has, temperatures of components, e.g. engines or electronics.

If a fault occurs in any of the sub-systems or components, the UAV may be designed automatically to take corrective action and/or alert its operator to the event. In the event, for example, that the radio communication between the operator and the UAV is broken, then the UAV may be programmed to search for the radio beam and re-establish contact or to switch to a different radio frequency band if the radio-link is duplexed. A more ‘intelligent’ UAV may have further programmed which enable it to respond in an ‘if that happens, do this’ manner. For some systems, attempts are being made to implement on-board decision-making capability using artificial intelligence in order to provide it with autonomy of operation, as distinct from automatic decision making.

1.2. Thesis Contribution

The main purpose of the this thesis is to design and development such an aircraft which will be cost effective, light in weight so that it can carry more payload, more stable against difficult weather condition, can able to take off without any flaps and minimum take off distance. The study also describes about the future research of the aircraft and the scope of development. It describes detailed design of an aircraft and how an autopilot system works in it. The main focus of the study is to inspire and share the technical details with the students of developing countries so that they also come forward to contribute on these projects according to their needs.

1.3. Categories of Unmanned Aircrafts

Although all UAV systems have many elements other than the air vehicle, they are usually categorized by the capability or size of the air vehicle that is required to carry out the mission. However, it is possible that one system may employ more than one type of air vehicle to cover different types of mission, and that may pose a problem in its designation. However, these definitions are constantly being changed as technology advances allow a smaller system to take on the roles of the one above. The terms currently in use cover a range of systems, from the HALE with an aircraft of 35 m or greater wing span, down to the NAV which may be of only 40 mm span. They are as follows [1]:

1.3.1. High Altitude Long Endurance

*High Altitude Long Endurance (HALE).*Over 15000 m altitude and 24+ hr endurance. They carry out extremely long-range (trans-global) reconnaissance and surveillance and increasingly are being armed. They are usually operated by Air Forces from fixed bases.

1.3.2. Medium Altitude Long Endurance

MALE – Medium Altitude Long Endurance. 5000–15000 m altitude and 24 hr endurance. Their roles are similar to the HALE systems but generally operate at somewhat shorter ranges, but still in excess of 500 km. and from fixed bases.

1.3.3. Tractical

TUAV – Medium Range or Tactical UAV with range of order between 100 and 300 km. These air vehicles are smaller and operated within simpler systems than are HALE or MALE and are operated also by land and naval forces. *Close-Range UAV* used by mobile army battle groups, for other military/naval operations and for diverse civilian purposes. They usually operate at ranges of up to about 100 km and have probably the most prolific of uses in both fields, including roles as diverse reconnaissance, target designation, NBC monitoring, airfield security, ship-to-shore surveillance, power-line inspection, crop-spraying and traffic monitoring, etc.

1.3.4. Mini

MUAV or Mini UAV – relates to UAV of below a certain mass (yet to be defined) probably below 20 kg, but not as small as the MAV, capable of being hand-launched and operating at ranges of up to about 30 km. These are, again, used by mobile battle groups and particularly for diverse civilian purposes.

1.3.5. Micro

Micro UAV or MAV. The MAV was originally defined as a UAV having a wing-span no greater than 150 mm. This has now been somewhat relaxed but the MAV is principally required for operations in urban environments, particularly within buildings. It is required to fly slowly, and preferably to hover and to ‘perch’ – i.e. to be able to stop and to sit on a wall or post. To meet this challenge, research is being conducted into some less conventional configurations such as flapping wing aircraft. MAV are generally expected to be launched by hand and therefore winged versions have very low wing loadings which must make them very vulnerable to atmospheric turbulence. All types are likely to have problems in precipitation.

1.3.6. Nano

NAV – Nano Air Vehicles. These are proposed to be of the size of sycamore seeds and used in swarms for purposes such as radar confusion or conceivably, if camera, propulsion and control sub-systems can be made small enough, for ultra-short range surveillance. However, HALE and MALE UAV and TUAV are increasingly being adapted to carry air-to-ground weapons in order to reduce the reaction time for a strike onto a target discovered by their reconnaissance. Therefore these might also be considered as combat UAV when so equipped. Other terms which may sometimes be seen, but are less commonly used today, were related to the radius of action in operation of the various classes.

1.4. Application of Unmanned Aircrafts

Before looking into UAV in more detail, it is appropriate to list some of the uses to which they are, or may be, put. They are very many, the most obvious being the following [2]:

1.4.1. Civilian Use

- Aerial photography - Film, video, still, etc.
- Agriculture - Crop monitoring and spraying; herd monitoring and driving
- Coastguard- Search and rescue, coastline and sea-lane monitoring
- Conservation - Pollution and land monitoring
- Customs and Excise - Surveillance for illegal imports
- Electricity companies - Power line inspection
- Fire Services and Forestry - Fire detection, incident control
- Fisheries - Fisheries protection
- Gas and oil supply companies - Land survey and pipeline security
- Information services - News information and pictures, feature pictures, e.g. wildlife
- Lifeboat Institutions - Incident investigation, guidance and control
- Local Authorities - Survey, disaster control
- Meteorological services - Sampling and analysis of atmosphere for forecasting, etc.
- Traffic agencies - Monitoring and control of road traffic
- Oil companies - Pipeline security
- Ordnance survey - Aerial photography for mapping
- Police authorities - Search for missing persons, security and incident surveillance
- Rivers authorities - Water course and level monitoring, flood and pollution control
- Survey organizations - Geographical, geological and archaeological survey
- Water boards - Reservoir and pipeline monitoring

1.4.2. Military Roles

1.4.2.1. Navy

- Shadowing enemy fleets
- Decoying missiles by the emission of artificial signatures
- Electronic intelligence
- Relaying radio signals
- Protection of ports from offshore attack
- Placement and monitoring of sonar buoys and possibly other forms of anti-submarine warfare

1.4.2.2. Army

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

1.4.2.3. Air Force

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

1.5. Necessities of UAV

Unmanned aircraft will only exist if they offer advantage compared with manned aircraft. An aircraft system is designed from the outset to perform a particular role or roles. The designer must decide the type of aircraft most suited to perform the roles and, in particular, whether the roles may be better achieved with a manned or unmanned solution. In other words it is impossible to conclude that UAVs always have an advantage or disadvantage compared with manned aircraft systems. It depends vitally on what the task is. An old military adage (which also applies to civilian use) links the use of UAVs to roles which are dull, dirty or dangerous (DDD) [3]. There is much truth in that but it does not go far enough. To DDD add covert, diplomatic, research and environmentally critical roles. In addition, the economics of operation are often to the advantage of the UAV.

1.5.1. Dull Roles

Military and civilian applications such as extended surveillance can be a dulling experience for aircrew, with many hours spent on watch without relief, and can lead to a loss of concentration and therefore loss of mission effectiveness. The UAV, with high resolution color video, low light level TV, thermal imaging cameras or radar scanning, can be more effective as well as cheaper to operate in such roles. The ground-based operators can be readily relieved in a shift-work pattern.

1.5.2. Dirty Roles

Again, applicable to both civilian and military applications, monitoring the environment for nuclear or chemical contamination puts aircrew unnecessarily at risk. Subsequent detoxification of the aircraft is easier in the case of the UAV. Crop-spraying with toxic chemicals is another dirty role which now is conducted very successfully by UAV.

1.5.3. Dangerous Roles

For military roles, where the reconnaissance of heavily defended areas is necessary, the attrition rate of a manned aircraft is likely to exceed that of a UAV. Due to its smaller size and greater stealth, the UAV is more difficult for an enemy air defense system to detect and more difficult to strike with anti-aircraft fire or missiles. Also, in such operations the concentration of aircrew upon the task may be compromised by the threat of attack. Loss of the asset is damaging, but equally damaging is the loss of trained aircrew and the political ramifications of capture and subsequent propaganda, as seen in the past conflicts in the Gulf. The UAV operators are under no personal threat and can concentrate specifically, and therefore more effectively, on the task in hand. The UAV therefore offers a greater probability of mission success without the risk of loss of aircrew resource. Power-line inspection and forest fire control are examples of applications in the civilian field for which experience sadly has shown that manned aircraft crew can be in significant danger. UAV can carry out such tasks more readily and without risk to personnel. Operating in extreme weather conditions is often necessary in both military and civilian fields. Operators will be reluctant to risk personnel and the operation, though necessary, may not be carried out. Such reluctance is less likely to apply with a UAV.

1.5.4. Covert Roles

In both military and civilian policing operations there are roles where it is imperative not to alert the ‘enemy’ (other armed forces or criminals) to the fact that they have been detected. Again, the lower detectable signatures of the UAV make this type of role more readily achievable. Also in this category is the covert surveillance which arguably infringes the airspace of foreign countries in an uneasy peacetime. It could be postulated that in examples such as the Gary Powers/U2 aircraft affair of 1960, loss of an aircraft over alien territory could generate less diplomatic embarrassment if no aircrew are involved.

1.5.5. Research Roles

UAVs are being used in research and development works in the aeronautical field. For test purposes, the use of UAV as small-scale replicas of projected civil or military designs of manned aircraft enables airborne testing to be carried out, under realistic conditions, more cheaply and with fewer hazards. Testing subsequent modifications can also be effected more cheaply and more quickly than for a larger manned aircraft, and without any need for changes to aircrew accommodation or operation. Novel configurations may be used to advantage for the UAV. These configurations may not be suitable for containing an aircrew.

1.5.6. Environmentally Critical Roles

This aspect relates predominantly to civilian roles. A UAV will usually cause less environmental disturbance or pollution than a manned aircraft pursuing the same task. It will usually be smaller, of lower mass and consume less power, so producing lower levels of emission and noise. Typical of these are the regular inspection of power-lines where local inhabitants may object to the noise produced and where farm animals may suffer disturbance both from noise and from sighting the low-flying aircraft.

1.5.7. Economic Reasons

Typically, an UAV is smaller than a manned aircraft used in the same role, and is usually considerably cheaper in first cost. Operating costs are less since maintenance costs, fuel costs and hangar age costs are all less. The labor costs of operators are usually lower and insurance may be cheaper, though this is dependent upon individual circumstances. An undoubted economic case to be made for the UAV is in a local surveillance role where the tasks would otherwise be carried out by a light aircraft with one or two aircrew. Here the removal of the air crew has a great simplifying effect on the design and reduction in cost of the aircraft. Typically, for two aircrew, say a pilot and observer, the space required to accommodate them, their seats, controls and instruments, is of order 1.2 m^3 and frontal area of about 1.5 m^2. An UAV to carry out the same task would require only 0.015 m^3, as a generous estimate, to house an automatic flight control system (AFCS) with sensors and computer, a stabilized high-resolution color TV camera and radio communication links. The frontal area would be merely 0.04 m^2. The masses required to be carried by the manned aircraft, together with the structure, windscreen, doors, frames, and glazing, would total at least 230 kg. The equivalent for the UAV would be about 10 kg. If the control system and surveillance sensor (pilot and observer) and their support systems (seats, displays, controls and air conditioning) are regarded as the ‘payload’ of the light aircraft, it would carry a penalty of about 220 kg of ‘payload’ mass compared with the small UAV and have about 35 times the frontal area with proportionately larger body drag. On the assumption that the disposable load fraction of a light aircraft is typically 40% and of this 10% is fuel, then its gross mass will be typically of order 750 kg. For the UAV, on the same basis, its gross mass will be of order 35 kg. This is borne out in practice. For missions requiring the carriage of heavier payloads such as freight or armament, then the mass saving, achieved by removing the aircrew, obviously becomes less and less significant.

2. AIRCRAFT BASICS

2.1. Aircraft Forces

Let’s start by looking at a passenger aircraft ignoring the take-off and landing for now and look at the main segment of the flight, called “cruise.” During this time, the plane is not getting faster or slower, it’s not getting higher or lower, and it’s not turning left or right. The plane is flying in a straight line at a constant speed. During this time there are four main forces acting on the plane, Weight, Lift, Drag and Thrust.

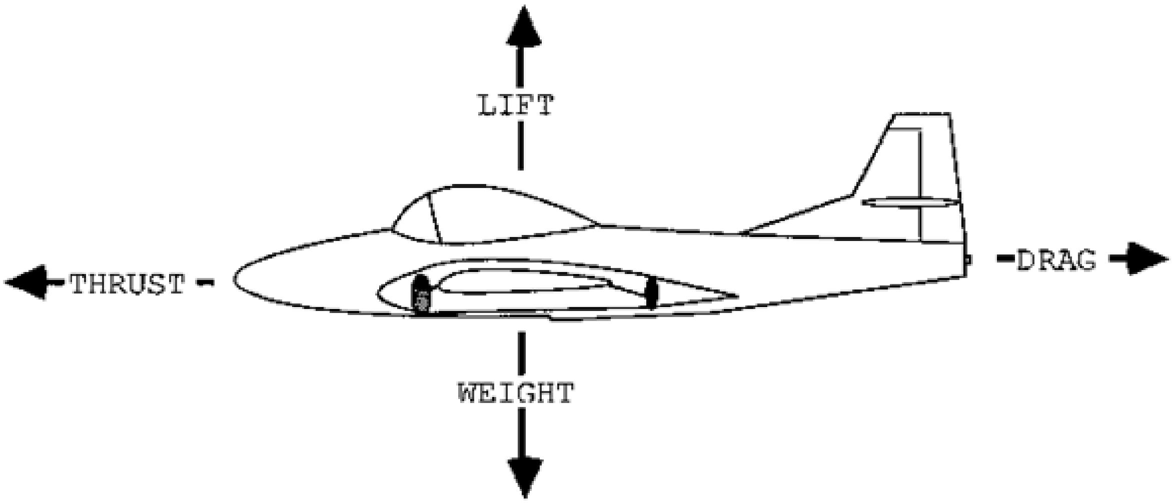


Fig. 2.1 Forces acting on aircraft [4]

2.1.1. Weight

Weight is the force produced by gravity pulling the plane towards the ground. All objects on Earth, including humans, are pulled towards the earth by gravity. The heavier the object is, the bigger this force is. If weight was the only force acting on the plane, it would fall straight down into the Earth. In order for the plane to fly, a second force must be acting on the plane to pull it upwards. We call this force lift.

2.1.2. Lift

Lift is produced by the plane as it travels through air, mostly by the plane’s wings. A plane’s wings have a special shape, called an airfoil, which forces air to flow over the top surface of the wing quicker than the bottom surface. The slow moving air beneath the wing puts more pressure on the bottom of the wing than the fast moving air on top, resulting in a force that pulls the plane up and balances the weight force.

2.1.3. Drag

Drag is also produced by the plane travelling through air. When objects move through fluids, like air and water, the fluid produces a force that opposes their motion. For instance, when you push a ball floating in water it will travel in the direction you push it, but it will slow down and eventually stop. This is because the water creates a force that pushes against the motion of the ball. Air acts the same way, so to keep a plane moving forwards at a constant speed, another force is needed to overcome drag.

2.1.4. Thrust

Thrust is the force produced by the aircraft’s engines. This force pulls the plane forward through the air and overcomes the drag force produced by the air. Aircrafts can have a variety of engines to produce thrust, but the engines usually produce thrust by turning a propeller or accelerating a stream of air. Propellers have a number of blades that rotate and create forces to pull the aircraft through the air. Each blade has an airfoil cross-section, like a wing, and generates a lift force. Jet engines often have fans that act like propellers, but they also accelerate a narrow stream of air. The air moves much faster than the plane, but it has a lower mass. The momentum added to the stream of air is balanced by momentum added to the plane, which provides the thrust force. Together, these four forces determine where the aircraft goes. For example, if the thrust force is greater than drag, the plane will accelerate. If the lift force is greater than weight, the plane will climb higher. It should be noted that the descriptions of the forces given here is very simplified.

2.2. Aircraft Components

Aircrafts have a number of different components to help them fly. As we already mentioned, the wing is responsible for generating lift. The main central body of the plane is called the fuselage. This houses the cockpit, where the pilot sits. It may also contain a cabin for passengers, or a cargo bay for carrying other items. At the rear of the fuselage are the horizontal and vertical tails (or stabilizers). These help the aircraft to fly smoothly and stay heading in one direction. One or more engines provide thrust. These engines may turn a propeller. Engines are usually located at the front of the fuselage, or below the wings if there are a number of them, but they can also be located at the rear of the fuselage, above the wing or in the wing. The components of the UAV can be divided into two parts

i. Electronic Components
ii. Mechanical Components

Electronic components consist of electrical motor, servos, electronic speed controller (ESC), battery, transmitter and receiver, camera and autopilot system. These components and their selection will be discussed in chapter 5. Later we shall conclude discussing an autopilot system. The other components are described below:

2.2.1. Fuselage

Fuselage is the main structural element of the aircraft or the body of the aircraft. The Wing, Horizontal and Vertical Tail are connected to the fuselage. The Engine is also mounted to the fuselage. The fuselage is made up of bulk-heads. The bulk-heads are structural members which give strength and rigidity to the fuselage, support load and weight of the aircraft. The engine bulk-head is made relatively stronger as compared to other bulk-heads of aircraft fuselage because it carriers the load of the engine as well as encounters vibrations during engine operation so it must be strong to resist all the loads. The nose gear and main landing gear are also connected to the fuselage. The fuselage also houses all the electronic components necessary for Aircraft flight including ESC (electronic speed controller), Receiver, Servos and Batteries. External or internal payloads are also carried inside the fuselage. The fuselage can be used to connect an external camera for example or to carry some payload inside the aircraft.

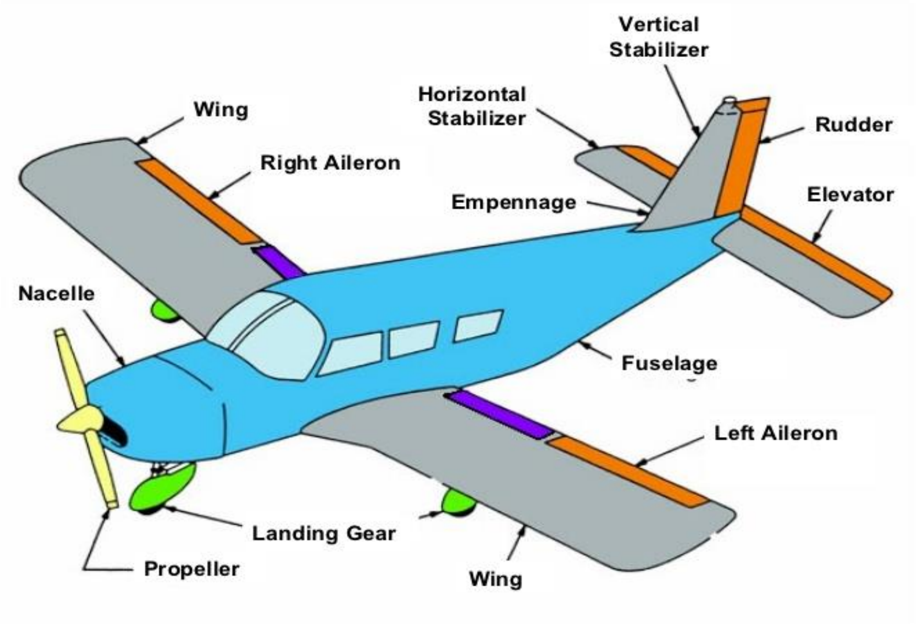


Fig. 2.2 Components of the aircraft [5]

2.2.2. Wings

Wings are the main lifting body of the aircraft providing the lift necessary for aircraft flight. The wing provides lift because of its aerodynamic shape which creates a pressure differential causing lift. If a cross-section of the wing is cut, a shape or profile is visible which is called an airfoil. Airfoil shape is the key to the wings ability to provide lift and is airfoil selection and design is an important criterion in the design of UAVs. The front most edge of the wing is known as leading edge and the back most edge of the wing is known as the trailing edge.

2.2.3. Horizontal Tail

The horizontal tail or the horizontal stabilizer provides pitch control to the aircraft. Elevator is mounted on the horizontal stabilizer or horizontal tail of the aircraft. Normally, the horizontal tail is set at a -1 degree angle of attack (AOA) relative to the wing.

2.2.4. Vertical Tail

The Vertical tail or the vertical stabilizer provides the yaw control to the Aircraft. Rudder is mounted to the vertical tail or vertical stabilizer of the Aircraft.

2.2.5. Nose Gear

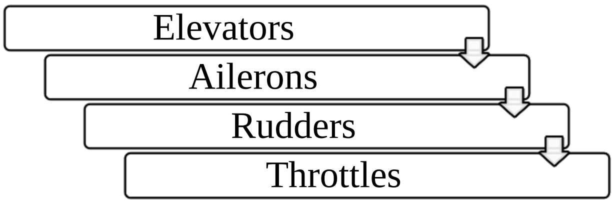
Nose gear is a member of the landing gear set on a typical conventional airplane configuration. The nose gear is used to steer the airplane nose to move airplane right or left when on the ground. The servo which connects the nose gear is also connected to the rudder. So, the direction in which the rudder moves the nose gear also follows that direction. During takeoff the nose gear is used to steer the Airplane so that airplane is centered to the runway. Without a steerable nose gear it is not possible to maneuver/ move on the ground without manually moving it. With a steerable nose gear the Airplane can be moved on the ground.

2.2.6. Landing Gear

Main Gear or Landing Gear is the main landing wheels of the aircraft which takes the entire Aircraft. Main gear have to be strong and yet flexible enough to provide safe takeoff and landing to the plane. A rigid inflexible landing gear can damage the plane structure as the entire weight / reaction force would be carried by the fuselage. So, in order to avoid this landing gears are designed to be strong yet flexible enough so they bend slightly during landing or takeoff to disperse the load and provides safe and smooth landing. Landing gear or Main gears consist of a pair of wheels which are generally larger in diameter as compared to the nose gear wheel. The landing gear wheels are not steerable.

2.3. Control Parts

As we already know which forces are acting on a plane to make it fly, we need to know how to control these forces in order to make a plane fly where we want it to. Pilots use a number of controls to do this, and some planes have different controls to others, but the aircraft has four main control systems:



2.3.1. Elevators

Elevators are located on the back of the plane’s horizontal tail and are used to make the plane climb or dive. The horizontal tail, usually at the back, has a similar shape to a wing (an airfoil) and produces lift. The purpose of the tail will be explained further but for now all we need to know is that when the tail produces more lift, the nose of the plane will go down and the plane will dive. Likewise, if the tail produces less lift, the nose of the plane will go up and the plane will climb. Elevators change the amount of lift produced by the horizontal tail by changing the shape of the airfoil. Airfoils are usually curved like an arch, and this is one of the reasons air moves slower beneath the wings than above them. The more curved an airfoil is, the more lift it will produce. By moving the elevator at the end of a wing down, the airfoil becomes more curved and produces more lift. Likewise, by moving the elevator up, the wing is effectively less curved and produces less lift.

2.3.2. Ailerons

Ailerons are located on the tips of the wings and are used to control roll. Ailerons work the same way that elevators do, by moving up and down to change the shape of the airfoil and produce more or less lift. By moving one aileron up and the other down, one wing will generate less lift than the other. The wing that generates less lift will drop, and the one that generates more will rise, and this will cause the plane to roll. When a plane rolls, the lift produced by the wings is no longer acting straight upwards, but is now acting upwards and towards the lower of the two wings. Because of this, the plane will now turn towards the low wing. Because of this, ailerons can be used to steer planes left or right.

2.3.3. Rudder(s)

A rudder is located on the plane’s vertical tail and is used to steer the plane left or right. Some aircrafts have more than one vertical tail, like the FA-18 fighter jet, and each tail has its own rudder. The vertical tail on a plane is also an airfoil shape, but the airfoil is not curved. As a result, the vertical tail does not normally generate lift. When the rudder is moved in one direction, the vertical tail is effectively curved, and produces lift. However, this lift does not act vertically, as the vertical tail is not horizontal like the wing. Lift always acts perpendicular to the wing or tail that generates it, so the lift generated by the vertical tail will act horizontally. This lift will cause the plane to rotate left or right. If the rudder is moved to the left, it will generate lift to the right, which will move the nose of the plane to the left. Rudders are often slower at turning an aircraft than the ailerons, but they can turn the aircraft without rolling it and are useful for small adjustments during takeoff, landing and other flights. Sometimes a pilot uses both the rudder and the ailerons together while turning in order to produce a smoother flight.

2.3.4. Throttle(s)

A throttle controls the thrust produced by an engine and is used to make the plane go faster or slower. Planes with more than one engine, like passenger jets, will have one throttle for each engine. The way that the throttle works depends on the type of engine, but it will generally increase the amount of fuel being consumed by the engine, which will in turn generate more heat or spin a propeller faster. Depending on the position of the engines, increasing the throttle may also cause the plane to climb, roll or turn. In fact, computer programs have been written that allow planes with two or more engines to be flown and landed using only the throttles! These programs are to help aircraft to land safely when the other controls have failed, and are not used very often.

2.4. Basic Aerodynamics

Let us first consider how an airplane stays up in the air. Although it seems to be the general view that the airplane is held in the air by the action of the propeller, it is of course, the wings that create the lift to suspend the aircraft [6]. Now if we look at the side elevation of the model in figure 2.2, we can see that the wing is set at slight angle, with the leading edge slightly higher than the trailing. When the aircraft is being propelled forward in straight and level flight in the air, when it reaches the leading edge of the wing, has to divide, some passing over the top of the wing and some underneath. The air passing beneath the wing is forced downwards, owing to the angle of incidence and because it is now in an area of relative pressure, tends to push the wing upwards [7]. Over the top of the wing there is, because of the angle of incidence and the camber of the upper wing surface, an increase in the speed of the airflow, causing an area of relatively low pressure, thus sucking the wing upwards. The combination of the area of high pressure pushing upwards and the low pressure over the wing sucking it upwards are together known as lift. About two-thirds of the wings total lift is created by the top surface of the wing and one-third from the airflow over the airflow over the lower surface [8].

3. DESIGN AND SELECTION OF THE SYSTEM

The design of most aircraft systems begin in three phases:

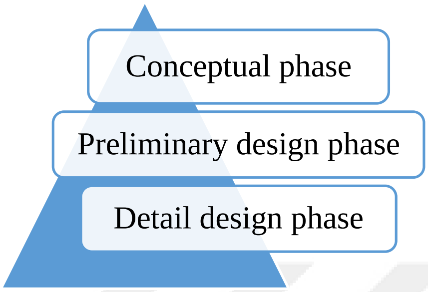


Fig. 3.1 Design phases of the aircraft [9]

Other phases follow after initial manufacture. These include the design of modifications during the development and subsequent modifications or improvements whilst the system is in service.

3.1. Conceptual Phase

Techniques of operational analysis, cost–benefit and economic studies should be used to answer in this phase. Unless a positive conclusion is obtained, the proposed program should be terminated unless changes could be made to achieve satisfactory answers or the program is fully supported by external, for example government, funding. Opportunity may be taken during this phase to carry out wind-tunnel testing of an aircraft model to confirm the theoretical aerodynamic calculations or to determine if any modification to the aircraft shape, etc. is needed. This would expedite the design in the next phase. It may be decided that the project is only viable if certain new technology is proven. This may apply, of course, to any of the elements of the system, whether it be, for example, in air vehicle control or navigation, or in computation, communications or displays. Therefore a phase of research may be conducted and the decision to proceed or not with the program will await the outcome.

3.2. Preliminary Design

Given the decision to proceed, the original outline design of the total system will be expanded in more detail. Optimization trade-offs within the system will be made to maximize the overall performance of the system over its projected operational roles and atmospheric conditions. A ‘mock-up’ of the aircraft and operator areas of the control station may be constructed in wood or other easily worked material, to give a better appreciation in three dimensions as to how components will be mounted relative to one another, ease of accessibility for maintenance and operator ergonomics, etc. This facility is becoming less necessary, however, with the availability of 3D computer design programs, though the physical appreciation obtainable from ‘real’ hardware should not be discarded lightly. It will be determined which elements of the system will be manufactured ‘in house’ and which will be procured, at what approximate cost, from alternative external suppliers.

3.3. Detail Design

At this point the work involves a more detailed analysis of the aerodynamics, dynamics, structures and ancillary systems of the aircraft and of the layout and the mechanical, electronic and environmental systems of the control station and any other sub-systems such as the launch and recovery systems. The detailed design and drawings of parts for production of each element of the system, including ground support and test equipment unless they are ‘bought-out’ items, will be made and value analysis applied.

The design of the aircraft consists of the vehicle design and design of the manufacturing plan. The vehicle design, including the electronic components, airframe structure, and vehicle assembly were drafted using Auto Cad. The CAD models include accurate weight and size of every component. The use of computer aided drafting allowed for partial design validation, and eliminated the need to construct a prototype for each of the three vehicle iterations to determine flight worthiness.

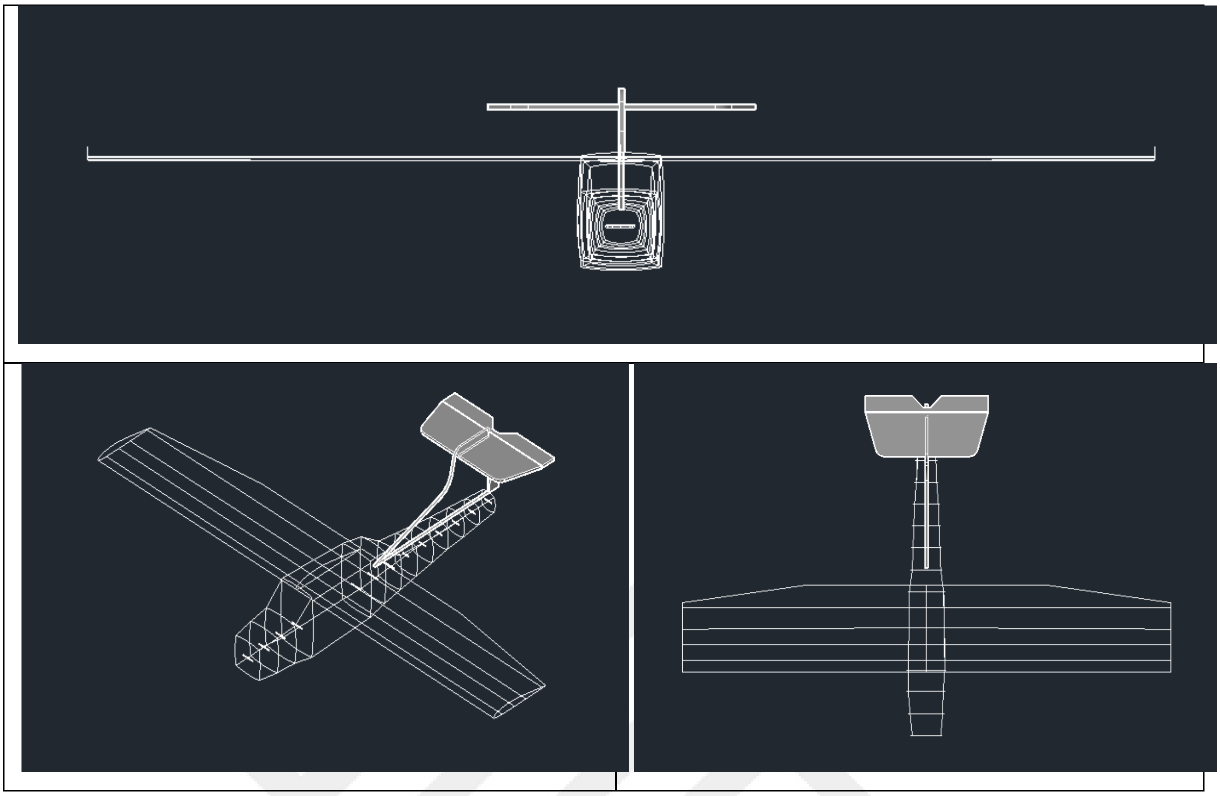


Fig. 3.2 CAD design of the aircraft

The workflow process shown in Figure 3.3 was used while designing three iterations of the airframe before moving the final design to prototype. Details of the manufacturing plan are described following the vehicle design. The design of the aircraft takes into account the necessary manufacturing and assembly processes in order to satisfy the low cost and home assembly requirements stated in the project definition. Design for Manufacturing and Assembly (DFMA) is an approach to product development that emphasizes manufacturing and assembly as part of the product design.

3.4. Vehicle Design

A goal of this project is to design the aircraft to fly using fundamental equations and widely known attributes of airplanes. The intention is not to optimize any of its features that would require significant knowledge in aerospace engineering. The design process continues the flow diagram in Figure 3.3 with the wing design.

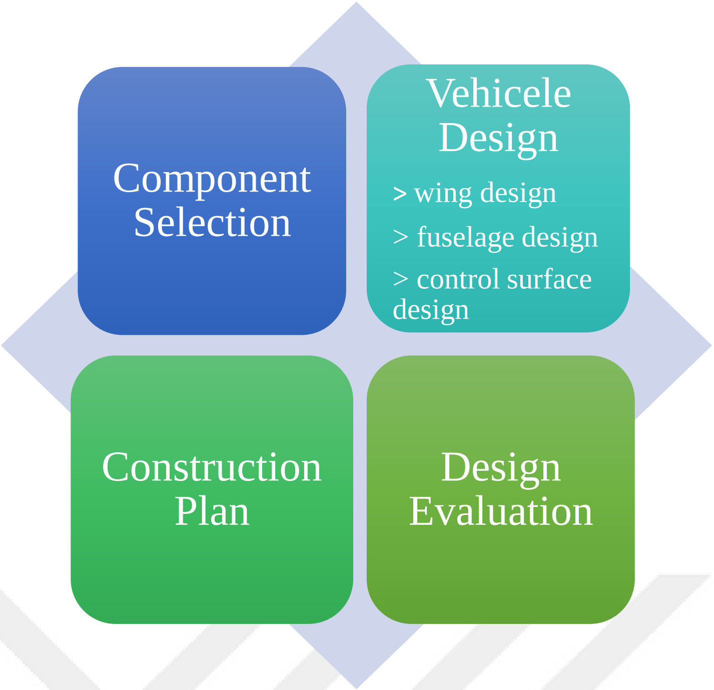


Fig. 3.3 Workflow diagram of the aircraft design [10]

3.4.1. Wing Design

The vehicle design of the aircraft begins with the wing design; the wing design begins with the fundamental equation of lift, shown in Equation 3.1. Parameters in Equation 3.1 are determined in the following paragraphs.

$$L = \frac{1}{2}\rho V^2 A C_L \tag{3.1}$$

In this equation, L is Lift, or the amount of upward force exerted on the wing. Air density ρ, represented by, varies with temperature and altitude; the aircraft is designed using a density of air at sea level and 59^0F. V represents velocity. C_L is the three dimensional coefficient of lift [11]. Before the design layout can be started, values for a number of parameters must be chosen. These include the airfoil(s), wing loading, thrust-to-weight or horsepower-to-weight ratio, estimated takeoff gross weight and fuel weight, estimated wing, tail, and engine sizes, and the required fuselage size. These are discussed in the next parts.

3.4.1.1. Aspect Ratio

The first to investigate aspect ratio in detail were the Wright Brothers using a wind tunnel they constructed. They found that a long, skinny wing (high aspect ratio) has less drag for a given lift than a short, fat wing (low aspect ratio). As most early wings were rectangular in shape, the aspect ratio was initially defined as simply the span divided by the chord. For a tapered wing, the aspect ratio is defined as the span squared divided by the area (which defaults to the earlier definition for a wing with no taper). When a wing is generating lift, it has a reduced pressure on the upper surface and an increased pressure on the lower surface. Air escaping around the wing tip lowers the pressure difference between the upper and the lower surfaces. This reduces lift near the tip. Also, the air flowing around the tip flows in a circular path when seen from the front, and in effect pushes down on the wing. Strongest near the tip, this reduces the effective angle of attack of the wing airfoils.

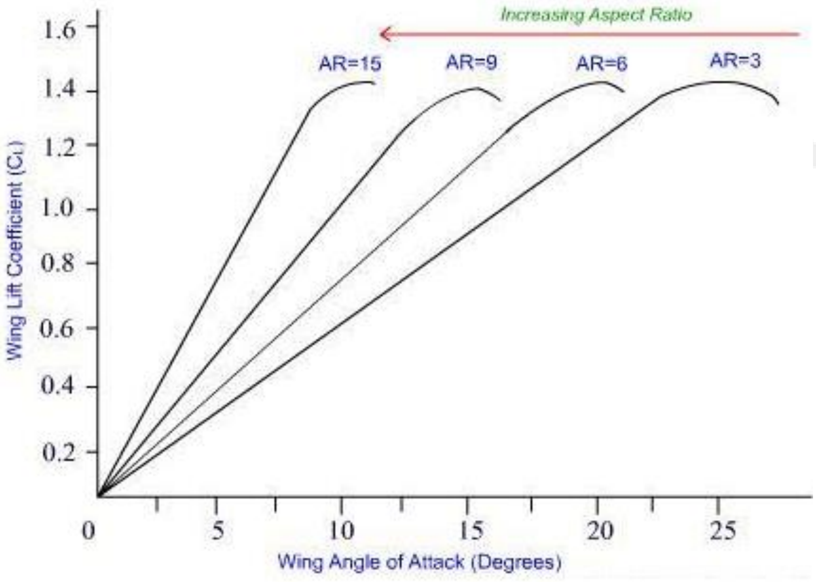


Fig. 3.4 Effect of aspect ratio on lift [12]

This circular, or "vortex" flow pattern continues downstream behind the wing. A wing with a high aspect ratio has tips farther apart than an equal area wing with a low aspect ratio. Therefore, the amount of the wing affected by the tip vortex is less for a high aspect ratio wing than for a low-aspect-ratio wing, and the strength of the tip vortex is reduced. Thus, the high aspect ratio wing does not experience as much of a loss of lift and increase of drag due to tip effects as a low aspect ratio wing of equal area. It is actually the wing span which determines the drag due to lift. However, wing area is usually held constant unless widely different aircraft concepts are being evaluated. When wing area is held constant, the wing span varies as the square root of the aspect ratio. The maximum Lift to Drag ratio (*L/D)* of an aircraft increases approximately by the square root of an increase in aspect ratio. On the other hand, the wing weight also increases with increasing aspect ratio, by about the same factor. Another effect of changing aspect ratio is a change in stalling angle. Due to the reduced effective angle of attack at the tips, a lower-aspect-ratio wing will stall at a higher angle of attack than a higher-aspect-ratio wing. This is one reason why tails tend to be of lower aspect ratio. Delaying tail stall until well after the wing stalls assures adequate control.

Table 3.1 Aspect ratio [13]

Propeller aircraft	Equivalent aspect ratio
Homebuilt	6.0
General aviation- single engine	7.6
General aviation- twin engine	7.8
Agricultural aircraft	7.5
Twin turboprop	9.2
Flying boat	8.0

*Equivalent aspect ratio = wing span squared/(wing and canard areas)

In the design process, the aspect ratio can be determined by a trade study in which the aerodynamic advantages of a higher aspect ratio are balanced against the increased weight. For initial wing layout the values provided in Table 3.1 can be used. Sailplane aspect ratio was found to be directly related to the desired glide ratio, which equals the *L /D.* Propeller aircraft showed no clear statistical trend, so average values are presented. Note that, for statistical purposes, Table 3.1 uses an equivalent wing area that includes the canard area in defining the aspect ratio of an aircraft with a lifting canard. To determine the actual wing geometric aspect ratio it is necessary to decide how to split the lifting area between the wing and canard. Typically, the canard will have about 10-25% of the total lifting area, so the wing aspect ratio becomes the statistically determined aspect ratio divided by 0.9-0.75.

3.4.1.2. Taper Ratio

Wing taper ratio is the ratio between the tip chord and the centerline root chord. Most wings of low sweep have a taper ratio of about 0.4-0.5. Most swept wings have a taper ratio of about 0.2-0.3. Taper affects the distribution of lift along the span of the wing. As proven by the Prandtl wing theory early in this century, minimum drag due to lift, or "induced" drag, occurs when the lift is distributed in an elliptical fashion. For an untwisted and unswept wing, this occurs when the wing plan form is shaped as an ellipse, an elliptical wing planform is difficult and expensive to build.

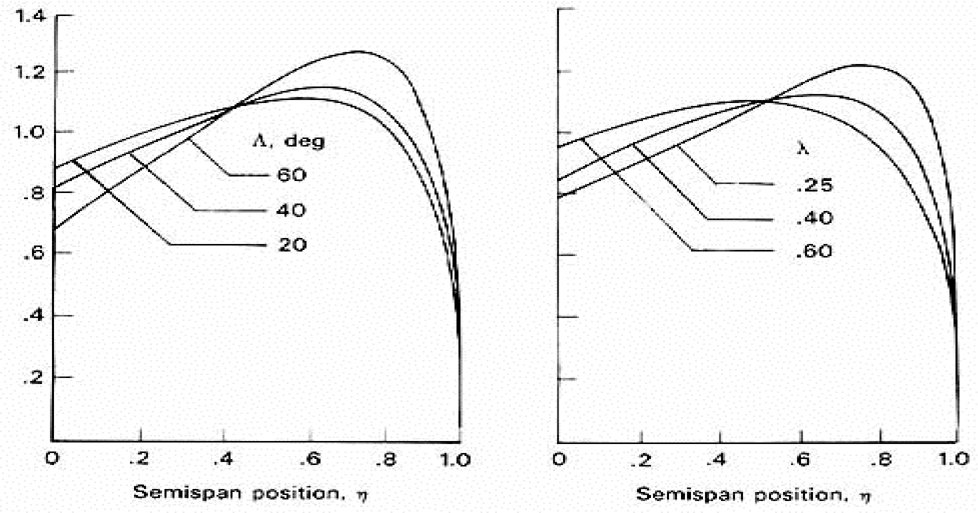


Fig. 3.5 Effect of taper on lift distribution [14]

The easiest wing to build is the untapered rectangular wing. However, the untapered wing has constant chord length along the span, and so has excessive chord towards the tip when compared to the ideal elliptical wing. This "loads up" the tip, causing the wing to generate more of its lift toward the tip than is ideal. The end result is that an untwisted rectangular wing has about 7% more drag due to lift than an elliptical wing of the same aspect ratio. When a rectangular wing is tapered, the tip chords become shorter, alleviating the undesired effects of the constant-chord rectangular wing. In fact, a taper ratio of 0.45 almost completely eliminates those effects for an unswept wing, and produces a lift distribution very close to the elliptical ideal (Fig. 3.5). This results in a drag due to lift less than 1 % higher than the ideal, elliptical wing. A wing swept aft tends to divert the air outboard, towards the tips. This loads up the tips, creating more lift outboard than for an equivalent unswept wing. To return the lift distribution to the desired elliptical lift distribution, it is necessary to increase the amount of taper (i.e., reduce the taper ratio)

3.4.2. Airfoil Selection

The airfoil, in many respects, is the heart of the aircraft. The airfoil affects the cruise speed, takeoff and landing distances, stall speed, handling qualities (especially near the stall), and overall aerodynamic efficiency during all phases of flight [15].

3.4.2.1. Airfoil Geometry

Figure 3.6 illustrates the key geometric parameters of an airfoil. The front of the airfoil is defined by a leading-edge radius which is tangent to the upper and lower surfaces. An airfoil designed to operate in supersonic flow will have a sharp or nearly-sharp leading edge to prevent a drag-producing bow shock. The chord of the airfoil is the straight line from the leading edge to the trailing edge. It is very difficult to build a perfectly sharp trailing edge, so most airfoils have a blunt trailing edge with some small finite thickness. "Camber" refers to the curvature characteristic of most airfoils. The "mean camber line" is the line equidistant from the upper and lower surfaces.

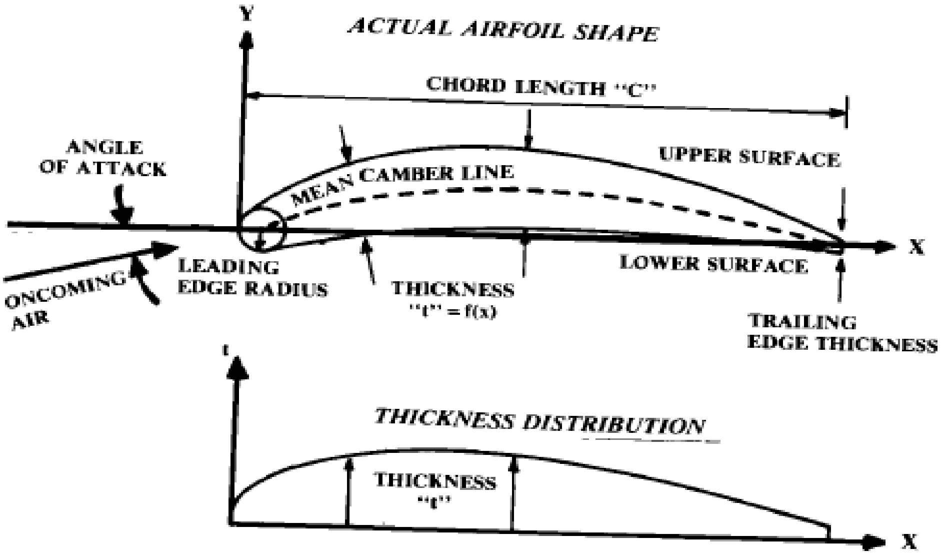


Fig. 3.6 Airfoil geometry [16]

Total airfoil camber is defined as the maximum distance of the mean camber line from the chord line, expressed as a percent of the chord. In earlier days, most airfoils had flat bottoms, and it was common to refer to the upper surface shape as the "camber." Later, as airfoils with curved bottoms came into usage, they were known as "double-cambered" airfoils. Also, an airfoil with a concave lower surface was known as an "under-cambered" airfoil. These terms are technically obsolete but are still in common usage. The thickness distribution of the airfoil is the distance from the upper surface to the lower surface, measured perpendicular to the mean camber line, and is a function of the distance from the leading edge. The "airfoil thickness ratio" *(t/c)* refers to the maximum thickness of the airfoil divided by its chord. For many aerodynamic calculations, it has been traditional to separate the airfoil into its thickness distribution and a zero-thickness camber line. The former provides the major influence on the profile drag, while the latter provides the major influence upon the lift and the drag due to lift. When an airfoil is scaled in thickness, the camber line must remain unchanged, so the scaled thickness distribution is added to the original camber line to produce the new, scaled airfoil. In a similar fashion an airfoil which is to have its camber changed is broken into its camber line and thickness distribution. The camber line is scaled to produce the desired maximum camber; then the original thickness distribution is added to obtain the new airfoil. In this fashion, the airfoil can be reshaped to change either the profile drag or lift characteristics, without greatly affecting the other.

3.4.2.2. Airfoil Lift and Drag

An airfoil generates lift by changing the velocity of the air passing over and under itself. The airfoil angle of attack and/or camber causes the air over the top of the wing to travel faster than the air beneath the wing. Bernoulli's equation shows that higher velocities produce lower pressures so the upper surface of the airfoil tends to be pulled upward by lower than ambient pressures while the lower surface of the airfoil tends to be pushed upward by higher than ambient pressures.

The integrated differences in pressure between the top and bottom of the airfoil generate the net lifting force. Figure 3.7 shows typical pressure distributions for the upper and lower surfaces of a lifting airfoil. Note that the upper surface of the wing contributes about two-thirds of the total lift.

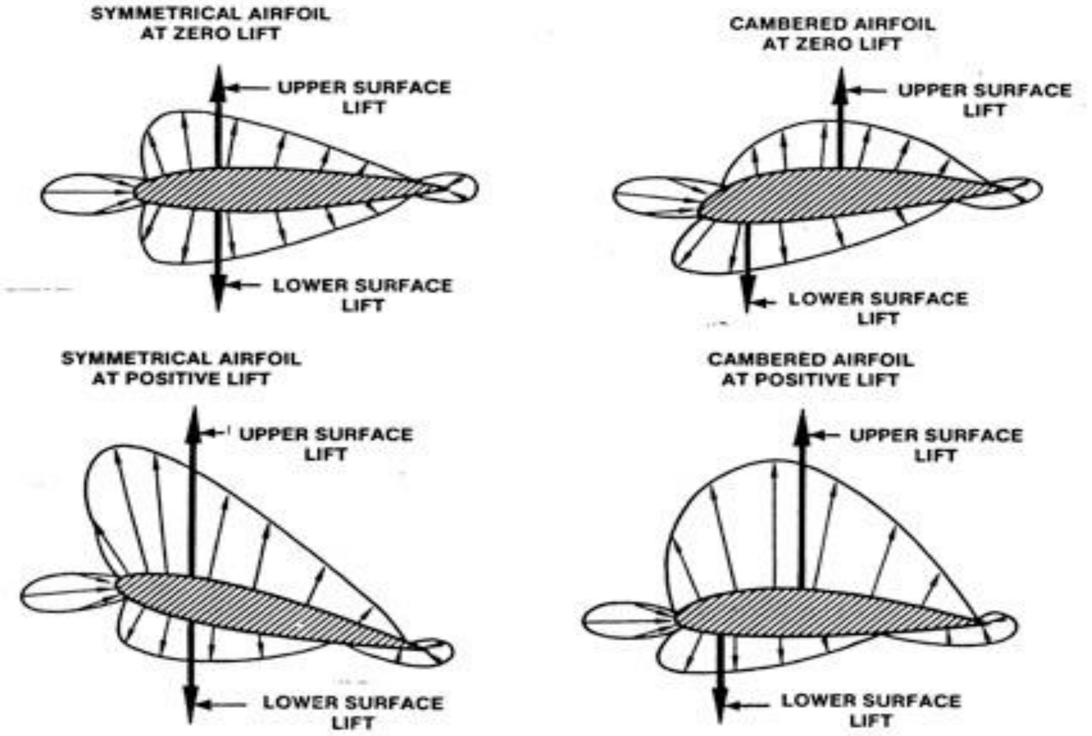
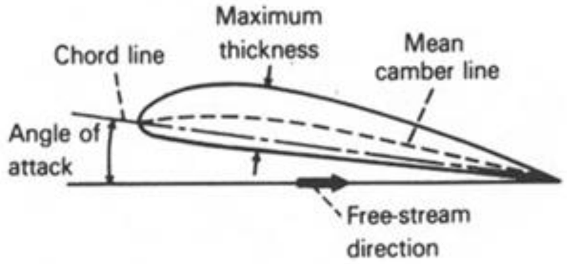


Fig. 3.7 Airfoil pressure distribution [17]

3.4.2.3. Airfoil Families

A variety of airfoils is shown in Figure 3.8. The early airfoils were developed mostly by trial and error. In the 1930's, the NACA developed a widely-used family of mathematically defined airfoils called the "four-digit" airfoils. In these the first digit defined the percent camber, the second defined the location of the maximum camber, and the last two digits defined the airfoil maximum thickness in percent of chord.

The uncambered four-digit airfoils are still commonly used for tall surfaces of most aircraft. The NACA five-digit airfoils were developed to allow shifting the position of maximum camber forward for greater maximum lift. The six-series airfoils were designed for increased laminar flow, and hence reduced drag. Six-series airfoils such as the 64A series are still widely used as a starting point for high-speed-wing design. NACA 6315 model airfoil has been chosen for the project.



(a) Wing cross section.

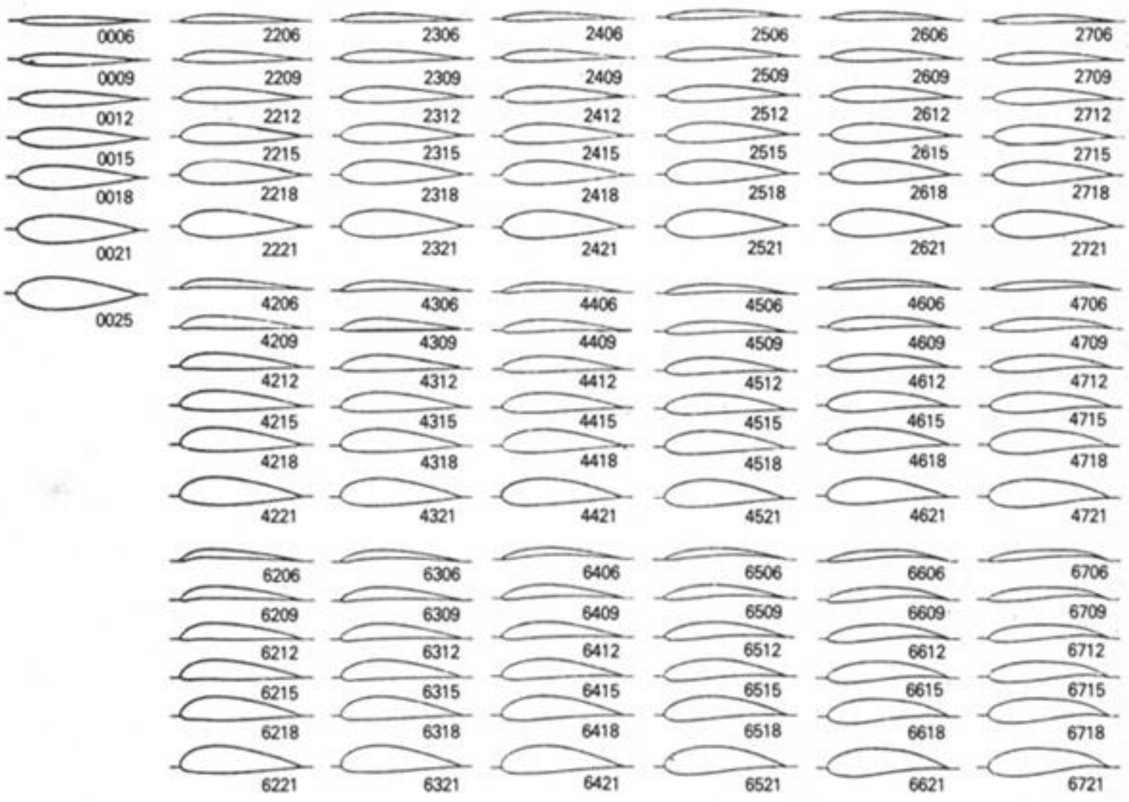


Fig. 3.8 Airfoil families [18]

3.4.2.4. Design Lift Coefficient

For early conceptual design work, the designer must frequently rely upon existing airfoils. From existing airfoils, the one should be selected that comes closest to having the desired characteristics. The first consideration in initial airfoil selection is the "design lift coefficient" This is the lift coefficient at which the airfoil has the best L/D. As a first approximation, it can be assumed that the wing lift coefficient $C_{L,}$ equals the airfoil lift coefficient, C_T. In level flight the lift must equal the weight, so the required design lift coefficient can be found as follows [19],

$$W = L = qSC_L \cong qSC_T \tag{3.2}$$

$$C_T = \frac{1}{q}\frac{W}{S} \tag{3.3}$$

Dynamic pressure *(q)* is a function of velocity and altitude. By assuming a wing loading *(W/S)* as described later, the design lift coefficient can be calculated for the velocity and altitude of the design mission. Note that the actual wing loading will decrease during the mission as fuel decreases. Thus, to stay at the design lift coefficient, the dynamic pressure must be steadily reduced during the mission by either slowing down, which is undesirable, or climbing to a higher altitude. In actual practice, a design lift coefficient usually will be based upon past experience, and for most types of aircraft typically will be around 0.5. In fact, the initial selection of the airfoil is often simply based upon prior experience or copied from some successful design.

3.4.2.5. Airfoil Thickness Ratio

Airfoil thickness ratio has a direct effect on drag, maximum lift, stall characteristics, and structural weight. The drag increases with increasing thickness due to increased separation. The thickness ratio affects the maximum lift and stall characteristics primarily by its effect on the nose shape [20]. For a wing of fairly high aspect ratio and moderate sweep, a larger nose radius provides a higher stall angle and a greater maximum lift coefficient. Thickness also affects the structural weight of the wing. Statistical equations for wing weight show that the wing structural weight varies approximately inversely with the square root of the thickness ratio. Halving the thickness ratio will increase wing weight by about 41 %. The wing is typically about 15% of the total empty weight, so halving the thickness ratio would increase empty weight by about 6%. When applied to the sizing equation, this can have a major impact. Frequently the thickness is varied from root to tip. Due to fuselage effects the root airfoil of an aircraft can be as much as 20-60% thicker than the tip airfoil without greatly affecting the drag. This is very beneficial, resulting in a structural weight reduction as well as more volume for fuel and landing gear. This thicker root airfoil should extend to no more than about 30% of the span.

3.4.2.6. Boundary Layer Behavior

It is well known that the performance of airfoils designed for chord Reynolds numbers greater than 500,000 deteriorates rapidly as the chord Reynolds number decreases below 500,000 because of laminar boundary-layer separation. Furthermore, the performance of three-dimensional wings (i.e., finite wings), as measured by *(CL=CD)max,* is less than that for airfoils. Because small UAVs operate in the chord Reynolds number regime ranging from 500,000 down to approximately 30,000, the design of efficient airfoils and wings is critical. The survey of low Reynolds number airfoils by Carmichael (1981), although two decades old, is a very useful starting point in the description of the character of the flow over airfoils over the range of Reynolds numbers of interest here.

The Reynolds' number is a ratio of the inertial force to the viscous force, or the ratio of the normal force due to aerodynamic pressure over the resistance to aerodynamic flow over the wing [21].

$$Re = \frac{\rho V L}{\mu} \tag{3.4}$$

In Equation 3.4, *Re* stands for Reynolds' number. The variable ρ is air density, L is the chord length, or the linear distance from the leading edge the trailing edge of the wing at a common cross section. The variable μ represents the dynamic viscosity of the fluid, which is air in this case. The dynamic viscosity of air at 60^0 F is: 3.75 x 10-7. Finally, estimating the velocity to be 17 mph, a reasonable stall speed and the Reynolds' number is determined to be 2.4×10^5. The following discussion of flow regimes ranging from $30{,}000 \cdot R \cdot 500{,}000$ is a modified version of Carmichael's original work. In The range $30{,}000 \cdot R \cdot 70{,}000$ is of great interest to MAV designers as well as homemade aircraft builders [22]. The choice of an airfoil section is very important in this regime because relatively thick airfoils (i.e., 6% and above) can have significant hysteresis in the lift and drag forces caused by laminar separation with transition to turbulent flow. Below chord Reynolds numbers of 50,000, the free shear layer after laminar separation normally does not transition to turbulent flow in time to reattach to the airfoil surface. When this separation point reaches the leading edge, the lift decreases abruptly, the drag increases abruptly, and the airfoil is stalled [23]. At Reynolds numbers in the range of 70,000 to 200,000, extensive laminar flow can be obtained, and therefore airfoil performance improves unless the laminar separation bubble still presents a problem for a particular airfoil. Many MAVs and small UAVs fly in this range. For *R* above 200,000, airfoil performance improves significantly because the parasite drag due to the separation bubble decreases as the bubbles get shorter. There is a great deal of experience available from large soaring birds, large radio-controlled model airplanes, and human-powered airplanes to support this claim.

3.4.3. Wing Incidence

The wing incidence angle is the pitch angle of the wing with respect to the fuselage. If the wing is untwisted, the incidence is simply the angle between the fuselage axis and the wing's airfoil chord lines. If the wing is twisted, the incidence is defined with respect to some arbitrarily chosen span wise location of the wing, usually the root of the exposed wing where it intersects the fuselage. Frequently the incidence is given at the root and tip, which then defines the twist as the difference between the two. Wing incidence angle is chosen to minimize drag at some operating condition, usually cruise. The incidence angle is chosen such that when the wing is at the correct angle of attack for the selected design condition, the fuselage is at the angle of attack for minimum drag. For a typical, circular straight fuselage, this is approximately zero degrees angle of attack.

Wing incidence angle is ultimately set using wind tunnel data. For most initial design work, it can be assumed that general aviation and homebuilt aircraft will have an incidence of about 2 degree, transport aircraft about 1 degree, and military aircraft approximately zero. Later in the design process, aero-dynamic calculations can be used to check the actual wing incidence angle required during the design condition. These values are for untwisted wings.

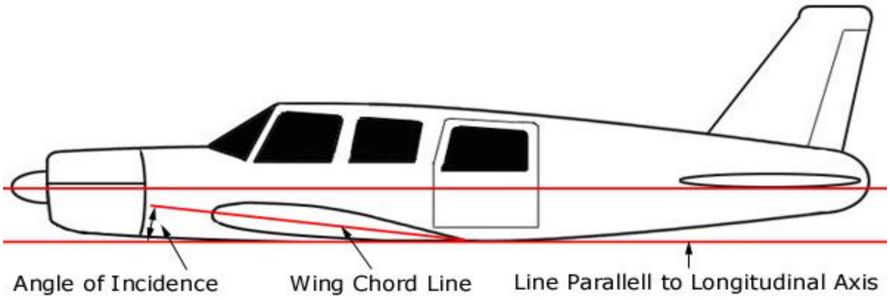


Fig. 3.9 Wing incidence [24]

For the author’s aircraft both 0 degree and 2 incident angle have been tested. For a small light weight unmanned aircraft incidence angle can be neglected according to designer’s choice. But applying a little angle increases the lift and reduces the take-off distance. On the other hand without applying any angle the aircraft can be taken off and fly without creating any problem.

3.4.4. Wing Dihedral

Wing dihedral is the angle of the wing with respect to the horizontal when seen from the front. Dihedral tends to roll the aircraft level whenever it is banked. This is frequently, and incorrectly, explained as the result of a greater projected area for the wing that is lowered. Actually, the rolling moment is caused by a sideslip introduced by the bank angle. The aircraft "slides" toward the lowered wing, which increases its angle of attack. The resulting rolling moment is approximately proportional to the dihedral angle. Wing sweep also produces a rolling moment due to sideslip, caused by the change in relative sweep of the left and right wings. For an aft-swept wing, the rolling moment produced is negative and proportional to the sine of twice the sweep angle. This creates an effective dihedral that adds to any actual geometric dihedral. Roughly speaking, 10 degree of sweep provides about 1 degree of effective dihedral. For a forward swept wing, the sweep angle produces a negative dihedral effect, requiring an increased geometric dihedral in order to retain natural directional stability. In addition, the position of the wing on the fuselage has an influence on the effective dihedral, with the greatest effect provided by a high wing. This is frequently, and incorrectly, explained as a pendulum effect. Actually, the fuselage in sideslip pushes the air over and under itself. The wing is high-mounted, the air being pushed over the top of the fuselage pushes up on the forward wing, providing an increased dihedral effect. For a high fixed wing aircraft dihedral angle plays a very important role in terms of stability when flying. Different types of wings with dihedral angle and zero angle have been implemented on the author’s aircraft. First a rectangular little angle wing was tested, the flight was really good. Later a wing with different aspect ratio but zero dihedral was tested. In that case the control was tough and was very smooth with pilot command. After that the author tested another wing providing dihedral angle thus the problems were solved. It should be noted that the wing must be flexible while mounted. A side part can be mounted both side of the wing to make the aircraft more stable while flying in difficult weather condition. Dihedral and side wing can increase drag and reduce speed of the aircraft but they provide more stability in difficult weather condition. These are also beneficial for unexperienced pilot in order to control the aircraft.

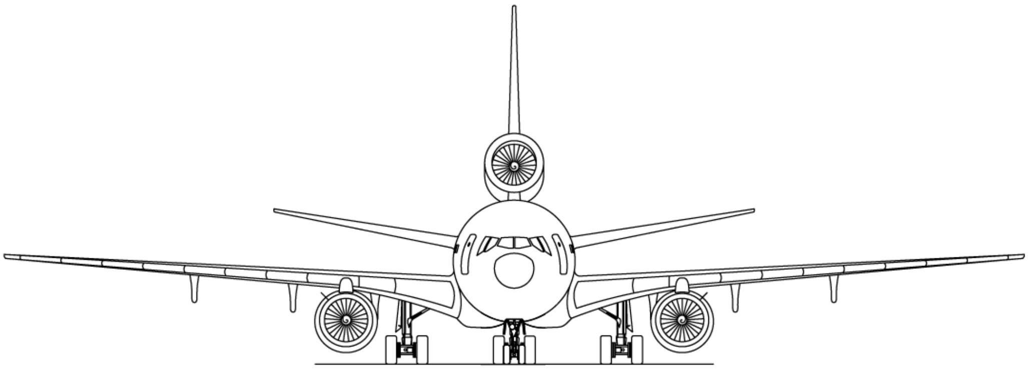


Fig. 3.10 Wing dihedral [25]

3.4.5. Tail Geometry and Arrangement

3.4.5.1. Tail Functions

Tails are little wings. Much of the previous discussion concerning wing scan also be applied to tail surfaces. The major difference between a wing and a tail is that, while the wing is designed routinely to carry a substantial amount of lift, a tail is designed to operate normally at only a fraction of its lift potential. Any time in flight that a tail comes close to its maximum lift potential. Tails provide for trim, stability, and control. Trim refers to the generation of a lift force that, by acting through some tail moment arm about the center of gravity, balances some other moment produced by the aircraft. For the horizontal tail, trim primarily refers to the balancing of the moment created by the wing. An aft horizontal tail typically has a negative incidence angle of about 2-3 degree to balance the wing pitching moment. As the wing pitching moment varies under different flight conditions, the horizontal tail incidence is usually adjustable through a range of about 3 degree up and down.

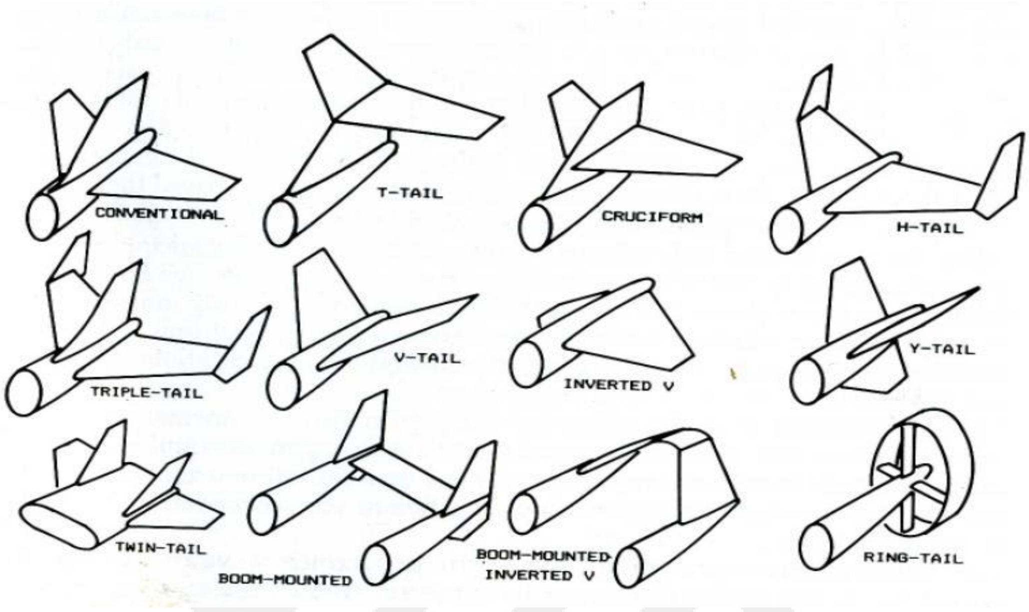


Fig. 3.11 Tail variations [26]

For the vertical tail, the generation of a trim force is normally not required because the aircraft is usually left-right symmetric and does not create any unbalanced yawing moment. The vertical tail of a multi-engine aircraft must be capable of providing a sufficient trim force in the event of an engine failure. A single-engine propeller airplane will experience a yawing moment caused by the tail itself. The propeller tends to "drag" the air into a rotational motion in the same direction that the propeller spins. Since the vertical tail is above the fuselage, it will be pushed on by the rotating prop wash, causing a nose-left motion for the normal direction of engine rotation. To counter this, some single-engine propeller airplanes have the vertical tail offset several degrees. The tails are also a key element of stability, acting much like the fins on an arrow. While it is possible to design a stable aircraft without tails, such a design is usually penalized in some other area, such as a compromised airfoil shape, excessive wing area or sweep, or narrow center-of-gravity range. The other major function of the tail is control. The tail must be sized to provide adequate control power at all critical conditions. These critical conditions for the horizontal tail or canard typically include nose wheel lift off, low-speed flight with flaps down, and transonic maneuvering. For the vertical tail, critical conditions typically include engine-out flight at low speeds, maximum roll rate, and spin recovery. Note that control power depends upon the size and type of the movable surface as well as the overall size of the tail itself.

3.4.5.2. Tail Arrangement

Figure 3.11 illustrates some of the possible variations in aft-tail arrangement. The first shown has become "conventional" for the simple reason that it works. For most aircraft designs, the conventional tail will usually provide adequate stability and control at the lightest weight. Probably 70% or more of the aircraft in service have such a tail arrangement. However, there are many reasons for considering others. The "T -tail" is also widely used. A T-tail is inherently heavier than a conventional tail because the vertical tail must be strengthened to support the horizontal tail, but the T -tail provides compensating advantages in many cases. Due to end-plate effect, the T -tail allows a smaller vertical tail. The T-tail lifts the horizontal tail clear of the wing wake and prop wash, which makes it more efficient and hence allows reducing its size. This also reduces buffet on the horizontal tail, which reduces fatigue for the structure. Finally, the T-tail is considered stylish, which is not a trivial consideration. The cruciform tail, a compromise between the conventional and T-tail arrangements, lifts the horizontal tail to avoid proximity to a jet exhaust, or to expose the lower part of the rudder to undisturbed air during high angle-of-attack conditions and spins. These goals can be accomplished with a T-tail, but the cruciform tail will impose less of a weight penalty. However, the cruciform tail will not provide a tail-area reduction due to end plate effect as will a T-tail. "H-tail" is used primarily to position the vertical tails in undisturbed air during high angle-of-attack conditions (as on the T-46) or to position the rudders in the prop wash on a multiengine aircraft to enhance engine-out control. The H-tail is heavier than the conventional tail, but its endplate effect allow smaller horizontal tail. H-tail also serves to hide the hot engine nozzles from heat seeking missiles when viewed from an angle off the rear of the aircraft. H-tails and the related triple-tails have also been used to lower the tail height to allow an aircraft such as the Lockheed Constellation to fit in to existing hangars.

The "V -tail" is intended to reduce wetted area. With a V-tail, the horizontal and vertical tail forces are the result of horizontal and vertical projections of the force exerted upon the "*V*" surfaces. For some required horizontal and vertical tail area, the required *V* surface area would be found from the Pythagorean Theorem, and the tail dihedral angle would be found as the arctangent of the ratio of required vertical and horizontal areas. The resulting wetted area of the *V* surfaces would clearly be less than for separate horizontal and vertical surfaces. When the right rudder pedal of a V-tail aircraft is pressed, the right ruddervator deflects downward, and the left ruddervator deflects upward. The combined forces push the tail to the left, so the nose goes to the right as desired. However, the ruddervators also produce a rolling moment toward the left-in opposition to the desired direction of turn, an action called "adverse roll-yaw coupling." The inverted V-tail shown in Fig. 3.11 avoids this problem, and instead produces a desirable "proverse roll-yaw coupling." The inverted V -tail is also said to reduce spiraling tendencies. This tail arrangement can cause difficulties in providing adequate ground clearance.

The "Y -tail" is similar to the V -tail, except that the dihedral angle is reduced and a third surface is mounted vertically beneath the *V*. This third surface contains the rudder, whereas the *V* surfaces provide only pitch control. This tail arrangement avoids the complexity of the ruddervators while reducing interference drag when compared to a conventional tail. An inverted Y-tail is uses primarily to keep the horizontal surfaces out of the wing wake at high angles of attack. Twin tails on the fuselage can position the rudders away from the aircraft centerline, which may become blanketed by the wing or forward fuselage at high angles of attack. Also, twin tails have been used simply to reduce the height required with a single tail. Twin tails are usually heavier than an equal-area centerline-mounted single tail, but are often more effective.

3.4.5.3. Tail Geometry

The surface areas required for all types of tails are directly proportional to the aircraft's wing area, so the tail areas cannot be selected until the initial estimate of aircraft takeoff gross weight has been made. The initial estimation of tail area is made using the "tail volume coefficient" method. Tail aspect ratio and taper ratio show little variation over a wide range of aircraft types. Table 3.2 provides guidance for selection of tail aspect ratio and taper ratio.

Table 3.2 Tail aspect and taper ratio [27]

Aircraft Type	Horizontal Tail		Vertical Tail	
	aspect ratio	taper ratio	aspect ratio	taper ratio
High speed aircraft	3-4	0.2-0.5	0.6-1.4	0.2-0.4
Sail plane	6-10	0.3-0.5	1.5-2.0	0.4-0.6
Others	3-5	0.3-0.6	1.3-2.0	0.3-0.6
T-tail	-	-	0.7-1.2	0.6-1.0

Note that T -tail aircraft have lower vertical-tail aspect ratios to reduce the weight impact of the horizontal tail's location on top of the vertical tail. Leading-edge sweep of the horizontal tail is usually set to about 5 degree more than the wing sweep. This tends to make the tail stall after the wing, and also provides the tail with a higher Critical Mach Number than the wing, which avoids loss of elevator effectiveness due to shock formation. For low speed aircraft, the horizontal tail sweep is frequently set to provide a straight hinge line for the elevator, which usually has the left and right sides connected to reduce flutter tendencies. Vertical-tail sweep varies between about 35 and 55 deg. For a low-speed aircraft, there is little reason for vertical-tail sweep beyond about 20 degree other than athletics. For a high-speed aircraft, vertical-tail sweep is used primarily to insure that the tail's Critical Mach Number is higher than the Wing's. The exact planform of the tail surfaces is actually not very critical in the early stages of the design process. The tail geometries are revised during later analytical and wind-tunnel studies. For conceptual design, it is usually acceptable simply to draw tail surfaces that look right based upon prior experience and similar designs. Tail thickness ratio is usually similar to the wing thickness ratio, as determined by the historical guidelines provided in the wing-geometry section. For a high-speed aircraft, the horizontal tail is frequently about 10% thinner than the wing to ensure that the tail has a higher Critical Mach Number. Note that a lifting canard or tandem wing should be designed using the guidelines and procedures given for initial wing design, instead of the tail design guidelines described above.

3.4.6. Power Loading Ratio

The power loading ratio (P/W) and the wing loading (W/S*)* are the two most important parameters affecting aircraft performance. Optimization of these parameters forms a major part of the analytical design activities conducted after an initial design layout. However, it is essential that a credible estimate of the wing loading and power loading ratio be made before the initial design layout is begun. Otherwise, the optimized aircraft may be so unlike the as-drawn aircraft that the design must be completely redone. Wing loading and power loading ratio are interconnected for a number of performance calculations, such as takeoff distance, which is frequently a critical design driver.

A requirement for short takeoff can be met by using a large wing (low W/S) with a relatively small engine (low P/W).While the small engine will cause the aircraft to accelerate slowly, it only needs to reach a moderate speed to lift off the ground. On the other hand, the same takeoff distance could be met with a small wing (high W/S) provided that a large engine (high P/W) is also used. In this case, the aircraft must reach a high speed to lift off, but the large engine can rapidly accelerate the aircraft to that speed. Due to this interconnection, it is frequently difficult to use historical data to independently select initial values for wing loading and power loading ratio. Instead, the designer must guess at one of the parameters and use that guess to calculate the other parameter from the critical design requirements.

In many cases, the critical requirement for wing loading will be the stall speed during the approach for landing. Approach stall speed is independent of engine size, so the wing loading can be estimated based upon stall speed alone. The estimated wing loading can then be used to calculate the (P/W) required to attain other performance drivers such as the single-engine rate of climb. For less obvious cases, the designer must guess one parameter, calculate the other parameter to meet various performance requirements, then recheck the first parameter. Table 3.3 provides reciprocal values, i.e., power loadings, for propellered aircraft. These values are all at maximum power settings at sea level and zero velocity ("static").

Table 3.3 Horsepower to weight ratio [28]

Aircraft Type	W/hp
Homebuilt UAV	12
Agricultural	11
Twin turbo prop	5
Flyingboat	10

An aircraft with a higher (P/W) will accelerate more quickly, climb more rapidly, reach a higher maximum speed, and sustain higher turn rates. Also, the engine's thrust varies with altitude and velocity. When designers speak of an aircraft's power loading ratio they generally refer to the (P/W) during sea-level static (zero-velocity), standard-day conditions at design takeoff weight and maximum throttle setting. Another commonly referred-to (P/W) concerns combat conditions. You can also calculate (P/W) at a partial-power setting. For example, during the approach to landing the throttle setting is near idle. The operating (P/W) at that point in the mission is probably less than 0.05. It is very important to avoid confusing the takeoff (P/W) with the (P/W) at other conditions in the calculations below. If a required (P/W) is calculated at some other condition, it must be adjusted back to takeoff conditions for use in selecting the number and size of the engines.

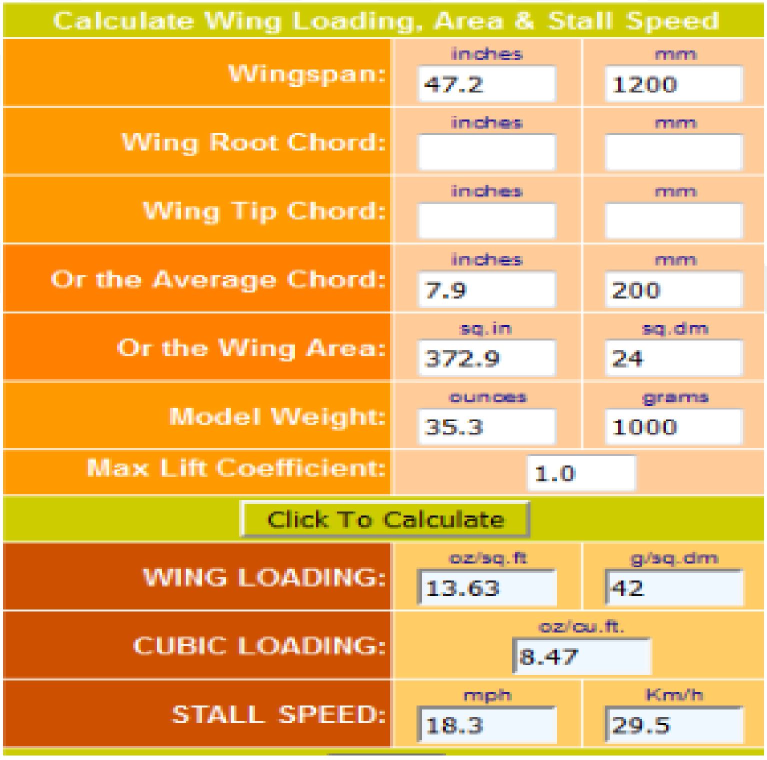
$$\frac{P}{W} = \frac{550\,np}{V} * \frac{W}{hp} \tag{3.4}$$

Power loadings typically range from 10-15 for most aircraft. An aerobatic aircraft may have a power loading of about six. A few aircraft have been built with power loadings as low as three or four. One such over-powered airplane was the Pitts Sampson, a one-of-a-kind airshow airplane. A propeller-powered aircraft produces thrust via the propeller, which has an efficiency defined as the thrust output per horsepower provided by the engine. An equivalent (P/W) for propellered aircraft can therefore be expressed as follows:

3.4.7. Wing Loading

The wing loading is the weight of the aircraft divided by the area of the reference (not exposed) wing. As with the power loading ratio, the term "wing loading" normally refers to the takeoff wing loading, but can also refer to combat and other flight conditions. Wing loading affects stall speed, climb rate, takeoff and landing distances, and turn performance. The wing loading determines the design lift coefficient, and impacts drag through its effect upon wetted area and wing span. Wing loading has a strong effect upon sized aircraft takeoff gross weight. If the wing loading is reduced, the wing is larger. This may improve performance, but the additional drag and empty weight due to the larger wing will increase takeoff gross weight to perform the mission. The leverage effect of the sizing equation will require a more-than-proportional weight increase when factors such as drag and empty weight are increased.

Table 3.4 Wing loading of the aircraft



Calculate Wing Loading, Area & Stall Speed

Wingspan: inches 47.2 mm 1200
Wing Root Chord: inches mm
Wing Tip Chord: inches mm
Or the Average Chord: inches 7.9 mm 200
Or the Wing Area: sq.in 372.9 sq.dm 24
Model Weight: ounces 35.3 grams 1000
Max Lift Coefficient: 1.0

WING LOADING: oz/sq.ft 13.63 g/sq.dm 42
CUBIC LOADING: oz/cu.ft. 8.47
STALL SPEED: mph 18.3 Km/h 29.5

Table 3.4 provides representative wing loadings. The calculation has been done by using a wing loading calculating software. Wing loading and power loading ratio must be optimized together. These allow the designer to begin the layout with some assurance that the design will not require a complete revision after the aircraft is analyzed and sized. This material generally assumes that an initial estimate of (P/W) has been made using the methods presented in the last section.

3.4.8. Aerodynamics of the Aircraft

The airfoil section and wing planform of the lifting surface are critically important to the performance of all flying vehicles. Therefore, all small UAVs share the ultimate goal of a stable and controllable vehicle with maximum aerodynamic efficiency. The aerodynamic efficiency is determined by the lift to drag ratio of the wing. Most small vehicles are designed for maximum range or endurance at a given cruising speed. For propeller-driven airplanes with reciprocating engines, the maximum range depends on the maximum lift to drag ratio as shown in Brequet's range equation.

$$\text{Range} = \frac{\eta}{c}\frac{C_L}{C_D}\ln\frac{W_0}{W_1}, \tag{3.5}$$

Where η is the propeller efficiency, c is the specific fuel consumption, $C_L=C_D$ is the lift to drag ratio, W_0 is the gross weight, and W_1 is the weight of the aircraft without fuel. Thus, the maximum range is directly dependent on the maximum value of $(C_L=C_D)$ at the cruise condition. Brequet's endurance equation for propeller-driven aircraft is

$$\text{Endurance} = \frac{\eta}{c}\frac{C_L^{3/2}}{C_D}(2\rho S)^{1/2}\left(W_1^{-1/2} - W_0^{-1/2}\right), \tag{3.6}$$

Where ρ is the air density and S is the wing area. In order to maximize endurance, one must maximize $(C_L^{3/2} = C_D)$. It should be noted that Equations (3.5) and (3.6) do not apply to electrically powered vehicles because their weight remains the same. As the aircraft related to the thesis is designed and constructed as an electric powered aircraft therefore these two equations were not considered when designing.

The actual estimation will be discussed in chapter 5. In this case the goal is to minimize the total power required from the battery for a given flight condition. The endurance is then the battery output power in watt hours divided by the total power required in watts, and the range is the endurance times the cruise velocity. The total drag on the vehicle is:

$$C_D = C_{D_0} + \frac{C_L^2}{\pi(AR)e}, \tag{3.7}$$

Where, C_{D0} is the parasite drag coefficient at zero lift and $C_L^2/(AR)e$ includes induced drag due to lift and the contribution to parasite drag due to lift. These equations point to the fact that parasite drag, including skin friction and pressure drag, on all of the vehicle's nonlifting parts must be reduced as much as possible. In order to reduce $C_L^2/(AR)e$ the aspect ratio (AR), the wingspan squared divided by the projected planform area of the wing, can be increased or the Oswald efficiency factor can be increased. Flying at a moderate lift coefficient will also reduce the induced drag (i.e., the drag due to lift). Because the maximum lift to drag ratio usually occurs at angles of attack where the lift coefficient is somewhat lower than its maximum value, and because the Oswald efficiency factor cannot be easily increased.

4. GEOMETRY SIZING

Aircraft sizing is the process of determining the takeoff gross weight and power supply (battery for the UAV) weight required for an aircraft concept to perform its design mission. Sizing is introduced in figure 4.1, in which a quick method based upon minimal information about the design was used to estimate the sizing parameters. The sizing method is limited to fairly simple design missions. An aircraft can be sized using some existing engine or a new design engine. The existing engine is fixed in size and thrust, and is referred to as a "fixed engine"

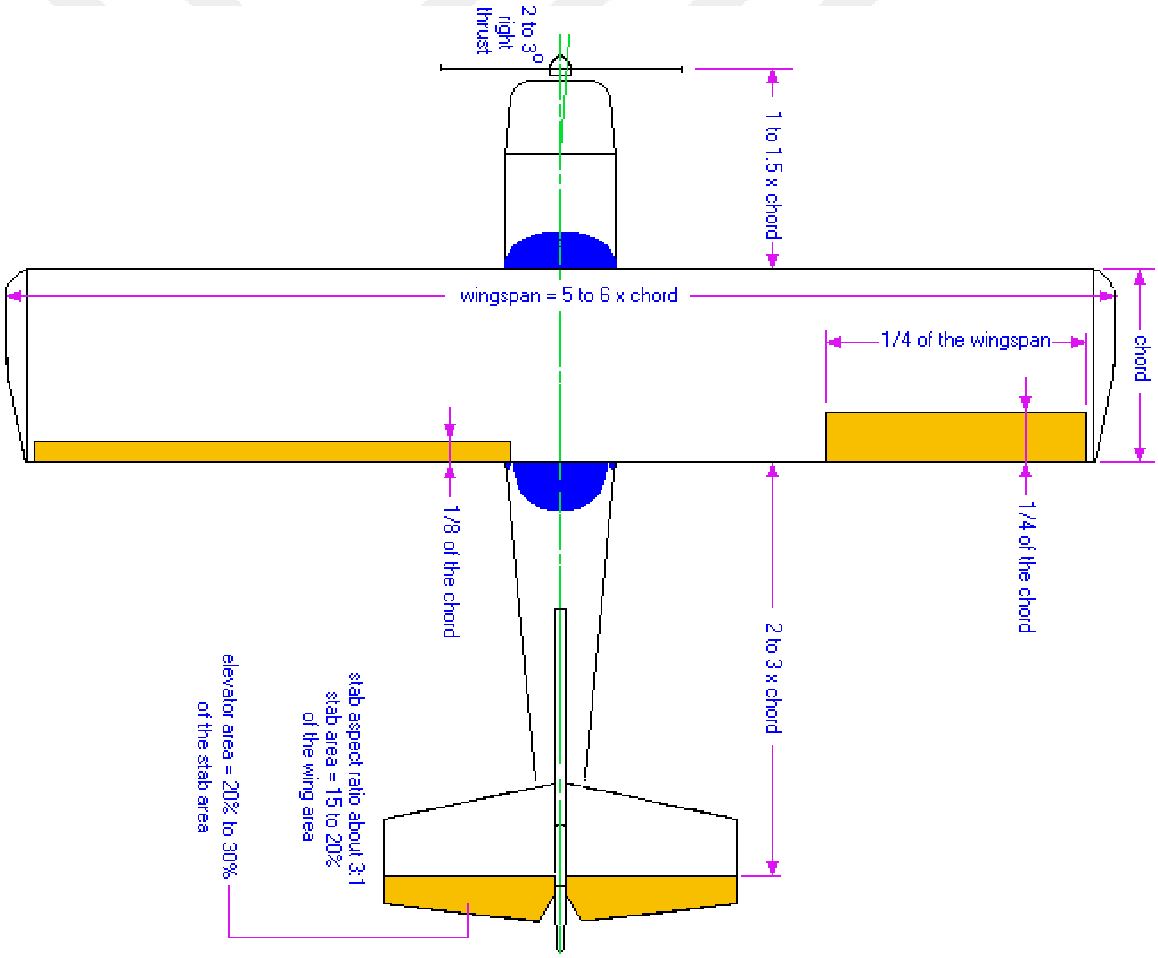


Fig. 4.1 Geometric sizing principle [29]

Geometry sizing of the UAV started setting the chord length of the UAV. According to chord length size of the wing has been set. Length and size of the fuselage, control surfaces also depend on the chord length. For a single motor fixed wing aircraft, the position of the wing also depends on size of the chord. Figure 4.1 shows the basic idea of designing and sizing of a fixed wing aircraft. The simple method of sizing the UAV is shown in figure 4.1. It is also important to determine the height of the fuselage, control surface area and the position of central of gravity. Figure 4.2 describes them.

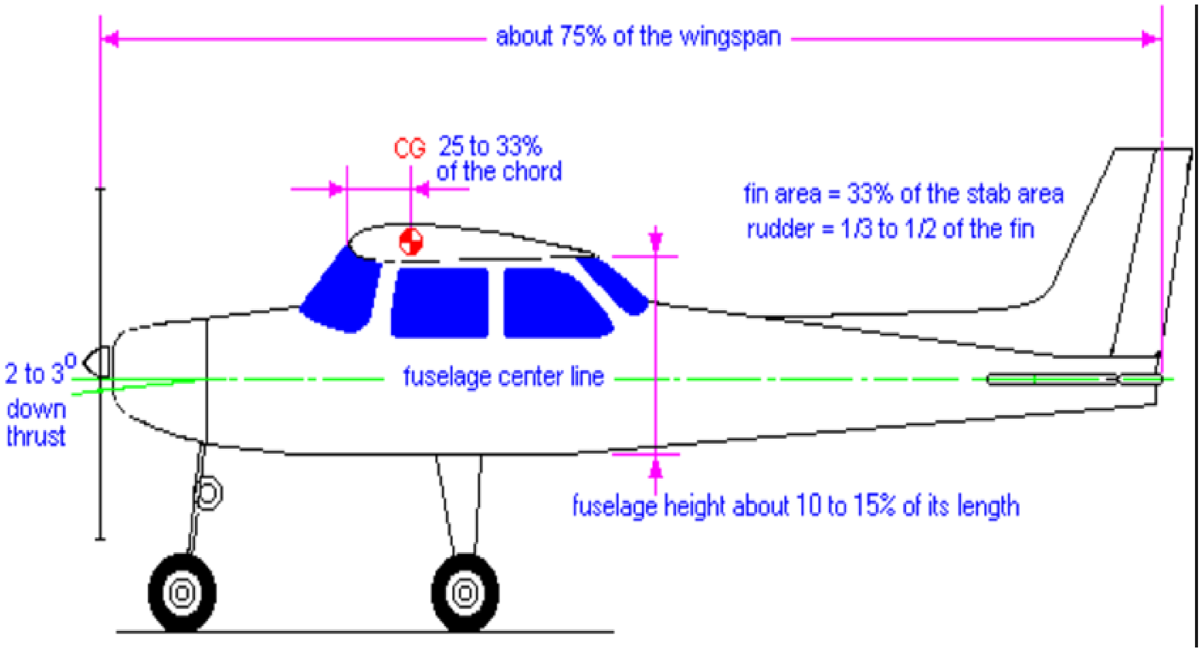


Fig. 4.2 Control surface area and position of C.G [30]

4.1. Fuselage

Once the takeoff gross weight has been estimated, the fuselage, wing, and tails can be sized. Many methods exist to initially estimate the required fuselage size. For certain types of aircraft, the fuselage size is determined strictly by "real-world constraints." For example, a large passenger aircraft devotes most of its length to the passenger compartment. Once the number of passengers is known and the number of seats across is selected, the fuselage length and diameter are essentially determined. For initial guidance during fuselage layout and tail sizing.

Table 4.1 Fuselage length vs W_0 [31]

Length = aW₀C	***a***	***C***
UAV- metal/wood	3.68	0.23
UAV- composite	3.50	0.23
Agricultural aircraft	4.04	0.23
Twin turboprop	0.37	0.51
Flying boat	1.05	0.40

Table 4.1 provides statistical equations for fuselage length. These are based solely upon takeoff gross weight, and give remarkably good correlations to most existing aircraft. Fuselage fineness ratio is the ratio between the fuselage length and its maximum diameter. If the fuselage cross section is not a circle, an equivalent diameter is calculated from the cross-sectional area.

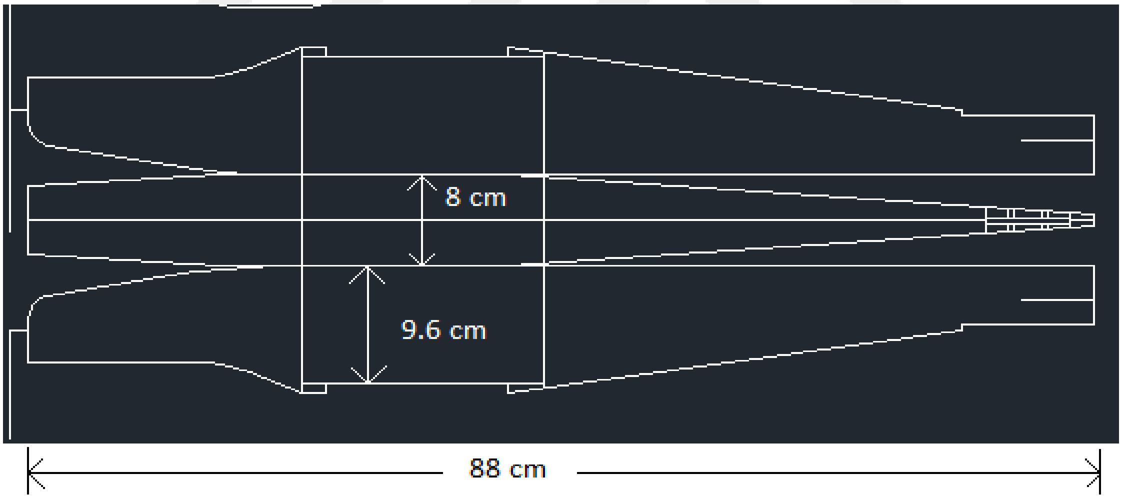


Fig. 4.3 Fuselage design and sizing the of the aircraft

A historically-derived fuselage fineness ratio can be used, along with the length estimate, to develop the initial fuselage layout. However, "real world constraints" such as payload envelope must take priority. For most design efforts the realities of packaging the internal components will establish the fuselage length and diameter. Figure 4.3 shows the fuselage design and sizing of the aircraft. The fuselage length of the UAV is 88 cm, width is 8 cm and height is 9.6 cm.

4.2. Wing

The actual wing size can now be determined simply as the takeoff gross weight divided by the takeoff wing loading. Remember that this is the reference area of the theoretical, trapezoidal wing, and includes the area extending into the aircraft centerline.

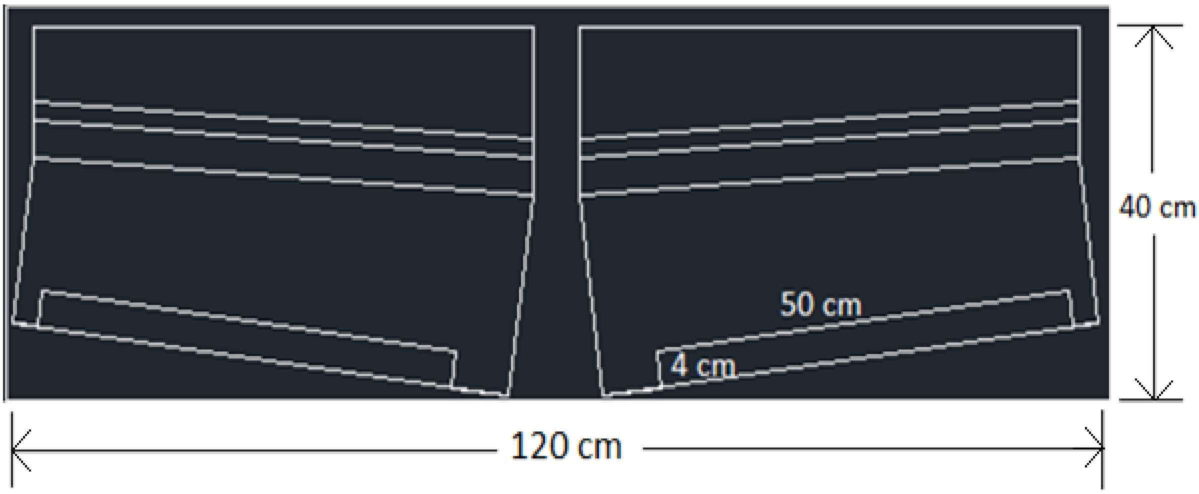


Fig. 4.4 Geometry size of the aircraft wing

Figure 4.4 shows the sizing of the wing. Here the chord average length is 20 cm. The wing has two different parts. Each part’s span is 60 cm, therefore full wing span is 120 cm. The author of the thesis tries also wing tips. As it is discussed earlier that wing tips have different benefits also they increase drag, therefore it depends on the choice of designer, aircraft model, wing shape and also weather condition and use. In the author’s aircraft no flaps been used thus two servo motors been saved. Now the question is how the aircraft takes off without using any flaps using very short distance. To increase lifting force the author increases the aileron length. In initial condition ailerons are kept some degrees up. Therefore, while running the aircraft gets enough lifting force to fly even in short distance. The ailerons are kept 4 cm width and 50 cm in length. Both rectangular plain shape and twisted shape wings are tested. For rectangular wing, wing tips were not necessary but in twisted shape wing, tips played important role in order to control the aircraft.

4.3. Tail Volume Coefficient

For the initial layout, a historical approach is used for the estimation of tail size. The effectiveness of a tail in generating a moment about the center of gravity is proportional to the force (i.e., lift) produced by the tail and to the tail moment arm. The primary purpose of a tail is to counter the moments produced by the wing. Thus, it would be expected that the tail size would be in some way related to the wing size. In fact, there is a directly proportional relationship between the two, which was presented in figure 4.1. Therefore, the tail area divided by the wing area should show some consistent relationship for different aircraft, if the effects of tail moment arm could be accounted for. The force due to tail lift is proportional to the tail area. Thus, the tail effectiveness is proportional to the tail area times the tail moment arm. This product has units of volume, which leads to the tail volume coefficient method for initial estimation of tail size. Rendering this parameter non dimensional requires dividing by some quantity with units of length. For a vertical tail, the wing yawing moments which must be countered are most directly related to the wing span *(Bw)·* This leads to the "vertical tail volume coefficient," as defined by Eq. (4.1). For a horizontal tailor canard, the pitching moments which must be countered are most directly related to the wing mean chord *(Cw)·* This leads to the "horizontal tail volume coefficient," as shown by Eq. (4.2).

$$C_{VT} = \frac{Lvt.Svt}{Bw.Sw} \tag{4.1}$$

$$C_{HT} = \frac{Lht.Sht}{Cw.Sw} \tag{4.2}$$

Note that the moment arm *(L)* is commonly approximated as the distance from the tail quarter-chord (i.e. 25% of the mean chord length measured back from the leading edge of the mean chord) to the wing quarter-chord. Observe that the horizontal tail area is commonly measured to the aircraft centerline, while a canard's area is commonly considered to include only the exposed area. If twin vertical tails are used, the vertical tail area is the sum of the two.

$$S_{VT} = C_{VT}B_W S_W / L_{VT} \tag{4.3}$$

$$S_{HT} = C_{HT}C_W S_W / L_{HT} \tag{4.4}$$

Table 4.2 provides typical values for volume coefficients for different classes of UAV and aircraft. These values (conservative are used in Eqs. (4.3) or (4.4) to calculate tail area. (Incidentally, Ref. 16 compiles a tremendous amount of aircraft data and is highly recommended for every designer's library.) To calculate tail size, the moment arm must be estimated. This can be approximated at this stage of design by a percent of the fuselage length as previously estimated. For an aircraft with a front-mounted propeller engine, the tail arm is about 60% of the fuselage length. For an aircraft with the engines on the wings, the tail arm is about 50-55% of the fuselage length.

Table 4.2 Tail volume Coefficient

Type	**Horizontal C_{HT}**	**Vertical C_{VT}**
UAV- Homebuilt	0.50	0.04
Agricultural aircraft	0.50	0.04
Twin turboprop	0.90	0.08
Flying boat	0.70	0.06

For aft-mounted engines the tail arm is about 45-50% of the fuselage length. A sailplane has a tail moment arm of about 65% of the fuselage length. For an all-moving tail, the volume coefficient can be reduced by about 10-15 %.

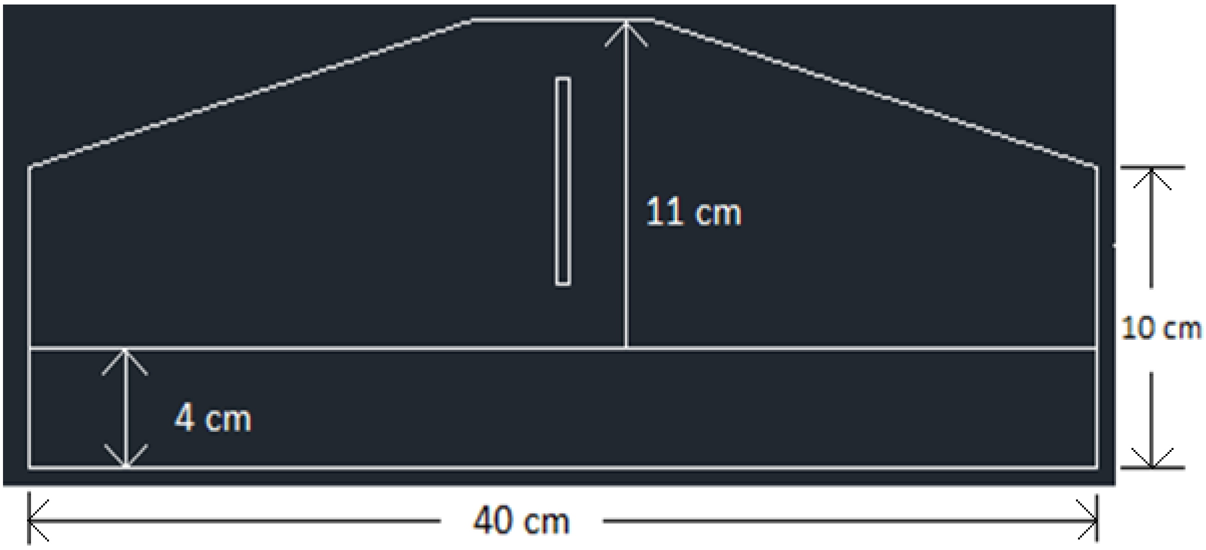


Fig. 4.5 Geometry size of the aircraft horizontal stabilizer

For a "T -tail," the vertical-tail volume coefficient can be reduced by approximately 5% due to the end-plate effect, and the horizontal tail volume coefficient can be reduced by about 5% due to the clean air seen by the horizontal. Similarly, the horizontal tail volume coefficient for an "Htail" can be reduced by about 5%. For an aircraft which uses a "V -tail," the required horizontal and vertical tail sizes should be estimated as above. Then the V surfaces should be sized to provide the same total surface area as required for conventional tails. The tail dihedral angle should be set to the arctangent of the square root of the ratio between the required vertical and horizontal tail areas. This should be near 45 deg. The horizontal tail volume coefficient for an aircraft with a control-type canard is approximately 0.1, based upon the relatively few aircraft of this type that have flown. For canard aircraft there is a much wider variation in the tail moment arm. Typically, the canarded aircraft will have a moment arm of about *30-50%* of the fuselage length.

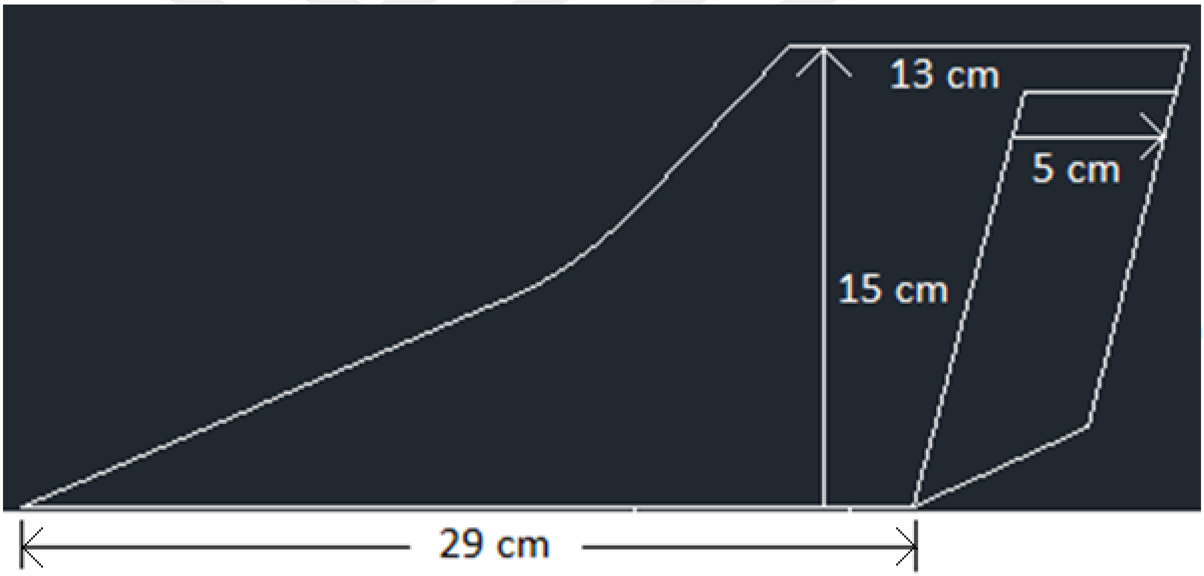


Fig. 4.6 Geometry size of the aircraft vertical stabilizer

For a lifting-canard aircraft, the volume coefficient method isn't applicable. Instead, an area split must be selected by the designer. The required total wing area is then allocated accordingly. Typically, the area split allocates about 25% to the canard and 75% to the wing, although there can be wide variation. A 50-50 split produces a tandem-wing aircraft. For an airplane with a computerized "active" flight control system, the statistically estimated tail areas may be reduced by approximately 10% provided that trim, engine-out, and nose wheel lift off requirements can be met.

In Fig. 4.5 and 4.6 horizontal and vertical tails as well as the elevator and rudder sizes are described. In vertical tail, the height of the tail is 15 cm where the length of the tail is 29 cm except the control surface. The length or volume of the tail can be reduced according to designer choice when constructing the aircraft. The frontal thinner part can be shorter. It can be noted that the longer vertical tail provides more strength to the horizontal surface, also it gives good looking to the fuselage. Other side, reduced length of the tail is easier to mount and without touching or changing the fuselage a stable empennage can be made. The control surface of the vertical tail is set to 5 cm. Its size is enough to rotate the aircraft right or left. In horizontal tail, the tail is as long as 15 cm and 40 cm width. The control surface is made 4 cm in length where the surface area is 160 cm^2. It can be noted that the lifting force depends on the control surface area of the horizontal tail. Therefore, the larger the area the higher the lifting force. The servos which control the motion of the elevator should be mounted carefully. In normal operation there must be 0^0 between the elevator and horizontal tail.

4.4. Tail Shape

The shape of the tail is fairly similar to the wing. Aircraft tail design is a complex process, and often the shape, size and position of the tail will change a few times during the design process. There are a few guidelines to designing a tail shape that will get you started on the right track, and will be good enough for most radio controlled UAVs. In the end, while some tails will work better than others, most tails will be flyable, so feel free to add your own artistic touch – this is the looking cool part I was talking about earlier. As a general rule, horizontal tails have a lower aspect ratio than the aircraft's wing. This means they are shorter and fatter. An aspect ratio between 3 and 5 is a good place to start (Fig. 4.5). The taper ratio of the horizontal tail can be similar to the wing, between 0.3 and 0.6 is a good place to start but feel free to use more or less. Draw a tail that you like the look of, then check what its aspect ratio and taper ratio are, and only change it if it's a long way outside the ranges above. Vertical tails have even lower aspect ratios, generally between 1 and 2 (Fig. 4.6) but they can be lower than 1, meaning the tail is longer than it is tall. It can be hard to judge the aspect ratio of a tail, especially on the ACE where the tail is curved, so just guess. As long as the tail's not a lot longer than it is wide it should be ok. Guidelines for taper ratio are the same as for the horizontal tail, between 0.3 and 0.6 is good.

4.5. Control Surface Sizing

Control surfaces are the parts of the aircraft, usually on the wings and tails, which help control the aircraft. We’ve already discussed the three most common and important ones – ailerons, elevators and rudders. The size of a control surface, like the size of the tail, changes a lot during design, and is usually based on complex stability and control calculations. Big control surfaces will make a plane turn, roll or climb faster, but they also cause more drag and require more force to move. If the force needed to move the control surfaces is too great, it will be very difficult to control the aircraft. This consideration is not as important for homemade UAVs, as the servo motors used to move control surfaces are usually stronger than the forces placed on the control surfaces by the passing air. There are a few key tips on how big your control surfaces should be, so we’ll look at them now. Ailerons are located close to the tips of the wings than the fuselage for the same reason that the tail is at the back of the plane. Ailerons are used to rotate the plane around the center of gravity, which is in the middle of the fuselage. Placing them near the outer edge of the wing increases this distance and therefore increases the effectiveness of the ailerons. For this reason, ailerons on a plane usually start at or near the tip and go to about half way along the wing. While the extra length doesn’t help to roll the plane quicker, it makes construction easier. Normal planes have another control surface called a flap that usually goes between the aileron and the fuselage. On most planes the aileron covers up to a quarter of the width of the wing. Elevators and rudders usually cover the whole length of the horizontal or vertical stabilizer. They can be anywhere from a quarter to half of the width of the stabilizer, with low speed aircraft having larger elevators and rudders than high speed aircraft. On the Extra 300, the rudder and elevators cover even more than half of the tails. Another thing you may notice is that the tips elevators and rudders cover the whole tail, while closer to the fuselage they only cover half. This extra area at the tip is called a horn. Many planes have them, and they are used to balance the weight of the elevator or rudder around its hinge, and also to make the rudders and elevators easier for the pilot to move. These factors aren’t important on light UAVs, so you can decide whether or not you want to include horns in your design based solely on whether you think they look cool or not. The primary control surfaces are the ailerons (roll), elevator (pitch), and rudder (yaw). Final sizing of these surfaces is based upon dynamic analysis of control effectiveness, including structural bending and control-system effects. For initial design, the following guidelines are offered. In span, the ailerons typically extend from about *50%* to about 90% of the span. In some aircraft, the ailerons extend all the way out to the wing tips. This extra 10% provides little control effectiveness due to the vortex flow at the wingtips, but can provide a location for an aileron mass balance. Wing flaps occupy the part of the wing span inboard of the ailerons. If a large maximum lift coefficient is required, the flap span should be as large as possible. One way of accomplishing this is through the use of spoilers rather than ailerons. Spoilers are plates located forward of the flaps on the top of the wing, typically aft of the maximum thickness point. Spoilers are deflected upward into the slipstream to reduce the wing's lift. Deploying the spoiler on one wing will cause a large rolling moment. Spoilers are commonly used on jet transports to augment roll control at low speed, and can also be used to reduce lift and add drag during the landing rollout. However, because spoilers have very nonlinear response characteristics they are difficult to implement for roll control when using a manual flight control system.

The UAV describing here is free of flaps. The maximum lift is managed by increasing the length of the ailerons. In case of carrying more weight initially some positive angles are given to the servos. As the ailerons initially set to a little upper, while running the aircraft gets some free lifting force that gives the aircraft maximum force to lift the maximum weight. Following the way, flaps are removed from the wing. High-speed aircraft can experience a phenomena known as "aileron reversal" in which the air loads placed upon a deflected aileron are so great that the wing itself is twisted. At some speed, the wing may twist so much that the rolling moment produced by the twist will exceed the rolling moment produced by the aileron, causing the aircraft to roll the wrong way. To avoid this, many transport jets use an auxiliary, inboard aileron for high-speed roll control. Spoilers can also be used for this purpose. Several military fighters rely upon "rolling tails" (horizontal tails capable of being deflected nonsymmetrically) to achieve the same result. Elevators and rudders generally begin at the side of the fuselage and extend to the tip of the tail or to about 90% of the tail span. High-speed aircraft sometimes use rudders of large chord which only extend to about 50% of the span. This avoids a rudder effectiveness problem similar to aileron reversal. Control surfaces are usually tapered in chord by the same ratio as the wing or tail surface so that the control surface maintains a constant percent chord. This allows spars to be straight-tapered rather than curved.

Ailerons and flaps are typically about 15-25% of the wing chord. Rudders and elevators are typically about 25-50% of the tail chord. Control-surface "flutter," a rapid oscillation of the surface caused by the airloads, can tear off the control surface or even the whole wing. Flutter tendencies are minimized by using mass balancing and aerodynamic balancing. Mass balancing refers to the addition of weight forward of the control surface hingeline to counterbalance the weight of the control surface aft of the hinge line. This greatly reduces flutter tendencies.

To minimize the weight penalty, the balance weight should be located as far forward as possible. Some aircraft mount the balance weight on a boom flush to the wing tip. Others bury the mass balance within the wing, mounted on a boom attached to the control surface. An aerodynamic balance is a portion of the control surface in front of the hinge line. This lessens the control force required to deflect the surface, and helps to reduce flutter tendencies. The aerodynamic balance can be a notched part of the control surface, an overhung portion of the control surface, or a combination of the two. The notched balance is not suitable for ailerons or for any surface in high-speed flight. The hinge axis should be no farther aft than about 20% of the average chord of the control surface. The horizontal tail for a manually-controlled aircraft is almost always configured such that the elevator will have a hinge line perpendicular to the aircraft centerline. This permits connecting the left- and right-hand elevator surfaces with a torque tube, which reduces elevator flutter tendencies. Some aircraft have no separate elevator. Instead, the entire horizontal tail is mounted on a spindle to provide variable tail incidence. This provides outstanding "elevator" effectiveness but is somewhat heavy.

5. ESTIMATION AND SELECTION OF COMPONENTS

Aircrafts have a number of different components to help them fly. As we already discussed the mechanical components in chapter 2, here we shall discuss the electronic components. As a part of electronic components an autopilot system will be discussed later. In electronic components list we used a brushless D.C. motor, 4 servo motors, an electronic speed controller (ESC), 1 LiPo battery, battery charger, transmitter and receiver, FPV system and an autopilot system.

Table 5.1 Required components for the Aircraft

Components	**Rating**	**Quantity**
Airframe	-	1
Brushless Motor	1100 kV	1
Servo	3 A	4
Electronic Speed Controller	40 A	1
LiPo Battery	3S 40 C 2200 mA	1
Transmitter	2.4 GHz	1
Receiver	12 Channel	1
FPV System	-	1
Autopilot System	-	1
Battery Charger	-	1
Propeller	11*5.5 inches	1

The estimation of components should have calculated at design process level. According to designer’s choice first the total weight of the aircraft is predicted or calculated. After that all required components are simultaneously selected. The first step in aircraft design is to determine how much a plane will weight. This may seem unusual, but an aircraft’s weight is very important, and can actually tell a lot about what a plane is designed to do. The weight is determined by working out what the plane should do – how far it needs to fly, how much payload it needs to carry, how many turns and maneuvers it needs to do – and comparing the aircraft to other aircrafts designed to do similar things. This process tells the designers how much the plane will weight, how much power it needs to carry, and how many payload it can carry.

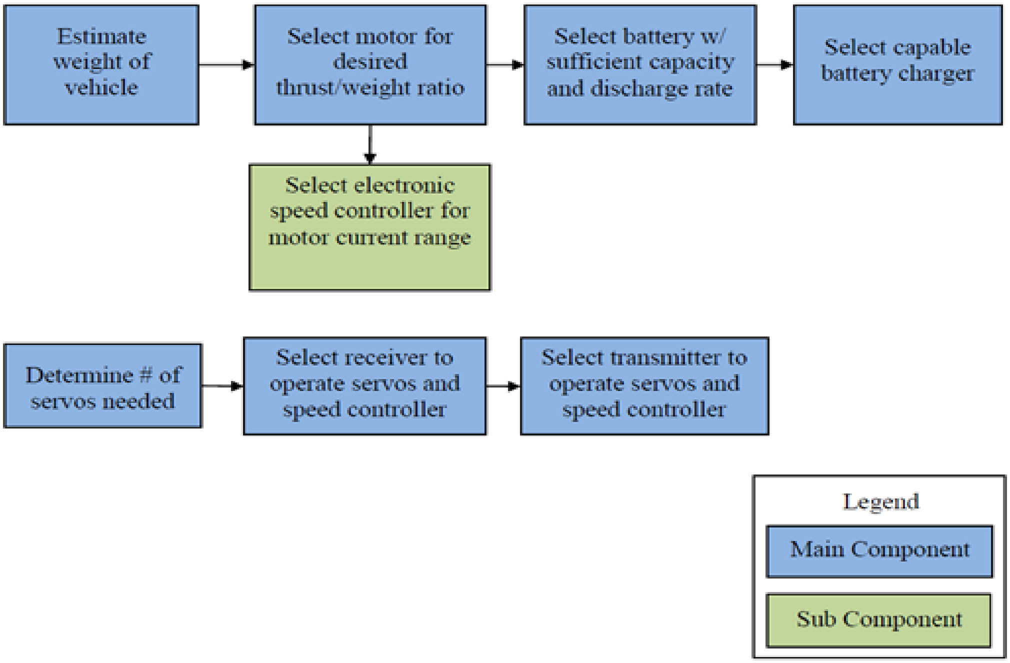


Fig. 5.1 Components selection process

Once an estimate of the aircraft's weight is found, the designer will analyze a number of flight conditions to work out how big the wing should be and how big the motor should be. Shorter runways usually need planes with bigger wings and more powerful motors or engines. This process tells designers how powerful their engine needs to be. Usually, they will then select an engine that produces enough thrust to satisfy these requirements. If the available engines are not powerful enough, they may have to change a few things about their design to make it lighter. They might decrease the range, endurance, which decreases the amount of power the plane needs to fly. Sometimes designers have a specific engine in mind before they begin design, in which case the whole process will revolve around this engine, and other things like range, payloads and performance (maximum speed, how high it flies etc.) will be adjusted to fit the engine. Whether a specific engine is chosen or not, the designer will have already decided on an engine type. This will be either electric motor or piston engine driving a propeller, or a jet engine. The jet engine may also drive a propeller, or it may just accelerate air by heating it. The choice of engine will affect the planes that the designer compares their design too during the first step of determining how much the plane will weight. Once the engine is chosen, other details like where to mount the engine, where to put power pack and what controls the pilot needs will be worked out during the rest of the design process.

5.1. Motor Selection

Once you have completed your design you need to select motor to fly your aircraft. As we mentioned earlier, motors are usually designed to be strong and slow turning or weak and fast turning. The power of a motor is the strength of the motor multiplied by the speed it turns, so two motors with the same power could be designed for completely different things, one turning fast and the other slow. Large propellers need strong, slow turning motors and small propellers need weaker, faster turning motors. With regard to size, you will probably use a motor that takes in about 100 Watts or more. If the motor manufacturer doesn’t list the wattage, multiply the voltage required by the current drawn and this will give you your power rating in watts. The motor you should get is called a “Brushless Outrunner”. These motors are more efficient than brushed motors and they spin slower, so they can be attached directly to propellers without needing a gearbox.

Product details

No.Of cells	2-3xLi-Poly
Stator dimensions	22x15mm
Shaft diameter	4mm
Weight	70g/2. 46oz
Recomended model weight	300-1100g
Recomended prop without gearbox	10x4.7 11x3.8

Model	Cell Count	RPM/V	Prop (APC)	RPM	MAX current (<60S)	Thrust
GT2215/12	3S	905	10x4.7	7450	15A	1000g 2.20lb
	3S	905	11x3.8	7000	18A	1050g 2. 31lb
GT2215/09	3S	1180	10x4. 7	8300	26A	1250g 2. 76lb
	3S	1180	10x6	8850	24A	1140g 2. 51lb

Fig. 5.2 Motor of the Aircraft

The kV rating of a motor is used to determine whether the motor should be used for strong, slow turning or weak, fast turning. The higher the kV the faster and weaker the motor will turn. Motors will usually indicate what size propeller they are designed to work with. If you’re looking at an online store, a number of details will be shown with the motor, and this should include a suggested propeller size. As a guideline, fast planes with 6x4 propellers should have a motor around 2200 kV (2000-2400 should be ok) and slow planes with 10x3.8/10x4.7 propellers should have a motor around 1000 kV (800-1200 should be ok).

5.2. Propeller Selection

Propellers come in many different sizes and shapes, and selecting the right one can be difficult. The first thing to do is to decide how fast you want your plane to go. You may have decided this already when you chose what type of plane to build. If you want to make a fast plane, like a model jet fighter, you will want a small propeller that spins very fast. If you want to make a slower plane, like an acrobatic stunt plane, you’ll want a larger propeller that spins slowly. This might seem unusual; surely a big propeller works better and pulls faster? Well, it’s not necessarily the case. Big propellers move more air every time they rotate, but this air provides resistance. This means the motor that turns it must be very strong.

As it turns out, you can have a strong motor that turns slowly or a weaker motor that turns quickly. Make sure you select a propeller designed for electric motors. If you want the motor at the front, select a normal propeller but if you want it at the back you’ll need to get a different type of propeller called a pusher. Propeller sizes are listed in inches, and usually have to numbers. The first number will tell you the diameter of the propeller, which is how long it is from tip to tip. The second number is called the pitch. The definition of pitch is confusing, but it is an indication of how steep the propeller is. A propeller with a pitch of 0 would be completely flat, and the higher the pitch the more the blades are rotated. A high pitch propeller will pull more air through each time it turns, but it will need a stronger motor. For example, an 8x5 propeller has a diameter of 8 inches and a pitch of 5 inches, so it will need a stronger motor than an 8x4 propeller.

Fig. 5.3 Propeller of the Aircraft

If you want to make a fast plane, try a 6x4 propeller. You could experiment a bit with different diameters and pitches (bigger or smaller), but this is a good place to start. A smaller propeller might make your plane go faster, but a larger one will make it accelerate faster. If you want to make a slow plane that can do plenty of tricks, try a 10x3.8 or 10x4.7 propeller. Once again you can experiment with this; a 9 inch diameter will go a little bit faster but may not climb quite as well.

5.2.1. Performance Properties of Propeller

While a propeller is a physically simple device, its performance characteristics are complex. There are four performance parameters, namely, Thrust (T), Thrust Power (Pt), Torque (Q) and Shaft Power (Ps). Considered alone performance is a function of diameter (D), pitch (p), rpm, forward velocity (V) and airfoil shape and dimensions characterized by lift (C_L) and drag (C_D) coefficients. Propeller performance theory was developed in the first half of the 20th century, reaching its zenith during WWII.

The amount of thrust generated by a propeller is minimum at the hub and maximum near the tip. The reason for this variation is due to the way the effective wind velocity varies along the blade. Refer to Fig. 5.4, on the right is an arrow labeled V parallel to the axis of rotation whose value (length) is proportional to the forward wind speed. Across the bottom is an arrow labeled $2\pi rn$ (which will be labeled V_R in what follows), which the wind speed is caused by the rotation of the propeller. Note that its value is proportional to the radius r. The two wind vectors combine to form the resultant vector V_R (which will be labeled Vp in what follows) which is the source of the pressure on the blade at r providing the lift, dL and the drag, dD. The angle of attack on the airfoil, α , is equal to the difference between the blade angle β and the angle φ formed by the wind vectors V and V_R. While V is constant, V_R varies with r so that Vp and φ vary with r as well. Another property of propellers can be derived by examination of Fig. 5.4. The angle α in the figure is the angle of attack, similar to that of a wing.The angle of attack on the airfoil, α , is equal to the difference between the blade angle β and the angle φ formed by the wind vectors V and V_R. While V is constant, V_R varies with r so that Vp and φ vary with r as well. Another property of propellers can be derived by examination of Fig. 5.4. The angle α in the figure is the angle of attack, similar to that of a wing.

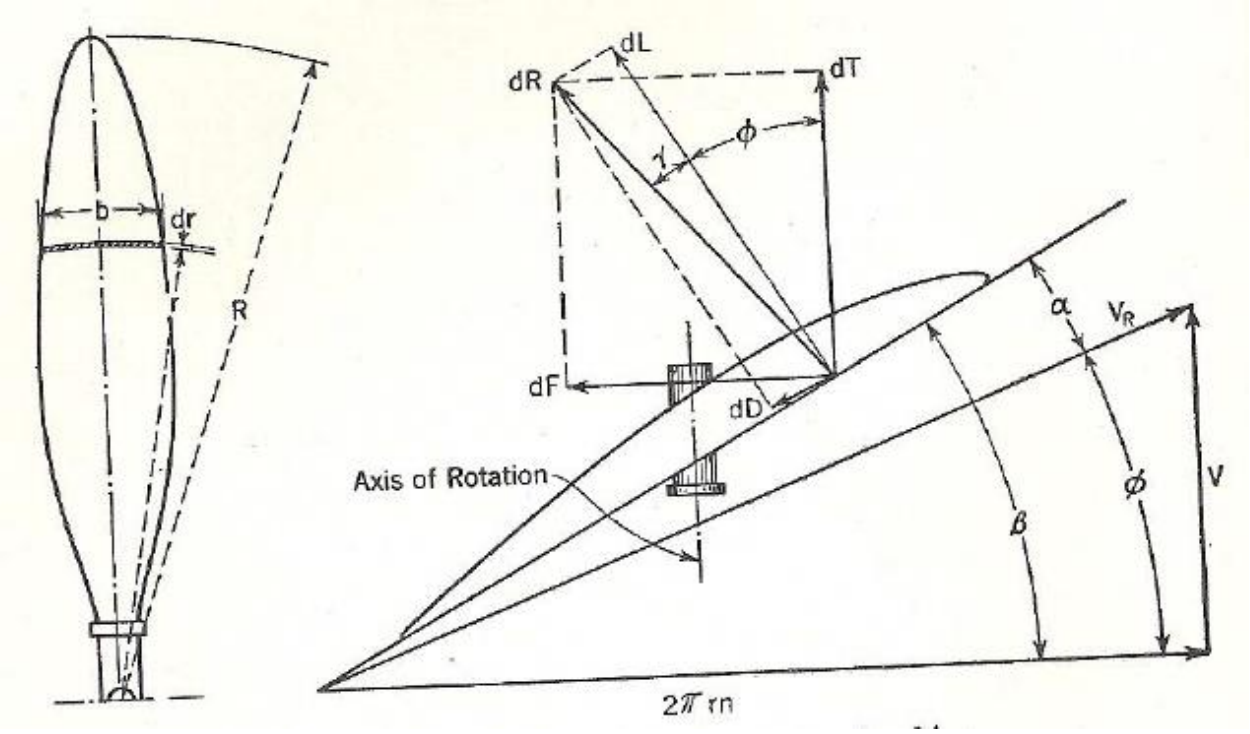


Fig. 5.4 Performance properties [32]

As it decreases the lift (in this case the thrust) decreases, eventually becoming zero. Assume for the moment that the rpm remains constant so $2\pi rn$ (the horizontal wind component) remains constant. An increase in the forward velocity V decreases α thereby decreasing the thrust. The thrust becomes zero when V =np/1056 mph where n is rpm and p is pitch in inches. Thus to achieve maximum speed increase rpm or pitch.

5.2.2. Balance Checking

Propellers must be balanced statically, dynamically, and aerodynamically. A perfectly balanced propeller will mean less vibration in your aircraft and this is very beneficial - severe vibration can cause weaknesses and failures over time, not just in the airframe but also the electronic components of the aircraft. During a propeller static balance check, all blades must be at the same blade angle. Before conducting the balance check, inspect to see that each blade has been set at the same blade angle. Unless otherwise specified by the manufacturer, an acceptable balance check requires that the propeller assembly have no tendency to rotate in any of the positions previously described. If the propeller balances perfectly in all positions, it should also balance perfectly in all intermediate positions. When necessary, check for balance in intermediate positions to verify the check in the originally describe positions.

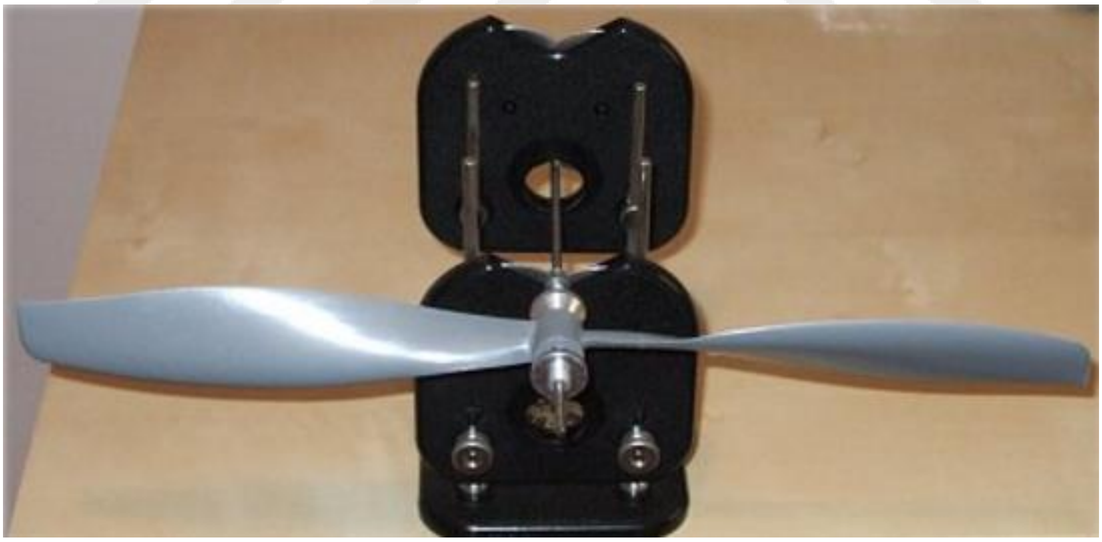


Fig. 5.5 Perfectly balanced propeller

To check the positions of a propeller you can use a balancer. One can follow the procedure: secure the propeller to be balanced in to the balancing tool (as per the instructions) and stand the tool somewhere where the propeller can hang freely. Also, it's important that there is no air movement in the room - even heavy breathing over the propeller can give you a false reading. Let the prop swing freely and let it come to a natural rest. If there is a discrepancy in weight between both blades, the heavier blade will hang lower than the lighter one. Once you've determined that there is a difference in weight between each side of the propeller, there are two ways you can attack the problem. One is to balance the hub of the propeller. This method is better for propellers of, say, 8" and upwards. Hub balancing is done by carefully drilling small holes on the lighter side of the back of the hub, and filling the holes with a liquid ballast material or small pieces of lead, or perhaps fishing shot. Obviously the lighter side will be identified when using your propeller balancer. Drill and fill one hole at a time and try the prop on the balancing tool after each time. The alternative method, especially on small diameter propellers, is to leave the hub as it is and balance the blades.

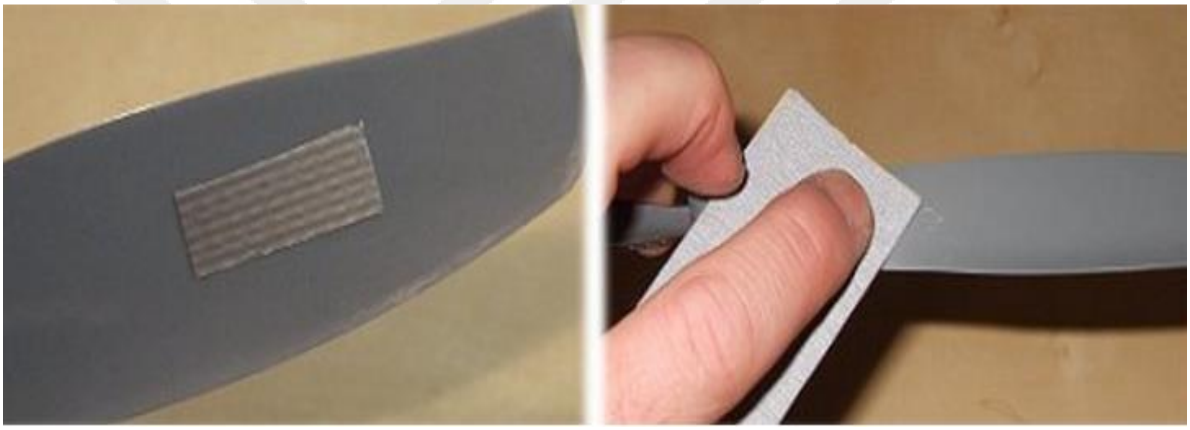


Fig. 5.6 Propeller balancing method

You can either add weight to the lighter blade, or remove weight from the heavier one. To add weight to a lighter blade, tape can be added to the back side of the blade. This quick fix but you need to be aware that, with time, the tape will likely come off. But the author has used this method and it's worked perfectly well.

5.3. Battery Selection

Choosing a battery is fairly straight forward, but should be done with caution. Batteries can be very dangerous if they’re chosen poorly or mistreated. The first thing to select about your battery is the number of cells. We have used Lithium Polymer batteries, called Li-Po’s for short. These provide the most power for the least weight out of all the commonly available batteries. Li-Po batteries commonly have anywhere from 1 to 6 cells. You should use either a 2 or 3 cell battery, depending on what your motor requires. Note that manufacturers sometimes use different codes, so a 2 cell battery may also be called a 2S battery or a 7.4 Volt battery, and a 3 cell batter may also be called a 3S battery or an 11.1 Volt battery. The next thing to select is the capacity of the battery. This will tell you how long your aircraft will fly for. Larger capacity batteries will keep a aircraft flying for longer, but they are also heavier, and they may slow a plane down and make it less manoeuvrable.

Fig. 5.7 LiPo Battery

You can choose a battery as small as about 700 mAh or as big as about 4000 mAh. A LiPo cell has a nominal voltage of 3.7 V. For the 7.4 V battery above, that means that there are two cells in series (which means the voltage gets added together). This is sometimes why you will hear people talk about a "2S" battery pack - it means that there are 2 cells in **S**eries. So a two-cell (2S) pack is 7.4V, a three-cell (3S) pack is 11.1 V, and so on. The C Rating is simply a measure of how fast the battery can be discharged safely and without harming the battery. One of the things that makes it complicated is that it's not a stand-alone number; it requires you to also know the capacity of the battery to ultimately figure out the safe amp draw (the "C" in C Rating actually stands for **C**apacity). Once you know the capacity, it's pretty much a plug-and-play math problem. Here, we can understand it much easier way. Think a pipe with water flowing through it. A big pipe can provide lots of water quickly, while a small pipe usually provides less water in the same amount of time. The C rating is like the size of the pipe – a big C rating provides lots of power quickly. You may think a bigger C rating all the time. But bigger C rating batteries are a little bit more expensive and they’re heavier, so if you don’t need it, don’t buy it. To work out what C rating you need, you’ll need to know the capacity of your battery and the maximum current your motor will draw. To find out how much current your battery can supply, multiply the C rating by the capacity of the battery (in mAh), and divide by 1000. This will give you a maximum current, in Amps. This current should be greater than the maximum current your motor might use, with a bit extra just in case.

5.3.1. Internal Resistance

There is one very important rating we haven't talked about yet: Internal Resistance (or IR). Problem is, you won't find the IR rating anywhere on the battery. That's because the internal resistance of a battery changes over time, and sometimes because of the temperature. However, just because you can't read the rating on the battery doesn't mean it isn't important. In a way, the internal resistance is one of the most important ratings for a battery. To understand why the IR is important, we have to understand what it is. In simple terms, Internal Resistance is a measure of the difficulty a battery has delivering its energy to your motor and speed control (or whatever else you have a battery hooked up to). The higher the number, the harder it is for the energy to reach its preferred destination. The energy that doesn't "go all the way" is lost as heat. So the internal resistance is kind of a measure of the efficiency of the battery. Measuring the IR of your battery requires a special toolset. You either need a charger that will measure it for you or a tool that specifically measures internal resistance. Some chargers measure each cell's IR separately, and some measure the entire battery pack as a whole. Since internal resistance is a cumulative effect, and the cells are wires in series, if you have a charger that does each cell independently, you need to add up the IR values of each cell. The first reason internal resistance is important has to do with your battery's health. As a LiPo battery is used, a build of up Li_2O forms on the inside terminals of the. As that build up occurs, the IR goes up, making the battery less efficient. After many, many uses, the battery will simply wear out and be unable to hold on to any energy you put in during charging - most of it will be lost as heat. If you've ever seen a supposed fully charged battery discharge almost instantly, a high IR is probably to blame.

5.4. Charger Selection

It's important to use a LiPo compatible charger for LiPos. Normally, LiPo batteries require specialized care. They charge using a system called CC/CV charging. It stands for Constant Current / Constant Voltage. Basically, the charger will keep the current, or charge rate, constant until the battery reaches its peak voltage (4.2v per cell in a battery pack). Then it will maintain that voltage, while reducing the current

Fig. 5.8 LiPo compatible battery charger

On the other hand, NiMH and NiCd batteries charge best using a pulse charging method. Charging a LiPo battery in this way can have damaging effects, so it's important to have a LiPo-compatible charger. The second reason that you need a LiPo-compatible charger is balancing. Balancing is a term we use to describe the act of equalizing the voltage of each cell in a battery pack. We balance LiPo batteries to ensure each cell discharges the same amount. This helps with the performance of the battery. It is also crucial for safety reasons. Most LiPo batteries need to be charged rather slowly, compared to NiMH or NiCd batteries. While we would routinely charge a 3000 mAh NiMH battery at four or five amps, a LiPo battery of the same capacity should be charged at no more than three amps. Just as the C Rating of a battery determines what the safe continuous discharge of the battery is, there is a C Rating for charging as well. For the vast majority of LiPo’s, the Charge Rate is 1C**.** The equation works the same way as the previous discharge rating, where 1000mAh = 1A. So, for a 3000mAh battery, we would want to charge at 3A, for a 5000mAh LiPo, we should set the charger at 5A, and for a 4500mAh pack, 4.5A is the correct charge rate. Now you have a 6S 5000mAh battery and you want to charge it at 1C, which would be 5A. If you have a compatible AC/DC charger you can set up the charger to charge at 5A for a 6S battery. But when you go to charge the battery, you may find that your charger is not providing the power you need. To calculate the power equation:

22.2V * 5A = 111W

The formula is saying that if we want to charge our 6S 5000mAh LiPo pack at 5A, we would need a charger that is capable of delivering at least 111W of power.

5.5. Electronic Speed Controller Selection

An electronic speed control or ESC is an electronic circuit with the purpose to vary an electric motor's speed, its direction and possibly also to act as a dynamic brake. ESCs are often used on electrically powered radio controlled models, with the variety most often used for brushless motors essentially providing an electronically generated three-phase electric power low voltage source of energy for the motor [33]. Electronic speed controller controls how fast your airplane’s motor spins. It serves the same purpose as the throttle servo of a glow powered airplane. It’s an interface between the airplane’s radio receiver and the power plant. An ESC will have three sets of wires. One leas will plug into your airplane’s main battery. The second lead will have a standard servo wire that plugs into the throttle channel of your receiver. And finally, the third set of wires actually power the motor. Most modern ESCs incorporate a battery eliminator circuit (or BEC) to regulate voltage for the receiver, removing the need for separate receiver batteries. BECs are usually either linear or switched mode. ESCs, in a broader sense, are PWM controllers for electric motors. The ESC generally accepts a nominal 50 Hz PWM servo input signal whose pulse width varies from 1 ms to 2 ms. When supplied with a 1 ms width pulse at 50 Hz, the ESC responds by turning off the motor attached to its output. A 1.5 ms pulse-width input signal drives the motor at approximately half-speed. When presented with 2.0 ms input signal, the motor runs at full speed.

Fig. 5.9 Electronic speed controller

ESC systems for brushed motors are very different by design; as a result brushed ESC's are not compatible with brushless motors. Brushless ESC systems basically create a tri-phase AC power output of limited voltage from an onboard DC power input, to run brushless motors by sending a sequence of AC signals generated from the ESC's circuitry, employing a very low impedance for motors, otherwise called outrunners or inrunners depending on their physical configuration, have become very popular with "electroflight" radio-control aeromodeling because of their efficiency, power, longevity and light weight in comparison to traditional brushed motors. However, brushless AC motor controllers are much more complicated than brushed motor controllers.

Table 5.2 Estimation of the ESC

Components	Max Current	Number	Total Current
Brushless Motor	25 A	1	25 A
Servo Motor	3 A	4	12 A
Required Electronic Speed Controller			>37 A
ESC used for the Aircraft			40 A

The correct phase varies with the motor rotation, which is to be taken into account by the ESC: Usually, back EMF from the motor is used to detect this rotation, but variations exist that use magnetic (Hall Effect) or optical detectors. Computer-programmable speed controls generally have user-specified options which allow setting low voltage cut-off limits, timing, acceleration, braking and direction of rotation. Reversing the motor's direction may also be accomplished by switching any two of the three leads from the ESC to the motor. ESCs designed for radio-control airplanes usually contain a few safety features. If the power coming from the battery is insufficient to continue running the electric motor the ESC will reduce or cut off power to the motor while allowing continued use of ailerons, rudder and elevator function. This allows the pilot to retain control of the airplane to glide or fly on low power to safety.

5.6. Radio System Selection

The radio system consist of a transmitter, receiver, servos, a battery and an electronic speed controller. As the battery and ESC has been described in previous sections. Now we shall discuss transmitter, receiver and servos. The pilot of the aircraft controls the model by a radio link, which means by using electromagnetic radiation. Basically the radio controlled equipment consists of a Transmitter operated by the pilot and the airborne units consisting in a Receiver together with one or more Servos depending on the number of channels used and a Battery pack. A typical radio controlled Transmitter has about 6 channels with at least 4 of them being proportional, which means the controlled surfaces or devices will move proportionally to the movements of the control sticks. Additional channels may function only in "on-off" manner like a switch, and are usually used to actuate retractable landing gears, airbrakes, lamps, etc. The example below shows a six channel radio controlled Transmitter with two joysticks (left/right and up/down movement) enabling four proportional channels, while the fifth channel is of switch type (on/off). The example shows the mode two configuration (most common) having the elevator control on the right joystick and the motor throttle on the left one. The right joystick self-centers in the both axis, whereas the left joystick only self-centers in left/right axis and "clicks" in the up/down axis in order to allow the throttle setting. The mode one configuration has the elevator control on the left joystick and the throttle on the right one. Most modern Transmitters have "dual-rate" facility, which means the pilot may change the max throw angle of the control surfaces during the flight, e.g. the max throw may be reduced when flying fast and increased when flying slow.

Fig. 5.10 2.4 GHz Transmitter

The possibility to choose exponential movement may be featured in some types. Many Transmitters have a servo-reversing feature, which facilitates the servo linkage assembly. Other feature such as channel mixing enables V-tail configuration and flaperons. Some Transmitters include a microprocessor and memory, enabling the user to save different model configurations and settings. Another facility is the so-called buddy box, which allows two compatible transmitters being connected by a cable. This is used for training purposes where a transmitter is held by the instructor and the other by the student. The student may control the model as long as the instructor holds down a push-button on his/her own transmitter. Should the student get in trouble, the instructor releases the push-button, and quickly takes over the control. The transmitter converts the pilot's movements into a radio signal in a process called modulation. The transmitter then broadcasts this signal to the receiver. The receiver inside the airplane picks up this signal the same way the radio in your car picks up the local radio station. The receiver pulls the information from the radio waves and relays this information to each servo. The movement of the servo is directly proportional to the movement of the control sticks on the transmitter. In other words, the control surface on the airplane move exactly the way you move the stick on the transmitter.

Fig. 5.11 Servo function

The servos and receiver battery simply plug into the receiver. Most people add a switch between the battery and receiver which is mounted to the side of the airplane. The switch allows you to turn the receiver off without removing the battery when you're not flying. A switch with a charging harness allows you to charge the battery without removing it.

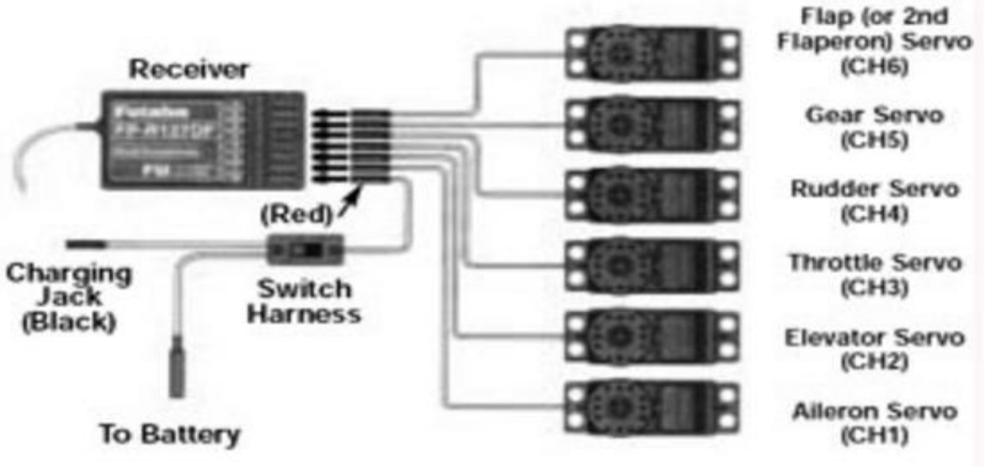


Fig. 5.12 Connection between servos and receiver [34]

There are several Frequency Bands allocated for Radio Control depending on the country. Each Frequency Band is divided in several Channels. In USA the Frequency Band for homemade Aircraft is 72 MHz, Channels 11 to 60 with 20 KHz separation. And for surface models (Cars, Boats, and Robots etc) is 75MHz, Channels 61 to 90. A recent technology in the radio system is called "Spread Spectrum". This is a radio system that can be used without having to worry about what frequency you're on. For example, the Futaba 2.4GHz system comes with a unique, permanent ID code that is preset at the factory. Pushing the Easy Link button locks the receiver to the transmitter using that code. It's the only code that it will recognize - and since it has over 134 million possible codes, there's no chance of a signal conflict. Most radio systems today use frequency modulation (FM) as it better rejects interference than the earlier amplitude modulation (AM). Frequency Modulation means that the Transmitter sends data by changing its carrier frequency with a deviation of for ex. +/- 1.5 KHz from its nominal value. The Transmitter RF power output combined with the Receiver sensitivity and selectivity are the main factors that influence the transmitting quality and the range limit of a particular outfit.

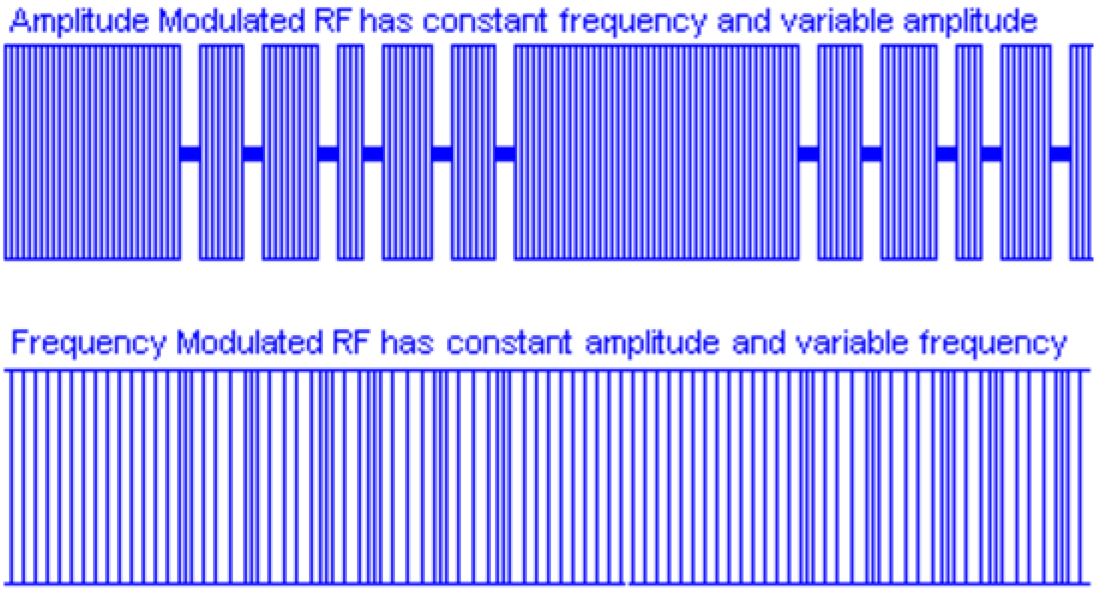


Fig. 5.13 AM and FM signals

The Transmitter aerial is part of the final RF amplifier stage tuned circuit. The aerial has a natural frequency resonance dependent upon its length. Since at 35MHz the physical length corresponding to a wavelength is 8.6 meters, the designers choose alternatives of 1/2 or 1/4 wavelength aerials in order to be more practical for a hand held transmitter, despite the small reduction in radiation efficiency. Aerial efficiency may be improved if the designer fits a loading coil to increase the effective length. The coil may either be located at base of the aerial inside the transmitter case or outside, part away along the aerial length. The latter is more efficient but makes aerial replacement more difficult since re-tuning is needed. There's a null in the radiation at the tip of a straight vertical rod aerial, so the pilot should avoid pointing the aerial tip towards the model when flying at a greater distance. In order to achieve a good selectivity the Receiver design is often based on Superheterodyne principle. There are two types: The Single Conversion and the Double Conversion. The block diagram below shows a typical Single Conversion Superheterodyne Receiver. The Receiver's RF stage is tuned to the transmitter's frequency and also may or not include a RF tuned amplifier. A local crystal controlled oscillator operates at frequency usually 455 kHz below the incoming RF signal.

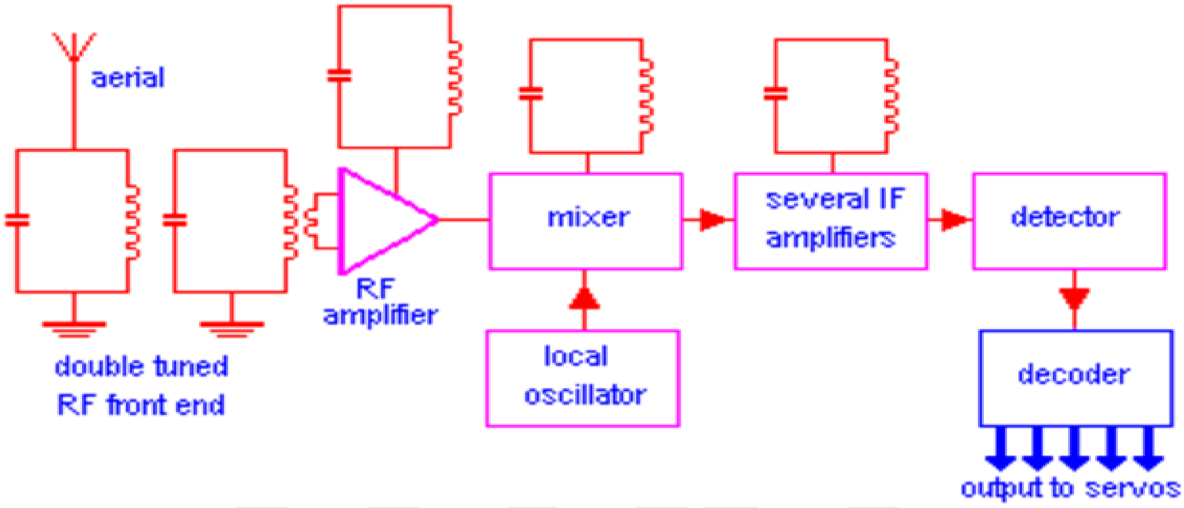


Fig. 5.14 Single conversion superheterodyne receiver

The local oscillator's frequency is mixed with the incoming RF signal at the mixer stage and the difference of these two frequencies is amplified by several tuned Intermediate Frequency circuits IF. In case of an AM receiver it is required an Automatic Gain Control (AGC) for the IF stage. The data received is detected at detector stage and send to the decoder, which in turn delivers it to each Servo. However, the Single Conversion Superhterodyne Receiver has some drawbacks that may cause problems in model control applications. The mixer stage produces a 455 kHz output from both the incoming RF signal and also from a signal 455 kHz below the local oscillator frequency. This signal is called the "image" and will cause interference if it enters the receiver.There are also a number of other signal combinations that may cause the generation of 455 kHz IF such as, Second, Third, Fourth etc. harmonics of the operating frequency and similar harmonics of the local oscillator plus and minus 455 kHz may also cause problems. Many of these drawbacks can be overcome by using a Double Conversion Superheterodyne Receiver. This concept uses two Intermediate Frequencies (IF) and two crystal controlled oscillators.

Fig. 5.15 Servo motor

The first Intermediate Frequency is higher than 455 kHz, typically 10.7 MHz. Signals that could cause spurious responses are now beyond the passband of the RF stage. A second mixer reduces the 10.7 MHz to 455 kHz to obtain a good selectivity. Due to its complexity, increased costs and added weight, such a design is not widespread among the manufactured VHF equipment, but under some severe operating conditions it may give the only solution to reliable performance. Receivers are available in different shapes, sizes and weights.

6. CONSTRUCTION OF THE AIRCRAFT

The basic understanding of the aerodynamic concepts and the correct scaling down methods can enable a designer to build a successful aircraft. This construction has an advantage of understanding the properties of the materials used, mechanisms design, concept creation and grading the components. The quality of the materials has to be given consideration for long life of the flight and better functionality.

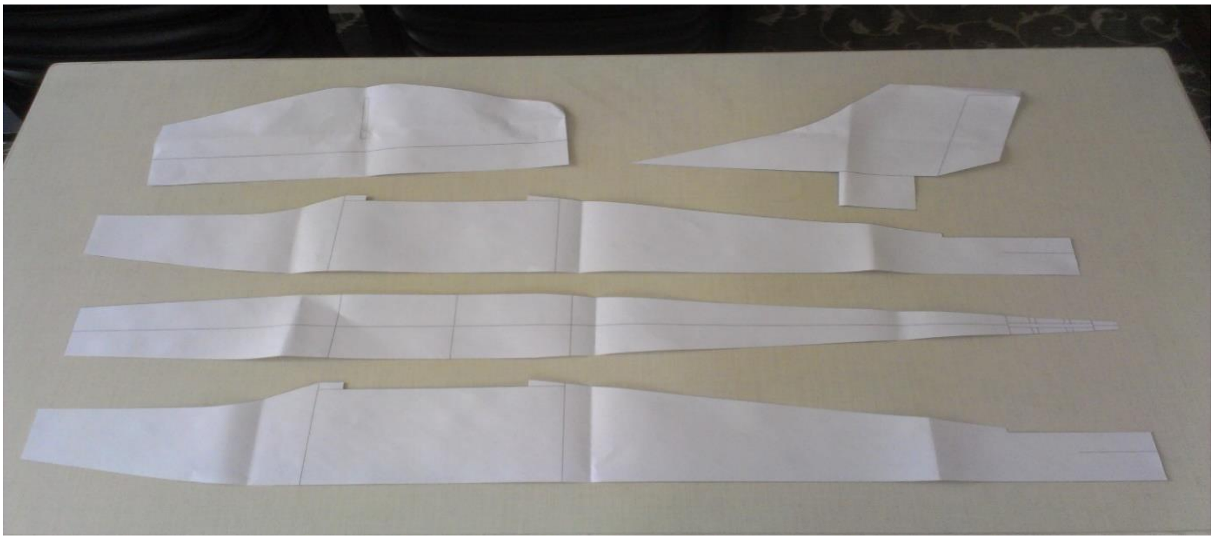


Fig. 6.1 Construction process of the aircraft

Construction of the aircraft starts with the basic design. Before going to the construction all required design of the aircraft, weight calculation, center of gravity and all other materials should be collected. A traditional unmanned aircraft typically comprises the plan and building instructions, all the balsa and ply wood needed to construct the aircraft and most, if not all, of the hardware needed such as servo linkages, control horns, undercarriage parts, motor mount, fuel tank, autopilot system, other payloads etc. Essentially, the kit will contain all you need to complete the airframe, leaving you to buy the covering material, radio gear and engine/motor and associated accessories. Aircraft construction takes place over the plan which must be laid out on a flat modelling board or a table. Whatever is used for the board, the key issue is that it needs to be perfectly flat. Any humps or twists in the board get transferred to the aircraft during construction, and that's not good. Typically balsa wood is used to construct mini unmanned aircraft because of their strength and weight ratio. But we have used photo block as the main construction material as it is lighter than balsa wood, easy to cut and join and easy to repair. Different glues are usually used when building airframe and the type of glue depends on the joint and the wood type/hardness, as well as the builder's personal preference. White wood glue (PVA), aliphatic resins and cyanoacrylate (CA) glues are commonly used on balsa to balsa joints. Hot silicon was used as glue for this aircraft.

6.1. Airframe Construction

To build a successful airframe, one that will allow the radio control equipment to operate the aircraft accurately, it is important to pay attention to the three A’s. Accuracy-Cut all parts as accurately as possible so that they fit without gaps or having to force fit joints. Alignment-Square and true construction at all times and correct alignment of wings and tail surfaces on the completed model. Avoirdupois-Weight is a key property. Keep the weight as low as possible.

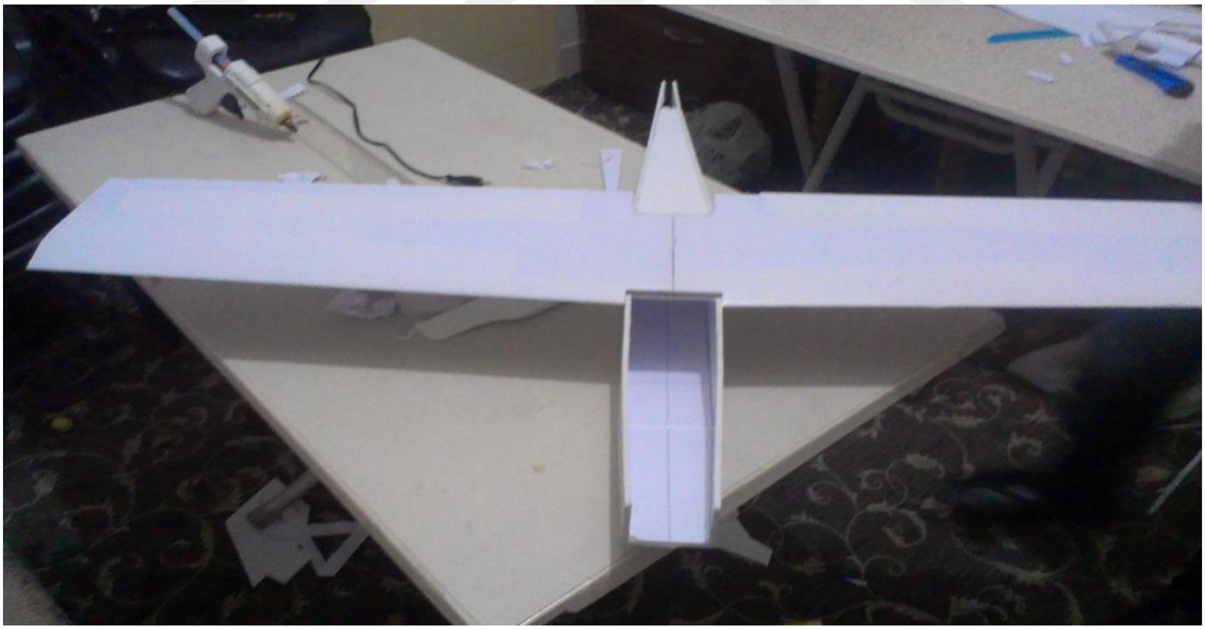


Fig. 6.2 Airframe construction of the aircraft

6.2. Wing Construction

Wing is probably the most important part of an aircraft. While constructing the airframe more effort has to be given for the wings. Building wings without warps is simple enough with flat bottom wings provided the photo block is reasonably evenly graded. With symmetrically wing sections it is often necessary to block up the leading and trailing edges and this must be done accurately and at close intervals to prevent any bowing between supports. The correct balance of the wings is also important; both panels should be of identical weight so that the wing balances around the center line. Try sanding down the heavier wing, particularly around the tip area where the reduction in weight will have most effect, but, if needs be, add some ballast to the tip of the light wing.

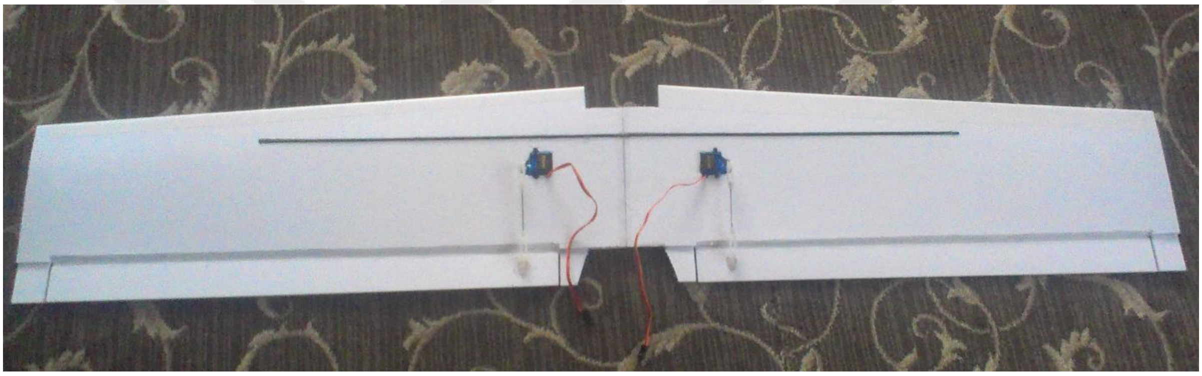


Fig. 6.3 Wing construction

The wing with few exceptions should be built in one piece. For a F/F original scale model it is better to choose simple dihedral, polyhedral or tip dihedral; just be sure to tip the wing 1/15 of the span above the center section. The outline can be rectangle or wit curved tips, tapered, or elliptical, in order of difficulty. The wing shows in figure has some dihedral angles according to design scheme. Choosing the aerofoil shape is critical to choose and is very important factor to decide to achieve the desired aero-stunts, which is case sensitive. We choose the centerline of the tail plane as the datum line as this is normally set as 0^0 incidences. Incidentally if we are using the incidence measurements in terms of degrees remember that the incidence angle of the flay bottom wing is measured from the center of the leading edge to the center of the trailing edge and not to the bottom of the wing.

Fig. 6.4 Construction procedure of the wing

With the datum line marked on the plan it is possible to measure off the distances to the wing leading and trailing edges, and by marking the fuselage in a similar way the incidences can be checked.

6.3. Tail Construction

Construction of tail is almost same as wing construction. As their design is almost same, therefore, accuracy can be easily achieved after building the wings. It has to be noted that the control surfaces of the rudder and elevator should be perfectly cut and mounted. After building the tail, it is necessary to check that it is perfectly sat on the fuselage. The free movement of rudder and elevator is very important. While building the tail the horizontal and vertical tail should be mounted as the control surfaces can able to move totally free according to the servos. Elevator movement is a key to take off while rudder’s free movement is very important to yaw control of the aircraft. An unexpected accident can be occurred just because of a few degree fault movement of the control surfaces.

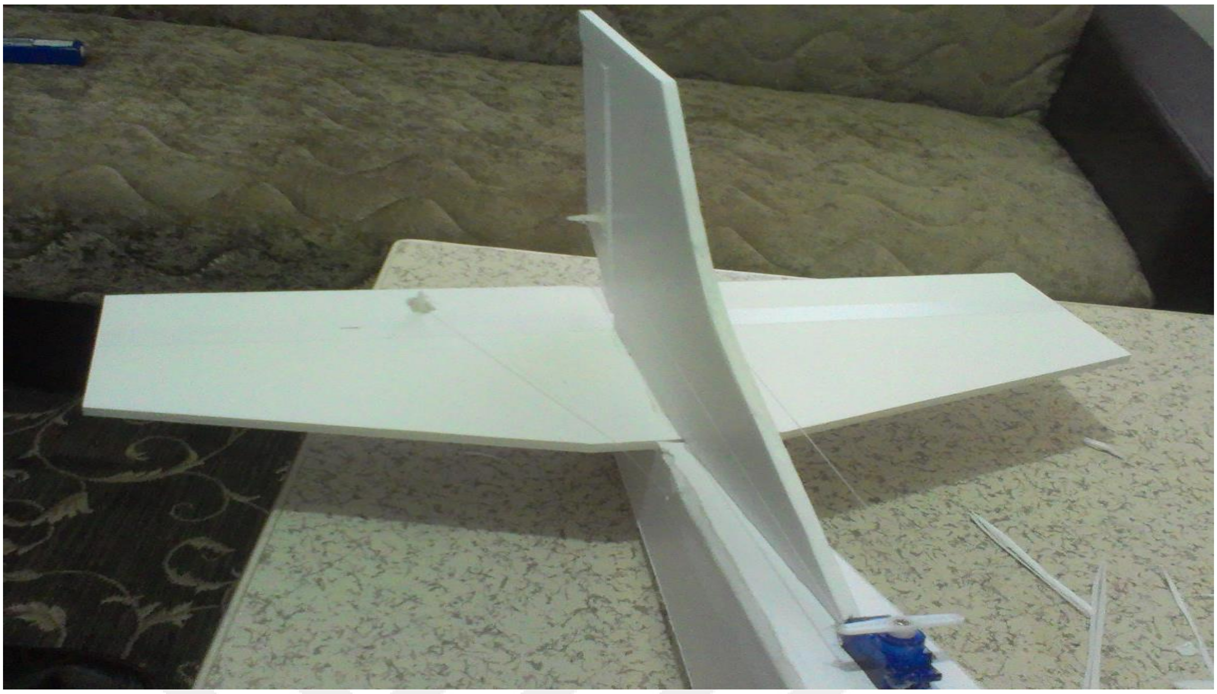


Fig. 6.5 Construction of tail

6.4. Installations

The installations can be divided into four parts as follows:

- Hinges
- Linkages
- Special Linkages
- Electronic equipment

The whole effort to improve the resolution of the equipment can be nullified by poor job of hinging of the control surfaces and installations of the pushrods and control horns. The aims to achieve a good control surface hinge are freedom of movement, close coupling of the control surface to the wing, fin or tail plane and strength of the hinge.

A wrong attachment of installations like hinges could result in the following drawbacks:

- Added loads at higher altitudes on the servos.
- Air loads on the control structures and surfaces during flying.

- Expense of greater battery drain and generally of accuracy too.
- Increased drag and hence the possibility of failure.

Close coupling of the control and primary surfaces is important for two reasons. It will allow passage of air between the surfaces, reducing the efficiency and creating turbulence. Many of the older, full sized, light aircrafts had strips of linen doped loosely between the surfaces to prevent this spillage of air. Other reason is that it will give improved movement for the structure than being offered by mechanism.

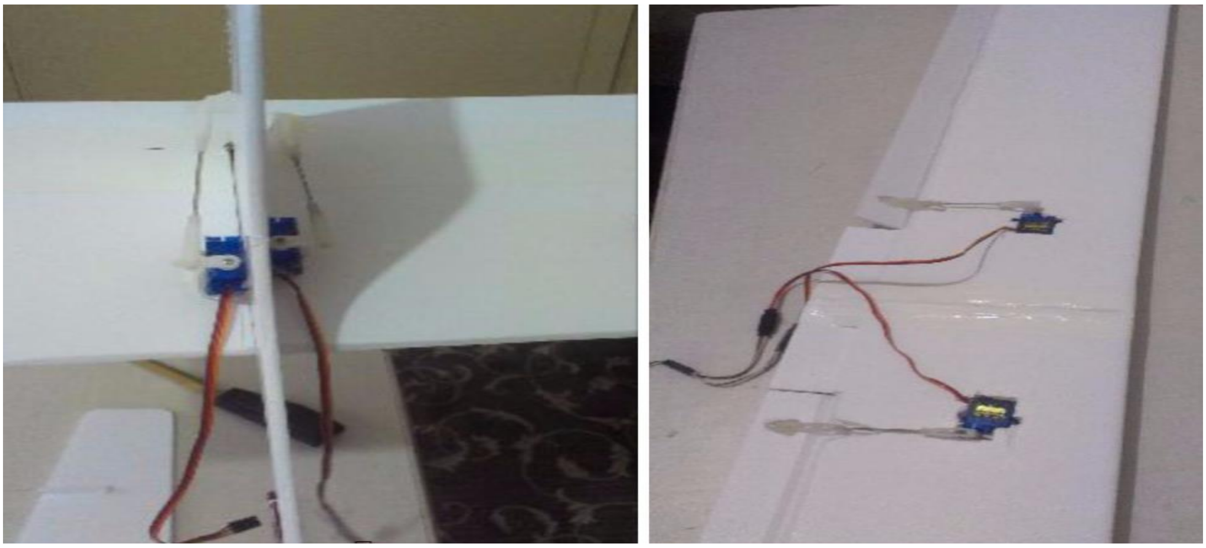


Fig. 6.6 Installation of servos

The linkage between the servo and the control surface, or control function is the area where most loss of control efficiency occurs. The inefficiency is caused by the wasted movements which ultimately may happen due to flexing control rods, over-large holes in horns and servo output arms and discs and a number of other reasons. To avoid it and obtain a greater accuracy of control, we take care to keep connection and connecting rod, as precise as possible. There are so many possible combinations of linkages, horns, cranks, etc. That it is impossible to discuss them all. But the one used in the plane alone is discussed in here. The following figure is self-explanative of the details used in the design.

6.4.1. Propulsion System Installation

The propeller is fixed to the motor on the shaft, which rests on the fuselage at the crevice provided at the front of the fuselage. This actually is being mounted using the x-mount supplied by the motor manufacturer along purchase. The x-mount holds the motor body firmly along with the fuselage by means of four screws. The figure 6.7 shows in detail how the motor and propeller is fixed. The propeller is held firmly by means of the knob-cap in the shape of a bullet. It is very crucial for the aircraft to have a good propulsion system and a perfect installation. As the rotation is very high it produces enormous vibration which can easily disturb the stability when flying and can cause failure. The motor supporting element should be strong enough to carry the load. All the nuts should be perfectly tightened. A very good designed aircraft can be destroyed in seconds just for a loose tightened of the joining nuts of the motor. In that case you may see that your motor comes out with the propeller and you have nothing to do without seeing.

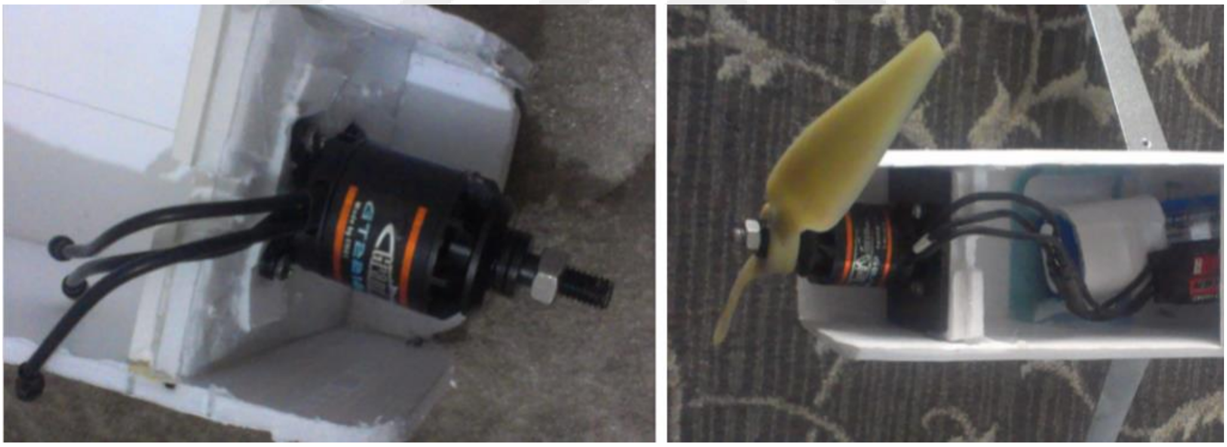


Fig. 6.7 Installation of propulsion system

While installing the motor there are some tips that you must implement in your mini aircraft. The motor should be always some degrees right and downwards. If not you may have experienced with an instantaneous fall just after taking off the aircraft.

Fig. 6.8 Installation of power system

The battery or the powerpack is the heaviest element of the aircraft. Logically heavier the element should be closer to center of gravity. A very little movement of the element can change the C.G position. You should always keep in mind that the battery should be placed such a position that it does not move even in aerobatic fly. Figure 6.8 shows that how you can protect your battery from movement.

6.5. Checking Structural Strength

Before starting to fly the aircraft, it is important to check the aircraft for strength. For most mini aircraft, wing should be designed and structured to carry at least 2g of loads in maneuvers. What it means is that your wings should be able to carry twice the weight of the aircraft. If the aircraft weight is 4 lb. 2g will mean that the airplane wing should be able to carry at least 8 lb of loads. For aerobatic models, the requirements may be high e.g. 4g or 6g loads. But adding more wood in the aircraft does not make it stronger. In mass consideration, the more structure added to the aircraft, the more weight gets added the aircraft. So it’s better to use improved design techniques to make the aircraft structure with lesser weight. Most of the time, new designers don't care about the grain direction of the balsa wood and ply wood when making these airplanes. If the strip of balsa wood and ply wood is examined closely, it could be seen to have a grain structure on it. With proper direction of the grain structure of balsa wood and plywood on your airplane, the weight can be saved and also make a stronger structured aircraft. The factors like the kind of loads the structure is taking, the direction in which the load is acting, and the nature of the load like compression or expansion.

6.6. Center of Gravity

Correctly balancing your aircraft is so important for safe flying, because any deviation from the aircraft's center of gravity can and probably will result in the aircraft being quite uncontrollable. Every aircraft has a correct C.G, this is the point where the model balances fore-aft correctly. A badly balanced airplane will, at best, be hard to control, and this is especially true for tail heavy planes.

Fig. 6.9 Checking center of gravity

Obviously the first thing you need to do is identify the correct center of gravity, according to the plan. Normally, the airplane center of gravity of the aircraft is to be located at 25% or 0.25c (of the mean aerodynamic chord). For the airplane, a vertical line is marked on the mean aerodynamic chord. At 25% or 0.25c of the mean aerodynamic chord, a horizontal line is marked on the wing. At the center point of the joint of two wings a straight vertical line is marked. The two lines will intersect each other at a point. That point is the reference cg point. An airplane can be either nose heavy or tail heavy. If the airplane is chosen to be statically stable you will most probably chosen 25% of the Mean Aerodynamic Chord as the reference. Now the reference CG point is obtained. Then the airplane is checked if the CG of airplane is at the reference CG point or is it nose heavy or tail heavy. To do this, two people are required. One person stands on each side of the wing. Wing is lifted with a single finger (don't lift up/touch any other part of the aircraft during this check) along the reference vertical line which passes through the reference CG point. If the airplane is nose heavy or tail heavy it will automatically move in either direction. If airplane not at the cg point add ballast either to the nose or tail until the cg point is reached. A correctly balanced airplane will either be level, or have the nose pointing slightly downwards. If the tail points downwards, then the model is tail heavy and you need to do something about it. If the balance does need to be adjusted to get the correct CG, the first thing to do is try moving the battery pack or any of the gear either further forward or further back inside the plane. By doing this, you are adjusting the balance without adding extra 'dead' weight to the model in the form of ballast. The motor/receiver battery pack is by far the best thing to move, because it is the heaviest item and will have the most effect with the smallest amount of movement. Carefully try and reposition it fore or aft, carefully rechecking the balance of the plane after you've moved it.

Table 6.1 Center of gravity calculation [35]

Components	Weight	Distance from nose
Fuselage + wing + landing gear	X_1	Y_1
Tail boom + tail plane	X_2	Y_2
Battery	X_3	Y_3
Auto pilot system	X_4	Y_4
Other electronics	X_5	Y_5

$$Center\ of\ gravity = \frac{X1,Y1+X2,Y2+X3,Y3+X4,Y4+X5,Y5}{X1+X2+X3+X4+X5} \tag{6.1}$$

Once you're happy with the new balance, make sure that the battery pack is secure and won't move from its new position. If you can’t reposition anything, which is always a possibility in airplanes, you might have to add ballast to either the nose or the tail of the plane to correct the CG. You need to remember, though, that ballast adds dead weight to a model which is never good - the lighter a plane is, the better it performs. So if you do need to add ballast to correct the CG, you need to add as little as possible**.** The way to do this is to add the ballast as far forward or as far back as you possibly can on the model. By doing this, the ballast will have the most effect on the CG. Add only enough to make your plane balance correctly on your fingertips. Suitable ballast to add to an airplane is modeling clay or fishing shots, for example. Whatever ballast you do add, make sure it is secure to the plane, and won't drop off in flight. Roll balancing your airplane. This is an often overlooked balance, and in a way isn't particularly important. But an airplane that has one side heavier than the other will have a tendency to naturally roll and turn to the heavier side, making your life a bit harder. However, roll balancing isn't nearly as important as the fore-aft balancing talked about above. Unless something is seriously wrong, the plane won't spiral out of control just because one wing is slightly heavier than the other. And the chances are that you can correct any unwanted roll with the aileron trim, if there is one. But to balance your airplane's roll anyway, simply loop some thread around the propeller shaft, between the spinner and the fuselage, and then some around the rear of the fuselage, as close to the tail as you can get. Lift the plane up and let it hang freely, see if it wants to roll to one side or another. If it does, then you need to add some small ballast to the wingtip of the lighter (higher) side. Add only enough to make the plane hang level, when viewed from the front. Taping the weights to the wingtip is an easy method, although you might want to take the trouble to set them into the wingtip and cover over them to hide them. For airplanes with foam wings, pushing a small gauge nail or panel pin into the foam is a great way of adding any necessary weight, and is easily hidden with white paint or marker pen.You have also the option of finding the center of gravity without test it manually. As a designer you have to do it mathematically before starting construction. For a heavy unmanned aircraft you may always not find the chance to find the CG manually, if so it would be hard and costly. Calculating it before will always give you advantage over manual test. Table 6.1 shows the calculation of center of gravity of the aircraft.

7. AUTOPILOT SYSTEM

In this chapter, the autopilot system is discussed. Under this discussion autopilot hardware and software have taken place. In addition, the avionics will be discussed, which include the autopilot and supporting hardware, such as the communications links and RC Bypass circuit. The next section will cover the hardware used in the video surveillance payload. We will conclude by discussing the ground station hardware.

7.1. Autopilot Hardware

A simple approach to understanding the UAV system is to separate it into four self-contained subsystems. The four subsystems are shown in figure 7.1.

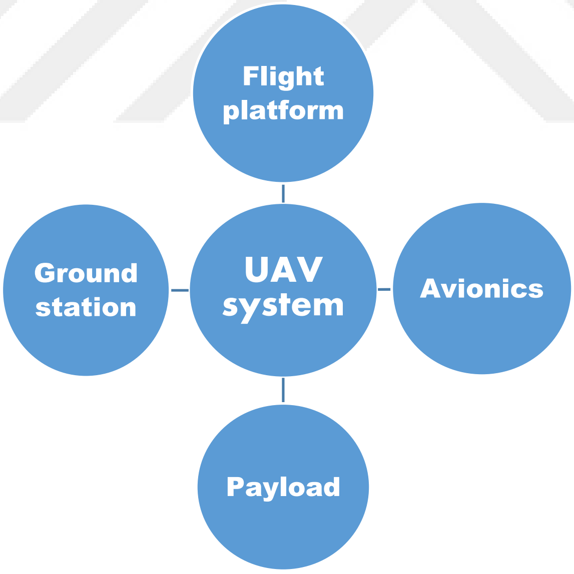


Fig. 7.1 UAV system [36]

The purpose of the flight platform is to carry the avionics and the payload. The flight platform consists of the airframe, the actuators that move the control surfaces, the batteries that power the autopilot, and the propulsion system. The flight platform has already discussed in detail in previous chapters. The avionics consist of the autopilot board, GPS receiver, and digital modem. Their purpose is to control the aircraft and communicate with the ground station. The payload subsystem consists of the hardware not related to the flight platform or avionics. The payload is placed on the aircraft to accomplish user objectives. One of the purposes of this thesis is to demonstrate the feasibility of small UAVs for surveillance purposes. Therefore, a video surveillance payload is used on our flight platform. The ground station includes hardware and software needed to support the avionics and payload in flight. The ground station includes a laptop computer, a 900 MHz digital modem, a RC controller to accept pilot inputs, and a 2.4 GHz analog video receiver and display for the video surveillance payload. A graphical interface was written for the autopilot.

7.1.1. Autopilot Board

The autopilot board is arguably the most important and complex piece of hardware in the UAV system. The function of the autopilot is to control the aircraft using the aircraft states, the user-programmed mission, and the pre-programmed fail-safe functions. The autopilot is a compact unit that contains: the Central Processing Unit, sensors to measure the aircraft states, input/output ports to accommodate the payload, GPS and communication devices and electronic components to support these devices. This section will discuss the elements of the autopilot hardware. First will come discussion of CPU selection, followed by discussion of the various sensors and hardware needed to determine the aircraft states. It will end by detailing the interfaces that support the GPS, radio modem, and payload.

The CPU is the heart of the autopilot. It is responsible for processing sensor data, handling I/O to the GPS, modem, and Bypass circuit, running the low-level control algorithms, and handling communications with the ground station. Based on these requirements, the CPU must have abundant serial and digital I/O ports, and be capable of rapid 32-bit floating point operations. It must also have sufficient RAM and flash memory for autopilot source code storage and runtime execution.

To control the aircraft effectively, an accurate, timely estimate of aircraft states is needed. The purpose of this section is to outline the method used to gather the aircraft state information. The commonly used notation for the 12 aircraft state variables follows:

- X = inertial position of the UAV along x1 north
- Y = inertial position of the UAV along y1 east
- H = altitude of the aircraft
- Vp = pressure airspeed (indicated airspeed)
- Beta = sideslip angle
- Alpha = angle of attack
- φ = roll angle
- θ = pitch angle
- ψ = yaw angle (heading)
- P = body fixed roll rate
- Q = body fixed pitch rate
- R = body yaw rate

Direct sensing of these aircraft states is ideal because it is fast and generally accurate. However, some states are difficult to measure directly. At this time, sensors to measure roll (φ), pitch (θ), and yaw (ψ) are not suitable because of high price, large size, and weight. Therefore, these states are estimated by combining information from several sensors. This section will discuss the sensors used to directly measure and estimate the aircraft states. The first states of interest are X and Y, which represent the aircraft's inertial position in the north direction and east direction, respectively. These states are measured directly using the GPS receiver. The next states of interest are the body fixed rotational rates, P, Q, and R. There are several low-cost, lightweight gyros available for this purpose. Some gyros accurately sense the aircraft states but suffer from a high drift rate, and susceptibility to interference from the onboard 900 MHz digital modem. Some gyros are more ideal, having a low drift rate, small physical size, and a built-in temperature sensor. The Adxrs300 has additional advantage of a maximum measurable rotational rate of 300 degrees/second, as compared to other gyros. For these reasons, the Adxrs300 rate gyro is recommended to measure P, Q, and R. Altitude and Airspeed (H and Vp) can be measured using pressure sensors. Altitude can be measured using Motorola MPX3000 absolute pressure sensor. Airspeed can be measured using Motorola MP4015 differential pressure sensor. Both of these sensors have internal temperature compensation and signal conditioning. Because of the small changes in pressure resulting from changes in altitude, the signal from the absolute pressure sensor should be amplified before being read by the A/D converter. The differential pressure sensor output also should be amplified. A first-order, low pass filter can be employed on the output of both sensors to attenuate high frequency noise. The GPS also produces an altitude estimate. However, the GPS altitude is not suitable for controlling the aircraft because it suffers from high latency and low sensitivity to small changes in altitude. The sensors, their states and interfaces are shown in Table 7.1.

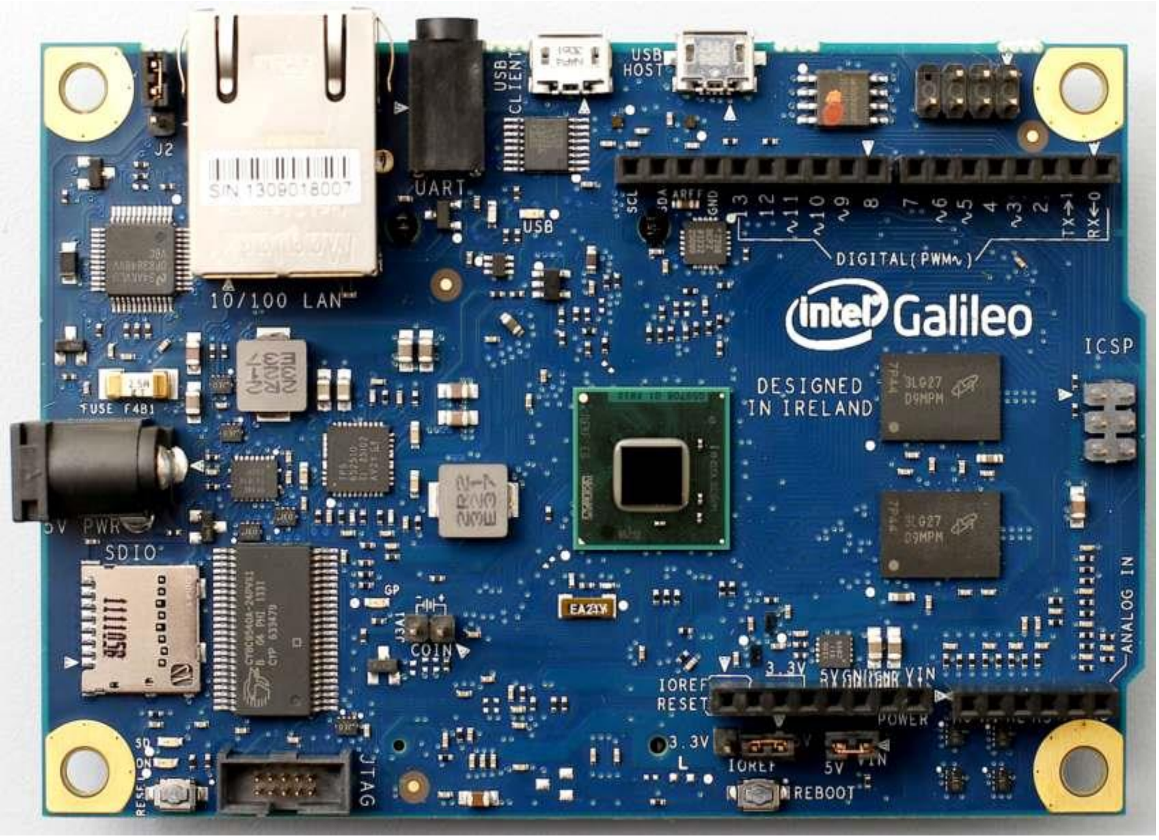


Fig. 7.2 Autopilot board [37]

However, the GPS altitude measurement is useful as it can be used to calibrate the absolute pressure sensor. The GPS can also be used to calibrate the differential pressure sensor, but this is only useful in an environment of low wind, when the GPS-measured ground speed is directly related to airspeed. The autopilot board must communicate with several devices during normal operation. These devices include the GPS, digital modem, Bypass circuit, and payload. The GPS, digital modem, and Bypass circuit use asynchronous serial communication. The payload interface, however, varies depending on user requirements. In order to support a variety of payloads, the autopilot can be designed with several different interfaces that may be used by the payload. These optional interfaces are accessible via a set of connectors on the front of the autopilot board. These connectors of the autopilot board are shown in figure 7.2.

Table 7.1 Autopilot sensors

Sensors	*Direct states*	*Estimated states*	*Interfaces*
Roll rate gyro	P	Phi, Theta, Psi	Analog
Pitch rate gyro	Q	Phi, Theta, Psi	Analog
Heading rate gyro	R	Phi, Theta, Psi	Analog
X accelerometer	A_x	Phi, Theta, Psi	Analog
Y accelerometer	A_y	Phi, Theta, Psi	Analog
Z accelerometer	A_z	Phi, Theta, Psi	Analog
Differential pressure	V_p		Analog
Absolute pressure sensor	H		Analog
GPS lat	X		Asynch. serial
GPS lon	Y		Asynch. serial
GPS altitude	H		Asynch. serial
GPS heading	Velocity vector	Phi, Theta, Psi	Asynch. serial
GPS velocity	Ground speed		Asynch. serial

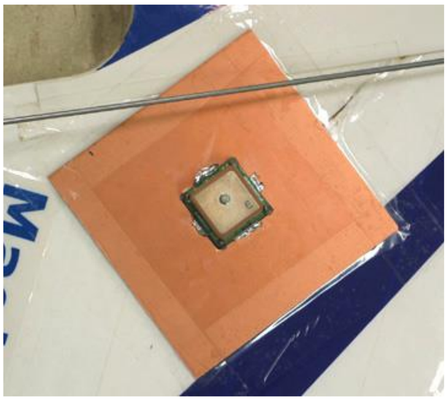
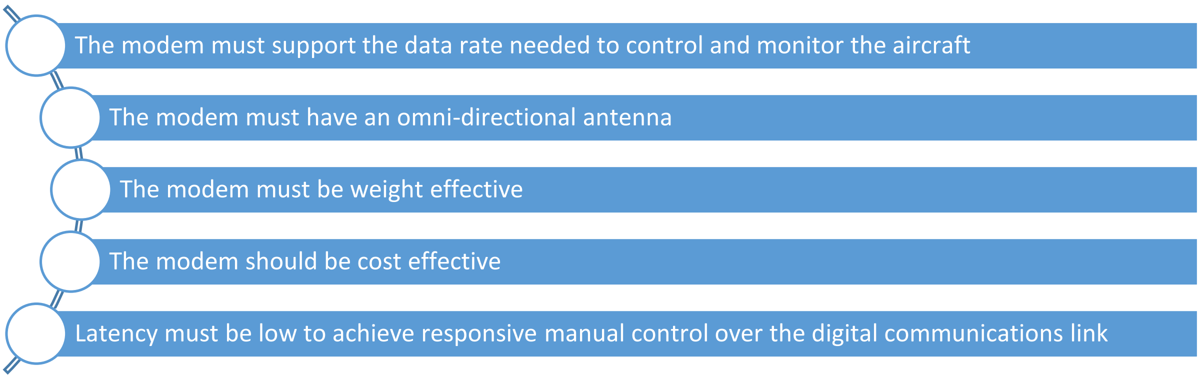


Fig. 7.3 GPS receiver

A good GPS receiver used in autopilot board is Furuno GH-80. This receiver suits the autopilot application for several reasons. First, it has an integrated antenna, which makes it self-contained and low-maintenance. Second, it is very small and lightweight, weighing only 17 grams. Third, it has desirable electronic characteristics. These include: a 12-channel receiver, low fix time, and the ability to accept differential corrections. Figure 7.3 shows the Furuno GPS installed in the aircraft. The Furuno suffers from the standard limitations of non-differential GPS. First, its accuracy is limited to around 10 meters. The second limitation is the 1 Hz update rate. The position, heading, velocity, and altitude are updated only once a second. Because of the aircraft's low velocity, this is sufficient for most of the control algorithms. The autopilot control could be improved if a filter were used to provide a position and heading estimate between GPS samples. This is also an area of future work.

7.1.2. Communication Hardware

An essential part of the autopilot avionics is the digital communication link. The digital communications link provides several important functions. First, it provides real-time status updates to the user. Second, it allows the autopilot to be dynamically configured in-flight. (This allows for in-flight gain tuning and sensor monitoring.) Third, it provides a means for commands to be sent to the autopilot. Fourth, it provides a method for Pilot-in-the-Loop aircraft control. The digital communications link can be used in place of the 72 MHz RC link to control the aircraft if desired. This section will discuss the specifications in choosing the digital modem for the communication link. The digital modem has five specifications. They are shown in figure 7.4



The modem must support the data rate needed to control and monitor the aircraft

The modem must have an omni-directional antenna

The modem must be weight effective

The modem should be cost effective

Latency must be low to achieve responsive manual control over the digital communications link

Fig. 7.4 Digital modem specifications [38]

Experience with mobile robots and autonomous aircraft suggests that 9600 baud is adequate, while higher rates are more desirable. While setup the modem, it should be installed upper portion of the aircraft may be on wing or in the wing tip. The manufacturer-supplied antennas should be used on the ground station side. An important component of the digital communication link is the antenna. Omnidirectional antennas are used on the aircraft and ground station because they do not require re-adjustment during flight. The aircraft antenna is a custom-built dipole with ¼-wave radiating elements. The antenna should be mounted on the aircraft in a vertical orientation to match the vertical polarization of the ground station antenna in level flight. When the aircraft banks, there is a degradation in signal strength as the polarization of the UAV antenna changes with respect to the ground station. The UAV is designed to function normally during these brief periods of degraded communication. Lost communication behavior will be discussed later. A manufacturer-supplied ¼-wave 2-dB dipole antenna can be used on the ground station (WCP- 2400-MMCX).

7.1.3. Bypass Circuit

The Bypass circuit is an essential component of the onboard avionics during autopilot development. If a problem arise during testing that puts the aircraft in danger, a human safety pilot can immediately takes control of the aircraft using a switch on the RC transmitter. The human pilot can either land the aircraft, or fly the aircraft until the problem is resolved and control returned to the autopilot. This approach to autopilot development allowed testing of new algorithms and hardware with minimal risk to the aircraft or people on the ground. This section will discuss the design of the Bypass circuit.

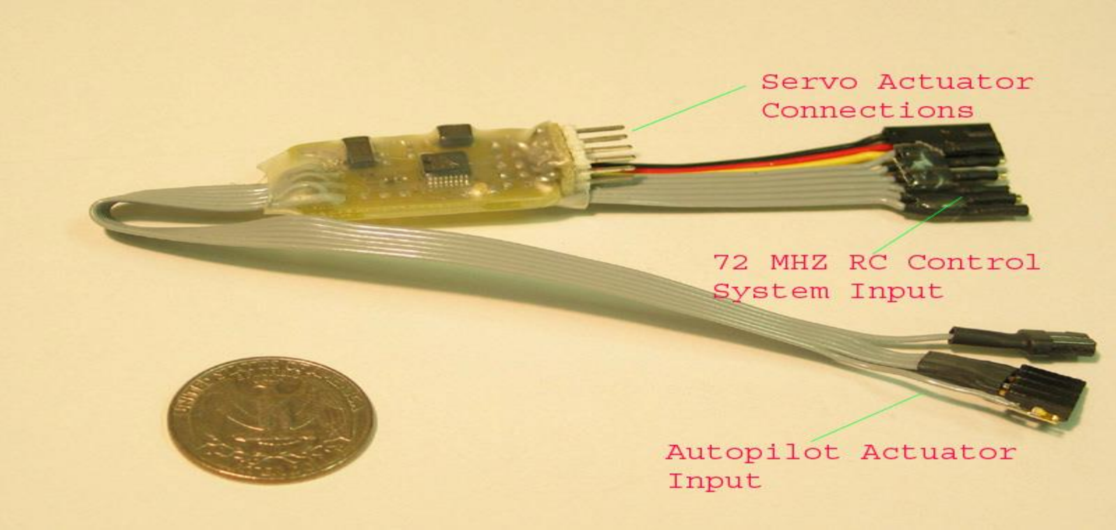


Fig. 7.5 Bypass circuit

When a human pilot takes control of the airplane via the RC transmitter, this switches control of the UAV actuators from the autopilot to the onboard 72 MHz control system. The bypass circuitry decodes the servo position signals from the 72 MHz RC receiver. This allows the RC transmitter stick positions to be used as flight control inputs, and also allows the stick positions to be logged for system identification and flight analysis. The Bypass circuit contains a PIC microcontroller and a digital multiplexer. The microcontroller decodes the pulse position modulation servo position signals from the RC receiver. Channels 1-4 and 6-8 are decoded into values representing the servo pulse high time. Channel 5 is decoded separately and is used as the control signal. If the Channel 5 pulse falls below a set threshold, the microcontroller switches the digital multiplexer to connect the RC receiver servo outputs directly to the servos. This mode is known as Pilot-in-Control mode (PIC), as the aircraft is controlled by a human pilot through the 72 MHZ control link.

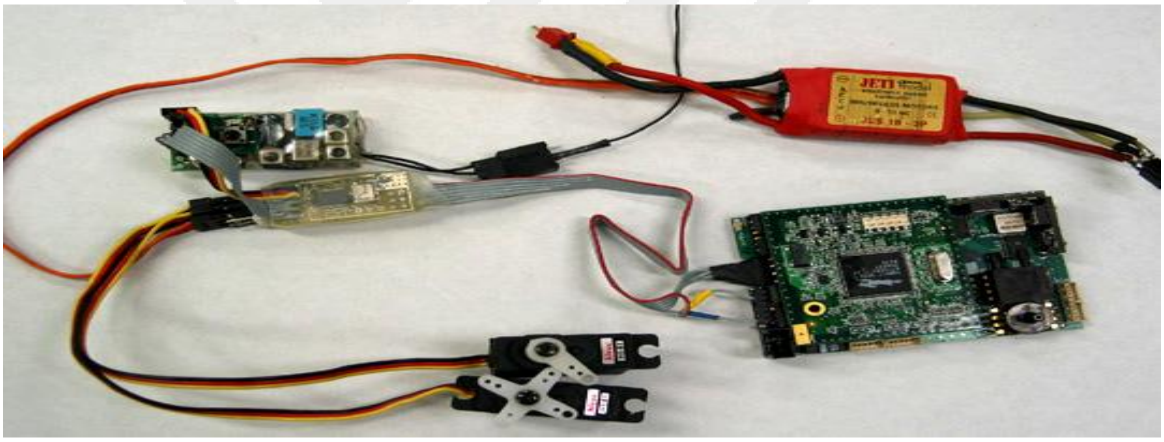


Fig. 7.6 Bypass circuit connected to the autopilot, servos and RC receiver

If the channel 5 pulse rises above the threshold, the digital multiplexer connects the autopilot servo outputs to the servos. This is known as Computer-in-Control mode (CIC) as the autopilot has control of the aircraft. The decoded servo positions and PIC/CIC mode information are sent the autopilot over an asynchronous serial port at 20 Hz. The data is sent regardless of control mode. During PIC mode, the autopilot logs the servo control information which can be used for flight analysis. In CIC mode, the autopilot can be configured to use the servo position signals as control inputs to the low level PID loops for autopilot-assisted flight. The autopilot can also be configured to use the control signals in conjunction with the control efforts of the PID loops to test disturbance rejection. Figure 7.5

shows the Bypass circuit where figure 7.6 shows its connection to the autopilot, servos, and RC receiver.

7.1.4. FPV System

The autopilot is designed to accommodate and interface with a wide variety of payloads. To demonstrate the effectiveness of the UAV as an observation platform, a video surveillance payload is used for testing. First Person View (FPV) system consists of a video camera, transmitter, receiver, screen or goggles. Usually it works on 1,2GHz, 2,4GHz or 5,8GHz band. The higher the frequency, the smaller the antenna. The transmitter transmits telemetric data encoded in the video signal. The data can be decoded, processed and stored by FPV Ground Station. Figure 7.7 describes the FPV system of the aircraft.

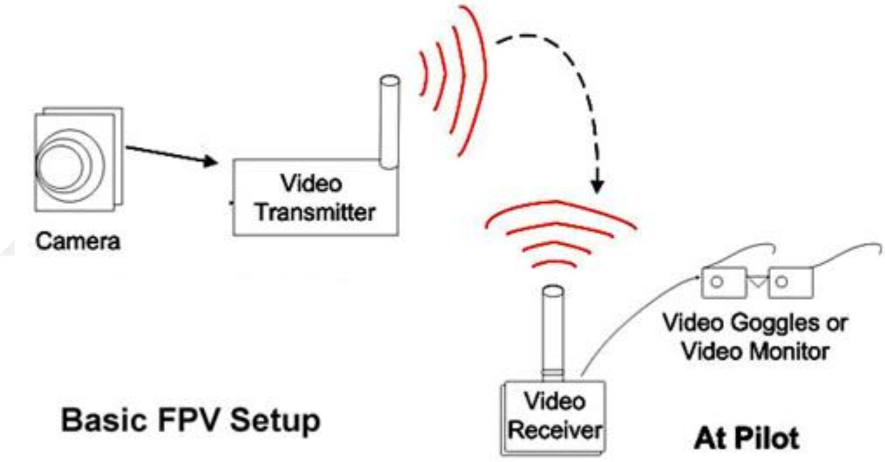


Fig. 7.7 FPV system [39]

The discussion of the video system components is divided into two sections. The first covers the airborne components. The second is the ground-based equipment to receive and display the video. The first component of the airborne system is the camera. The Panasonic GPCX171 hi-resolution CCD camera can be used because of its high resolution and low weight. The second component is the video transmitter. The Felsweb TX612 can be used because of its low cost, 20 gram weight, small size, and 500 mW power output. The Felsweb transmitter, is capable of a 5-km range. The final component of the airborne video system is the antenna. Because the orientation and position of the aircraft with respect to the ground constantly changes, an omni-directional antenna must be used on the aircraft. A ¼-wave dipole is used for this purpose. Figure 7.7 shows the FPV system used in the UAV.

7.1.5. Ground Station Hardware

The final section of the hardware deals with the hardware used in the ground station. The purpose of the ground station hardware is to control and monitor the UAV and payload. The ground station hardware can be divided into two systems. The first is the autopilot-specific hardware. The second is the payload-specific hardware. There are two components that make up the autopilot-specific ground station hardware. The first is the digital modem that communicates with the digital modem in the UAV. The second component of the ground station is the user interface.

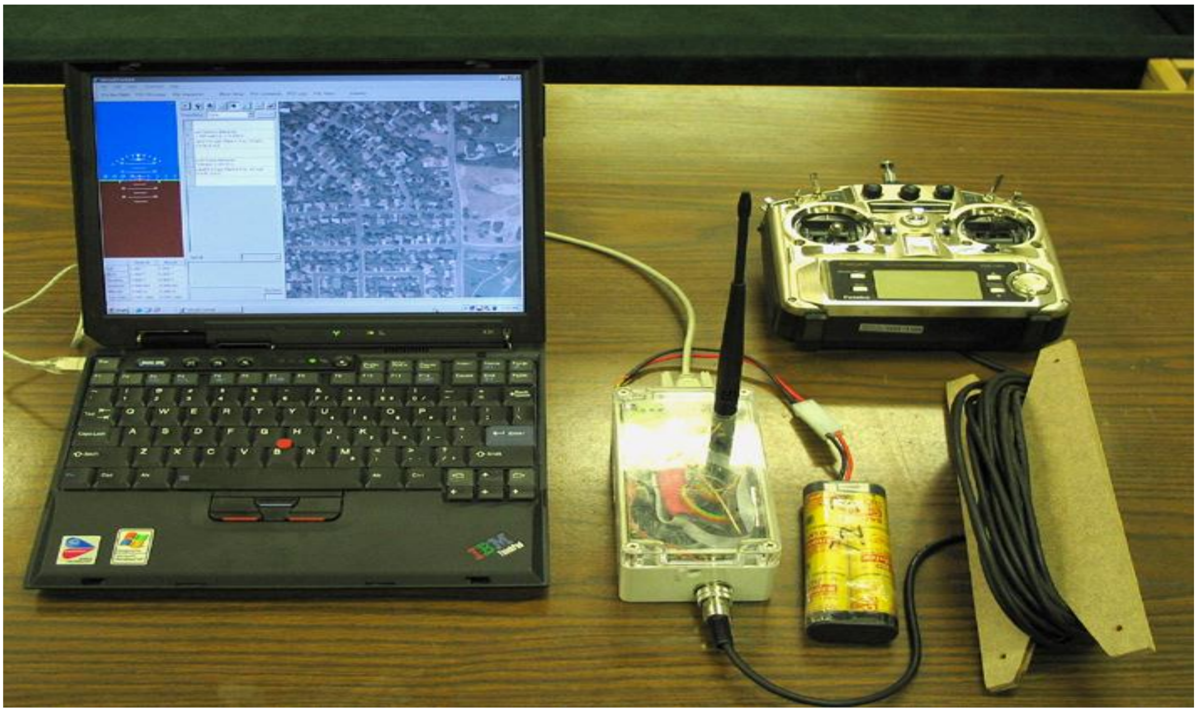


Fig. 7.8 Ground station hardware

A laptop computer running Microsoft Windows is used. An in-house graphical user interface controls the autopilot. The ground station hardware is shown in Figure 7.8. The payload-specific portion of the ground station consists of the ground-based hardware necessary to make use of the payload carried by the UAV. In the case of the video surveillance payload, a video receiver, antenna, and video display are needed. The Felsweb RX612 receiver receives the video from the airplane. A high-gain directional patch antenna from Hyper Link Technologies is necessary to achieve a 5 km range.

7.2. Autopilot Software

The purpose of this section is to discuss the software on the autopilot and in the ground station. The autopilot software is responsible for attitude estimation, processing sensor data, parsing GPS data, controlling the aircraft, and handling communications with the ground station. The ground station software's purpose is to provide an easy-to-use graphical interface to the autopilot. The ground station software runs on a Windows-based laptop computer. In this section specific software code will not be discussed but the structure of an autopilot software will be discussed. Today it is possible to use open source code of autopilot software. You can use them easily or develop, modify according to your choice and expectations from your UAV.

7.2.1. Data Collection

The data collection takes place in three steps: data sampling, temperature compensation, and bias removal. The analog-to-digital converters communicate with the Processor via the SPI serial interface. Each of the sixteen analog to digital channels are read and the corresponding 12-bit values are stored in the AD_Value portion of the appropriate sensor structure. The raw analog values are then for temperature drift using:

$$Compensated\_value = Sensor_{RAW\_AD} + C_{sensor}.\, \Delta T \tag{7.1}$$

Where $Sensor_{RAW\_AD}$ is the raw analog-to-digital converter output, *sensor C* is the temperature compensation coefficient for the sensor, and ΔT is the difference in temperature from the time of calibration. The base temperatures are collected during the calibration process of each sensor. The temperature is read from the temperature sensor built into the Z rate gyro. Because only one temperature sensor is used, and every sensor has different temperature drift characteristics, the coefficient must be determined using an empirical method.

7.2.2. Sensor Processing

The purpose of sensor processing is to convert the temperature-compensated, bias shifted value into the correct units. This is done using the appropriate formula based on the sensor. There are eleven sensors on the autopilot that must be processed [40]. The four payload analog ports will not be discussed here as they are not part of the autopilot core. The discussion on sensor processing will discuss the following: absolute pressure sensor, differential pressure sensor, rate gyros, accelerometers, current shunt, and system voltage. The absolute pressure sensor used on the autopilot is the Motorola MPX 4115a. It outputs a voltage based on the absolute atmospheric pressure. This pressure is relative to an internal vacuum reference in the sensor. The absolute pressure is used to measure pressure altitude. This is the main altitude reference for the autopilot. The sensor units are meters. The altitude is relative to the altitude at which the pressure sensor bias was stored. In general this is the altitude of the ground station. Thus, the calibrated value for the absolute pressure sensor is in meters above the ground station. The formula to convert from the raw output of the analog to digital converter was derived using empirical data. The differential pressure sensor used on the autopilot is the Motorola MPX 5000. It outputs a voltage based on the difference in pressure between its two external ports. The pivot tube is connected to one of the ports and the other is left open to the ambient air. The flow of air against the pivot tube causes a pressure difference proportional to the speed of the air. The corresponding voltage produced by the sensor is used to calculate the airspeed of the UAV. The units are knots indicated airspeed (KIAS). KIAS is a unit that represents that pressure of the air and as such it is not compensated for pressure altitude or air density.

$$\begin{Bmatrix} P \\ Q \\ R \end{Bmatrix} = \begin{bmatrix} RollGyro_{Tcomp\_AD} \\ PitchGyro_{Tcomp\_AD} \\ YawGyro_{Tcomp\_AD} \end{bmatrix} \cdot 0.044380 \tag{7.2}$$

The autopilot uses three Analog Devices ADXL300S rate gyros to measure the angular rates P, Q, and R. These values are in radians/second. A constant multiplier is used to convert the output of the rate gyros to radians/second. This is demonstrated in equation (7.2). The constant is determined by placing the rate gyro on a rate table spinning at a constant velocity. The output of the analog-to-digital converter is divided by the known rate of the table to produce the constant 0.044380. Two Analog Devices ADXL200E two-axis accelerometers are used to measure the body fixed accelerations Ax, Ay, and Az. Because only relative accelerations are needed, the accelerations remain in temperature-compensated, bias-shifted units. Empirical data suggests that approximately 270 analog-to-digital converter counts are equal to the gravity acceleration due to gravity. The relative accelerations are used in an arctangent function in the attitude estimation filter to produce reference values for roll and pitch. The autopilot temperature is derived from the built-in temperature sensor in the Q rate gyro. This value is never converted to a temperature reading in conventional units. It is kept in biased analog-to-digital converter units for use in the temperature compensation algorithm. The current shunt is a resistive device used to measure the current delivered to the propulsion motor. The voltage drop across the shunt is converted from bias compensated analog-to-digital converter units using the equation:

$$I = Shunt_{RAW\_AD}.z.y \tag{7.3}$$

The constant y is the conversion from voltage drop in millivolts across the current shunt to current in amps through the shunt. It is dependent on the resistance of the current shunt used. The constant z converts the analog-to-digital converter output to millivolts. This value is 0.17, which is based on the gain of the current shunt circuit. The system voltage is sampled from the main power connector on the autopilot board. The raw analog output of the measuring digital-to-analog converter is converted to volts using:

$$V = Vin_{RAW\_AD}.y \tag{7.4}$$

The constant y is the conversion from analog-to-digital units to volts and is based on the gain of the system voltage circuit.

7.2.3. Attitude Estimation

The autopilot uses two separate attitude estimation filters to determine the aircraft attitude. The first is used to estimate the roll and pitch angles. The technique employed in this filter uses integrated values from the rate gyros and estimated roll and pitch angles produced by the accelerometers. The purpose of this technique is to produce estimates of roll and pitch that have low drift and decent accuracy. The second filter is used to produce a heading estimate that has a faster response than GPS heading. The first step in estimating the roll and pitch angles is to derive a roll and pitch reference based on the arctangent of the aircraft's acceleration vectors and the gravity vector. This is accomplished using equation (7.5).

$$\begin{Bmatrix} \overline{\phi} \\ \overline{\theta} \\ \overline{\psi} \end{Bmatrix} = \begin{bmatrix} \tan^{-1}(\frac{Ay}{Ax}) \\ \tan^{-1}(\frac{Ax}{-Az\cdot\cos(\phi)-Ay\cdot\sin(\phi)}) \\ GPS\_Heading \end{bmatrix}, \qquad (7.5)$$

Where, $\overline{\varphi}$ is used as a roll angle reference and $\overline{\theta}$ is used as a pitch angle reference. Both of these values are in radians. They suffer from inaccuracy in coordinated turns where the net acceleration of the aircraft is in the negative Z direction. In this case, (7.5) will produce a 0 degree roll angle. Experience shows that the resulting error can be limited during extended coordinated turns by giving minimal weight to the reference roll angle produced by (7.5) relative to that produced by integrating the rate gyros. A similar error in the reference pitch occurs during a coordinated pull-up where (7.5) will show zero pitch. However, because coordinated pull-ups are transient events in normal flight, they are not a significant factor. The next step is to update the current state estimate using the roll and pitch components of P, Q, and R rate gyros. The pitch and roll components of the angular rates are calculated by

$$\begin{bmatrix} \dot{\phi} \\ \dot{\theta} \\ \dot{\psi} \end{bmatrix} = \begin{bmatrix} 1 & Q\cdot\sin(\phi) & \cos(\phi)\cdot\tan(\theta) \\ 0 & \cos(\phi) & -\sin(\phi) \\ 0 & \sin(\phi)\cdot\cos(\theta) & 0 \end{bmatrix} \cdot \begin{bmatrix} P \\ Q \\ R \end{bmatrix}. \qquad (7.6)$$

The integration is accomplished using the Euler approximation,

$$\begin{bmatrix} \hat{\phi} \\ \hat{\theta} \\ \hat{\psi} \end{bmatrix}_{k+1} = \begin{bmatrix} \hat{\phi} \\ \hat{\theta} \\ \hat{\psi} \end{bmatrix}_{k} + \Delta t \cdot \begin{bmatrix} \dot{\phi} \\ \dot{\theta} \\ \dot{\psi} \end{bmatrix}_{k}. \qquad (7.7)$$

Where $\hat{\varphi}$, $\hat{\theta}$, and $\hat{\psi}$ are the state estimates of roll, pitch, and yaw. The updated state values of pitch and roll produced by (7.7) are then subtracted from the reference values for pitch and roll computed in (7.5). The corresponding value is the state estimation error. This error value is multiplied by a gain and subtracted from the state estimate to form the new state estimate. This process is shown in the following equations:

$$\begin{bmatrix} \tilde{\phi} \\ \tilde{\theta} \\ \tilde{\psi} \end{bmatrix} = \begin{bmatrix} \bar{\phi} \\ \bar{\theta} \\ \bar{\psi} \end{bmatrix} - \begin{bmatrix} \hat{\phi} \\ \hat{\theta} \\ \hat{\psi} \end{bmatrix}, \tag{7.8}$$

$$\begin{Bmatrix} \phi \\ \theta \\ \psi \end{Bmatrix} = \begin{bmatrix} \hat{\phi} \\ \hat{\theta} \\ \hat{\psi} \end{bmatrix} - \Delta t \cdot \begin{bmatrix} \tilde{\phi} & 0 & 0 \\ 0 & \tilde{\theta} & 0 \\ 0 & 0 & \tilde{\psi} \end{bmatrix} \cdot \begin{bmatrix} k_\phi \\ k_\theta \\ k_\psi \end{bmatrix}. \tag{7.9}$$

Where $\tilde{\varphi}$, $\tilde{\theta}$, $\tilde{\psi}$ are the state errors. This process minimizes the integration error caused by rate gyro drift. Gains $\begin{bmatrix} k\varphi \\ k\theta \\ k\psi \end{bmatrix}$ are determined empirically in flight. The gains are tuned until the roll and pitch estimates correspond visually with the airplane's behavior during level flight and in coordinated turns. The accuracy of the state estimates in flight has not been determined, as it is not now possible to obtain state sensors small enough and light enough to fly on our aircraft. The same process that is used to estimate roll and pitch (7.5 - 7.9), is used to estimate heading. The only difference is in obtaining the reference value. The reference heading is obtained from the GPS heading. However, because GPS heading is inaccurate when the GPS velocity is low, or when there is poor GPS lock, the heading estimate is only updated when the GPS velocity is above a certain threshold and the GPS has a valid lock. The velocity threshold is determined to be 2 m/s, using empirical data gathered from the GPS receiver. At values above 2 m/s, the GPS heading produced by this receiver is accurate. To produce accurate values, most of the autopilot sensors and the GPS receiver must be calibrated. The calibration routines determine the bias or steady-state value of the sensor in an unexcited state; the calibration routine of the GPS receiver produces the GPS Home Position. The sensors should be calibrated after the autopilot board temperature has stabilized. This usually occurs within 5 minutes of power on. The GPS Home Position is comprised of the latitude, longitude, and altitude of the home position. This is the position that the relative positions of the aircraft (in meters east and meters north) are calculated from. The following formula is used for this calculation:

$$X = (longitude - h\_longitude).cos\left(\frac{h\_latitude}{60\ min/deg} . \frac{\pi}{180}\right).1853.2\ min/meter \tag{7.10}$$

$$Y = (latitude - h\_latitude).1853.2\ min/meter \tag{7.11}$$

The longitude and latitude used in the equation are in minutes. The X and Y position are in meters east and north of GPS Home Position, respectively. The GPS altitude is also referenced from the altitude stored in the GPS Home Position. The home position is also the set of coordinates to which the aircraft will fly, if it loses communication with the ground station. This is typically the coordinates of the ground station. The GPS Home Position is acquired automatically after GPS lock is first acquired. The first five samples after lock are averaged to form the home longitude, home latitude, and home altitude. Because the GPS position tends to drift for some time after GPS lock is acquired, it is advisable to re-acquire the GPS home position once the GPS position has stabilized. This can be accomplished using the button labeled “Gather GPS Home Position” in the ground station.

7.2.4. Control Algorithms

Control algorithms of the aircraft have divided into three levels:

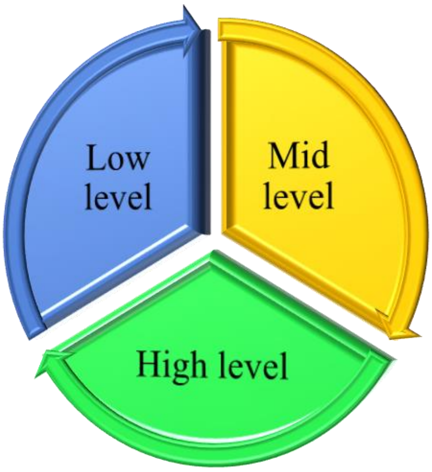


Fig. 7.9 Control algorithm [41]

7.2.4.1. Low Level Control Algorithm

Low-level control of the aircraft is accomplished using the PID loop structure. This is a collection of servo PID loops that produce aileron, elevator, throttle, and rudder outputs and a collection of outer PID loops that produce commanded values for the servo PID loops. Figure 7.10 shows the basic PID loop structure as implemented in the autopilot code. The purpose of the low-level control algorithms is to control the aircraft in the roll and pitch axis, hold a commanded velocity, hold a commanded heading, and hold a commanded altitude. The PID loops are implemented in the autopilot software using Dynamic C structures. The structures contain the proportional, integral, and derivative gains, along with saturation limits on the outputs of the PID loops

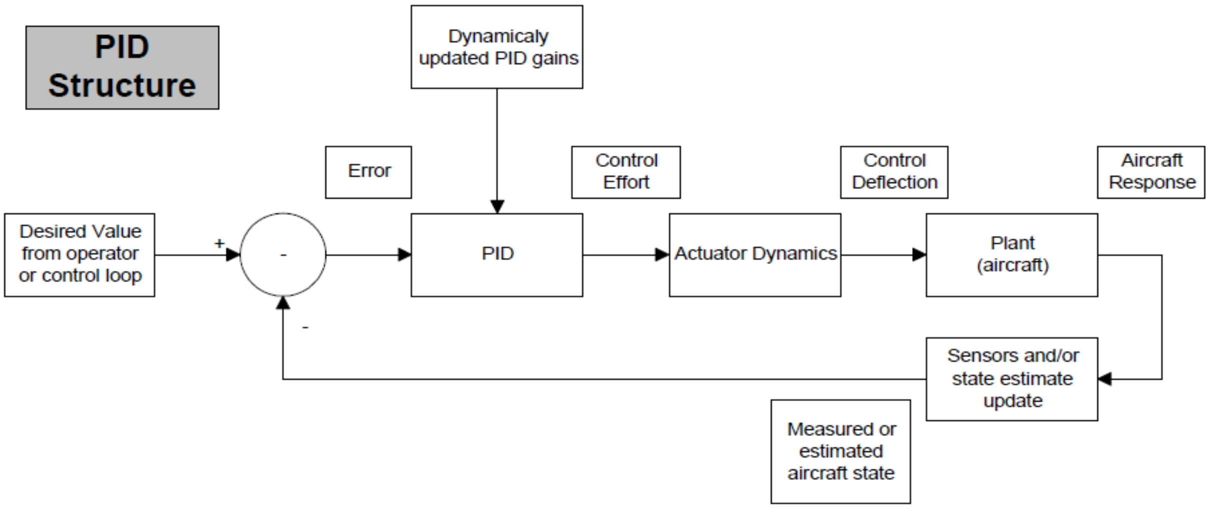


Fig. 7.10 PID loops in the autopilot

The PID structures also contain pointers to access autopilot sensors and actuators. In this way the PID loops can be reconfigured to use any sensor on the autopilot as the reference value, and write the effort to any actuator or variable in the autopilot code. The gains and effort limits can be updated during flight using the ground station software. The gains and effort limits are backed up in the nonvolatile memory of the Processor. A PID structure is instantiated for each PID loop in the pre-main portion of the autopilot code. The structures are initialized with the gains and effort limits and stored in the nonvolatile memory as well as with the hard coded values representing the correct sensors and actuators for each loop. The PID loop efforts are calculated in the main loop, which executes at approximately 130

Hz. Standard PID calculation techniques are used to implement the effort calculations in the source code.

7.2.4.2. Mid Level Control Algorithm

There are two mid-level algorithms on the autopilot. The first is the Altitude Tracker. The purpose of the altitude tracker is to enable the correct PID loops to maintain the commanded altitude in an efficient manner. The second mid-level control algorithm is the Waypoint Navigation script. The Waypoint Navigation script executes the set of navigation commands uploaded to the autopilot by the user. The purpose of the Altitude Tracker is to maintain the aircraft's commanded altitude in an efficient and safe manner. At the heart of the Altitude Tracker are the Throttle from Airspeed and Pitch from Altitude PID loops. When the aircraft is near its commanded altitude, the aircraft's altitude can be controlled easily with small changes in pitch. The altitude error is small in this region; therefore, the commanded pitch angles will also be small and within the maximum angle of attack of the airframe. However, if altitude error is large, the Pitch from Altitude loop will saturate and possibly produce a pitch angle that exceeds the maximum angle of attack of the airframe. A stall will result. The Throttle from Airspeed loop may also have difficulty maintaining airspeed at these high pitch angles, depending on the thrust available from the motor. In the case where the commanded altitude is significantly below the actual altitude, the Pitch from Altitude loop will command a large negative pitch which may cause the aircraft to exceed its maximum structural airspeed of the airframe. The solution to these problems is to reconfigure the PID loops based on the altitude error. This is a technique used in general aviation aircraft. When the altitude error is large, the aircraft pitch is trimmed for a safe and efficient climb or descent airspeed and the throttle is used to control the rate of climb or descend. In the case of a large positive altitude error, the autopilot is configured to use the Pitch from Airspeed PID loop, which regulates the airspeed using pitch. The throttle is set to full for maximum climb performance. As the airspeed is regulated, the aircraft will never enter a stall situation. Once the altitude error is reduced to a set threshold, the Pitch from Altitude and Throttle from Airspeed loops are re-enabled and the Pitch from Airspeed loop is disabled. In the case of a large negative altitude error, the same technique is used to lower the aircraft at a constant airspeed to the desired altitude. The throttle is held at idle and the aircraft is allowed to descend at a safe airspeed. The Waypoint Navigation script executes a set of navigation commands uploaded to the autopilot by the user. Its purpose is to navigate the airplane based on the specific command being executed. There are 8 different waypoint commands that can be executed. The Waypoint Navigation script uses the low-level control algorithms to navigate the airplane. It does this either by commanding heading, altitude, and velocity or by commanding roll angle, altitude, and velocity. The method used is determined automatically by the waypoint command being executed. Waypoints are executed sequentially in the order they are uploaded by the user. When the autopilot finishes the last command, it will re-execute the first command.

7.2.4.3. High Level Control Algorithm

There are two types of high level control algorithms used by the autopilot. The first is the Lost Communication Go Home fail-safe, or Go Home fail-safe . The purpose of this fail-safe is to utilize the navigation capabilities of the autopilot to fly the aircraft back to the GPS Home Position in the event of a communication failure between the aircraft and ground station. The second high level control algorithm is the Pilot-in- Command Lost Communication fail-safe, or PIC fail-safe. The purpose of this failsafe is to utilize the low-level control and navigation capabilities of the aircraft to safely fly the aircraft in the event of a lost communication scenario when the autopilot is in Pilot-in- Command mode (PIC).

7.2.4.3.1. Go Home Fail Safe

It is possible that the communication link between the aircraft and the ground station may be interrupted or lost completely in flight. Several events could cause this. First, the aircraft may simply fly out of range on its way to a waypoint or while being piloted via the video link. Second, the line-of-sight communication path may be temporarily obstructed by obstacles or terrain. Both of these scenarios could potentially result in the loss of the aircraft, as without the communication link there is no way to know the position of the aircraft and no ability to command the aircraft home. The Go Home fail-safe is designed for the lost communications scenario. The Go Home fail-safe operates under the following premises. First, the autopilot will send a navigation status packet to the ground station every time the autopilot receives a packet from the GPS receiver (about once a second). Second, the ground station will send a packet back to the autopilot acknowledging the navigation status packet. Third, the autopilot will have GPS lock while navigating. Under these premises, there will be two-way communication between the autopilot and ground station at least once per second. The Go Home fail-safe algorithm keeps track of the number of navigation status packets that have been sent since the last navigation status acknowledgment was received. If that number exceeds a threshold specified in parameter Lost Communication Go Home Timeout, then it is assumed that the communication link is down and the aircraft is commanded to fly to the GPS Home Position. Once the GPS Home Position is reached, the autopilot is configured to orbit at a constant radius around the GPS Home Position. Flying the aircraft to the home position is intended to reduce the line-of-sight distance to the aircraft and allow for communication with the aircraft to be re-established. At the very least, the user knows where the aircraft is and can retrieve it once the batteries run out.

7.2.4.3.2. PIC Fail Safe

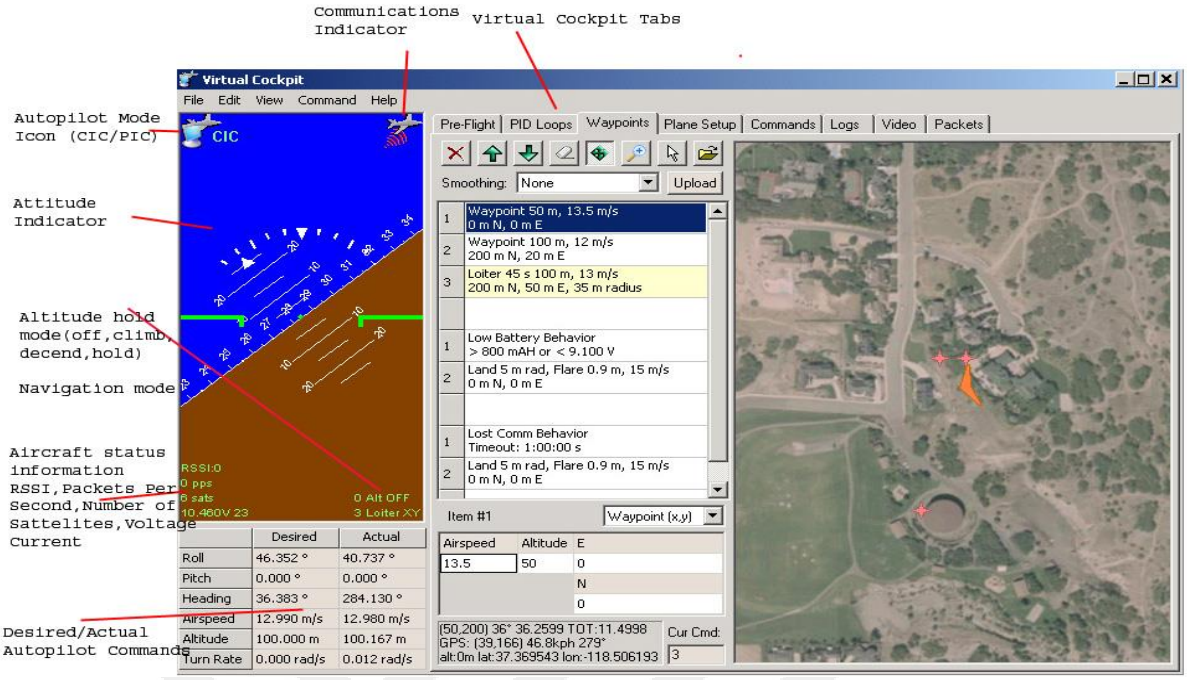
The previous section discusses scenarios that could lead to a loss of communication between the aircraft and ground station. We also discussed the Go Home fail-safe, which will fly the aircraft to the GPS home position if communications are lost while the autopilot is enabled. This section will discuss what happens if communications are lost when the autopilot is not enabled. One method of Pilot-in-the-Loop control of the aircraft is to send the raw elevator, aileron, throttle, and rudder commands generated by the pilot through the communication link. The advantage of this over other methods which use the onboard Bypass circuit and RC receiver is that the Bypass circuit and RC receiver are not required on the aircraft, saving weight and space which can be used for additional payload. The disadvantage is that if the digital communication link between the aircraft and ground station is interrupted for any reason, the pilot will lose control of the aircraft. To address this situation, the PIC fail-safe mode was developed. This fail-safe is active only when Pilot in-the-Loop commands are being sent through the communications link (PIC mode). The second mode is the go-home mode. If communications are not re-established during level mode during a specific period of time, the aircraft flies to the GPS Home Position. Level mode is initiated when no pilot commands are received in the period specified by parameter RC over Comm Level Timeout. This mode is intended to level the aircraft during periods of brief communication interruption. The level mode will exit automatically when communications are re-established. In the level mode, the occurring incidents are described in sequences below. If communications are interrupted, the autopilot will enable itself (switch to CIC mode) and fly itself home if communications are not re-established after a short period of time.

1. Commanded roll angle is set to zero
2. Commanded pitch angle is set to 15 degrees
3. Pitch and roll PID loops are enabled
4. Autopilot is switched to CIC mode
5. Throttle is set to zero

There are two modes in this fail-safe. The first is the level mode. This mode simply engages the autopilot (CIC mode) and holds a nose-up, level flight attitude. If the period of interrupted communication extends past the value specified in the parameter RC over Comm Go Home Timeout, then the autopilot will enter the second stage of the PIC fail-safe. At that point, the autopilot will enable the appropriate PID loops and navigate to the GPS Home Position using the Waypoint Navigation script. To exit PIC fail-safe go-home mode, the user must switch the autopilot to CIC mode, and then back to PIC mode.

7.2.5. Ground Station Software

A graphical interface is needed to control the autopilot. The graphical interface software is known as the Virtual Cockpit. The Virtual Cockpit is a complete system that is used to configure, debug, program, and monitor the autopilot. The Virtual Cockpit shown in figure 7.11 contains several screens accessible by tabs and a Status screen that is always visible. There are several options available in the dropdown menus. The purpose of the Status window is to give the user an indication of the aircraft’s status and health. The Virtual Cockpit has four tab windows, which contain specific control and setup information. The discussion on the Virtual Cockpit will begin with the Status window, and then proceed to the four tab windows: PID Loops, Waypoints, Plane Setup and pre-flight.



RSSI:0
0 pps
6 sats
10.460V 23

0 Alt OFF
3 Loiter XY

	Desired	Actual
Roll	46.352 °	40.737 °
Pitch	0.000 °	0.000 °
Heading	36.383 °	284.130 °
Airspeed	12.990 m/s	12.980 m/s
Altitude	100.000 m	100.167 m
Turn Rate	0.000 rad/s	0.012 rad/s

Smoothing: None

1	Waypoint 50 m, 13.5 m/s 0 m N, 0 m E
2	Waypoint 100 m, 12 m/s 200 m N, 20 m E
3	Loiter 45 s 100 m, 13 m/s 200 m N, 50 m E, 35 m radius
1	Low Battery Behavior > 800 mAH or < 9.100 V
2	Land 5 m rad, Flare 0.9 m, 15 m/s 0 m N, 0 m E
1	Lost Comm Behavior Timeout: 1:00:00 s
2	Land 5 m rad, Flare 0.9 m, 15 m/s 0 m N, 0 m E

Item #1 Waypoint (x,y)

Airspeed	Altitude	E
13.5	50	0
		N
		0

(50,200) 36° 36.2599 TOT:11.4998
GPS: (39,166) 46.8kph 279°
alt:0m lat:37.369543 lon:-118.506193

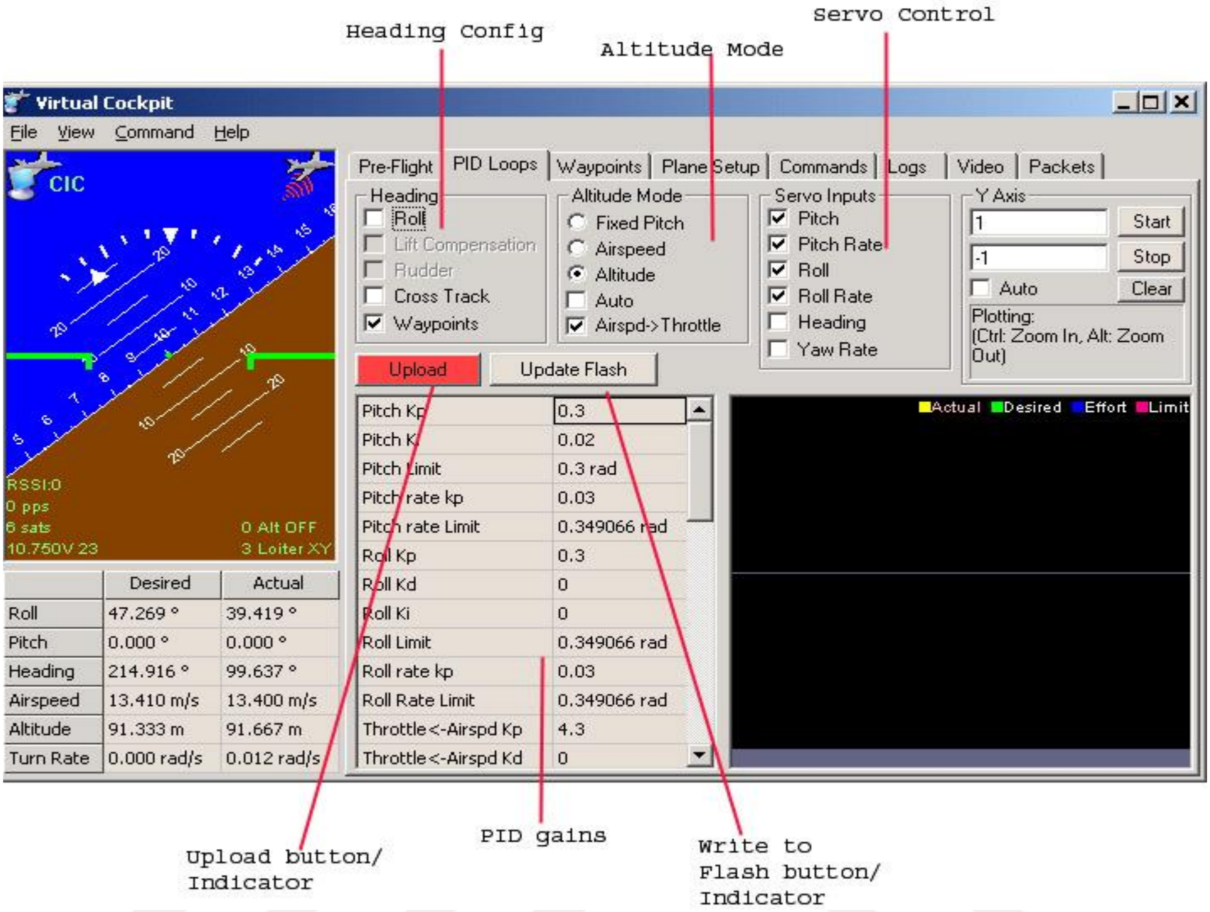
Cur Cmd: 3

Fig. 7.11 Virtual cockpit window

The Status window shown is always visible and contains a collection of vital aircraft status information. The purpose of the Status window is to give the user an indication of the aircraft's status and health. The Status window is divided into two windows: the Attitude Indicator and the Desired/Actual window. The PID Loops tab is used to configure the PID loops on the aircraft. Here the loops can be configured, and gains can be set. The PID Loops tab is shown in figure 7.12. The PID Loops tab is divided into two sections: the PID Control window and the PID Gains window.

The PID Control window is used to enable and disable the PID loops on the autopilot. The PID Control window is further divided into three sections: Servo Inputs window, Altitude Mode window, and Heading Mode window. The PID Gains window is used to set the PID gains on the autopilot.

The Waypoint tab window contains autopilot Waypoint Navigation information. The principle components of the Waypoint tab window are the Map window, the Waypoint Editor window, and the Navigation Status window. The Navigation Status window displays GPS and Waypoint Navigation status information.



RSSI:0
0 pps
6 sats
10.750V 23
0 Alt OFF
3 Loiter XY

	Desired	Actual
Roll	47.269 °	39.419 °
Pitch	0.000 °	0.000 °
Heading	214.916 °	99.637 °
Airspeed	13.410 m/s	13.400 m/s
Altitude	91.333 m	91.667 m
Turn Rate	0.000 rad/s	0.012 rad/s

Heading
☐ Roll
☐ Lift Compensation
☐ Rudder
☐ Cross Track
☑ Waypoints

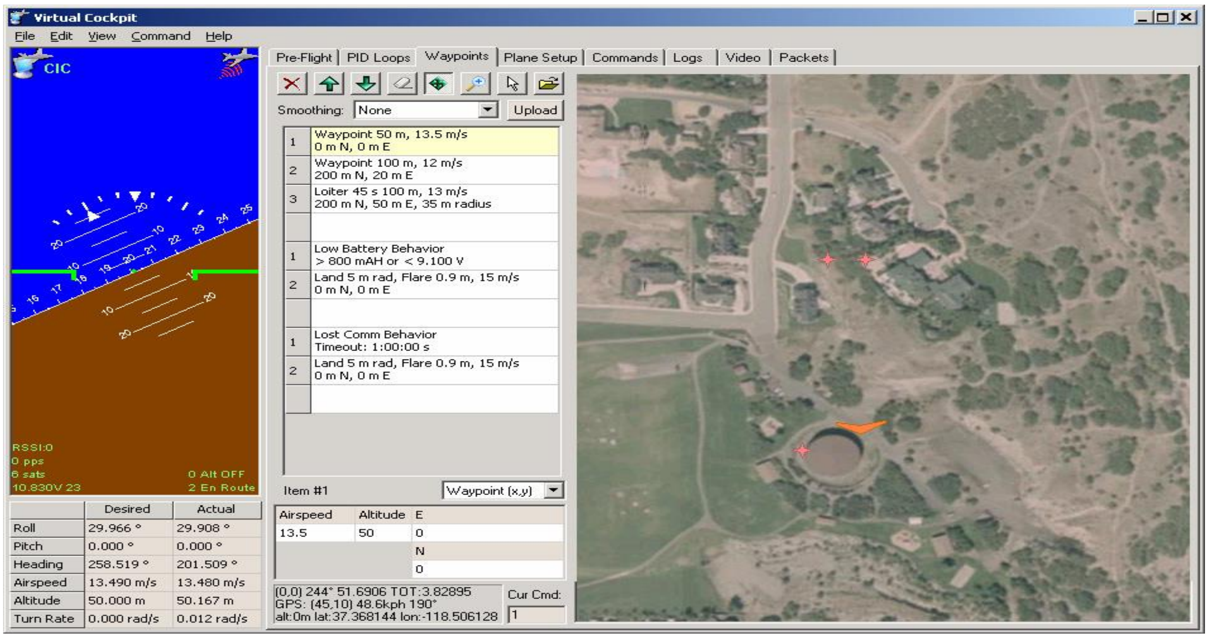
Altitude Mode
○ Fixed Pitch
○ Airspeed
● Altitude
☐ Auto
☑ Airspd->Throttle

Servo Inputs
☑ Pitch
☑ Pitch Rate
☑ Roll
☑ Roll Rate
☐ Heading
☐ Yaw Rate

Y Axis
1
-1
☐ Auto
Plotting:
(Ctrl: Zoom In, Alt: Zoom Out)

Pitch Kp	0.3
Pitch Ki	0.02
Pitch Limit	0.3 rad
Pitch rate kp	0.03
Pitch rate Limit	0.349066 rad
Roll Kp	0.3
Roll Kd	0
Roll Ki	0
Roll Limit	0.349066 rad
Roll rate kp	0.03
Roll Rate Limit	0.349066 rad
Throttle<-Airspd Kp	4.3
Throttle<-Airspd Kd	0

Fig. 7.12 PID loop configuration tab



Smoothing: None

1	Waypoint 50 m, 13.5 m/s 0 m N, 0 m E
2	Waypoint 100 m, 12 m/s 200 m N, 20 m E
3	Loiter 45 s 100 m, 13 m/s 200 m N, 50 m E, 35 m radius
1	Low Battery Behavior > 800 mAH or < 9.100 V
2	Land 5 m rad, Flare 0.9 m, 15 m/s 0 m N, 0 m E
1	Lost Comm Behavior Timeout: 1:00:00 s
2	Land 5 m rad, Flare 0.9 m, 15 m/s 0 m N, 0 m E

Item #1 Waypoint (x,y)

Airspeed	Altitude	E
13.5	50	0
		N
		0

(0,0) 244° 51.6906 TOT:3.82895
GPS: (45,10) 48.6kph 190°
alt:0m lat:37.368144 lon:-118.506128

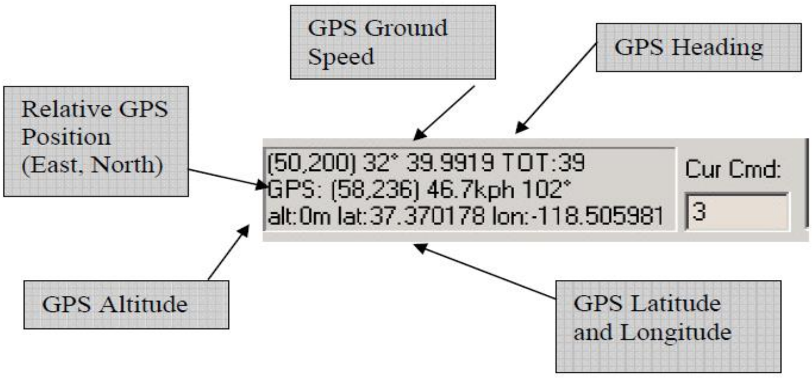
Cur Cmd: 1

RSSI:0
0 pps
6 sats
10.830V 23
0 Alt OFF
2 En Route

	Desired	Actual
Roll	29.966 °	29.908 °
Pitch	0.000 °	0.000 °
Heading	258.519 °	201.509 °
Airspeed	13.490 m/s	13.480 m/s
Altitude	50.000 m	50.167 m
Turn Rate	0.000 rad/s	0.012 rad/s

Fig. 7.13 Waypoint tab window

Waypoint Navigation status information is valid only when Waypoint Navigation is enabled. The Navigation Status window also contains the Current Waypoint Number box. This window shown in figure 7.13 displays the Waypoint Command Number that is currently executing.



```
(50,200) 32° 39.9919 TOT:39
GPS: (58,236) 46.7kph 102°
alt:0m lat:37.370178 lon:-118.505981
```

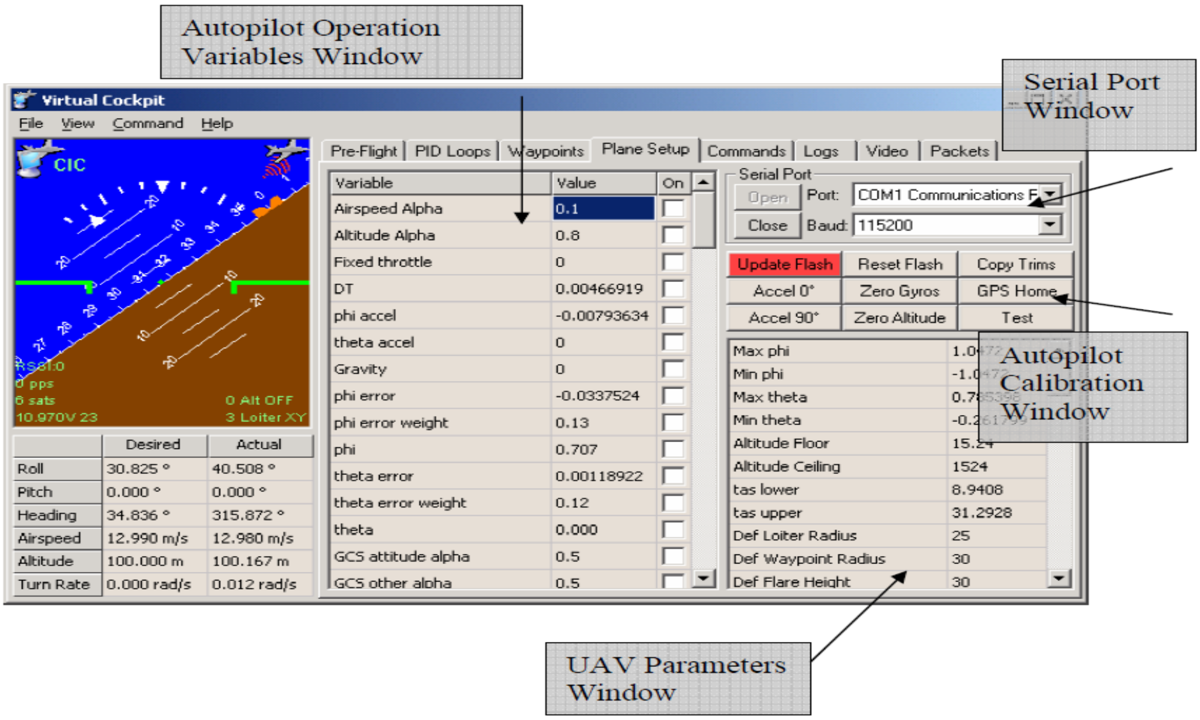
Cur Cmd: 3

Fig. 7.14 GPS information

To command the Navigation script to execute a different Waypoint Command Number, place the mouse cursor in the box, and enter the new waypoint number. The background will change from white to grey when the ground station receives acknowledgment from the autopilot that the new command number was received. Figure 7.14 details the GPS status information visible in the Navigation Status box.

1. GPS Position in meters east and meters north of the GPS Home Position
2. GPS Ground Speed in kilometers/hour
3. GPS Heading in degrees (0 to 360)
4. GPS Altitude in meters above the GPS Home Position
5. GPS Latitude and Longitude in degrees

The autopilot is a complex system of sensors and software which must be setup and calibrated to function correctly. Because of the risks associated with UAV flight, it is important to carefully test the critical components of the system before each flight. Figure 7.15 describes the setup window of the autopilot.



Port: COM1 Communications P
Baud: 115200

	Desired	Actual
Roll	30.825 °	40.508 °
Pitch	0.000 °	0.000 °
Heading	34.836 °	315.872 °
Airspeed	12.990 m/s	12.980 m/s
Altitude	100.000 m	100.167 m
Turn Rate	0.000 rad/s	0.012 rad/s

Variable	Value	On
Airspeed Alpha	0.1	☐
Altitude Alpha	0.8	☐
Fixed throttle	0	☐
DT	0.00466919	☐
phi accel	-0.00793634	☐
theta accel	0	☐
Gravity	0	☐
phi error	-0.0337524	☐
phi error weight	0.13	☐
phi	0.707	☐
theta error	0.00118922	☐
theta error weight	0.12	☐
theta	0.000	☐
GCS attitude alpha	0.5	☐
GCS other alpha	0.5	☐

Max phi	1.0472
Min phi	-1.0472
Max theta	0.785398
Min theta	-0.261799
Altitude Floor	15.24
Altitude Ceiling	1524
tas lower	8.9408
tas upper	31.2928
Def Loiter Radius	25
Def Waypoint Radius	30
Def Flare Height	30

Fig. 7.15 Plane setup window

It is much easier to detect and fix a small problem before flight, then pick up the pieces after a crash. The purpose of this section is to outline a pre-flight procedure that is quick, and thorough. This procedure should be carefully followed and checked off a step at a time before each UAV flight.

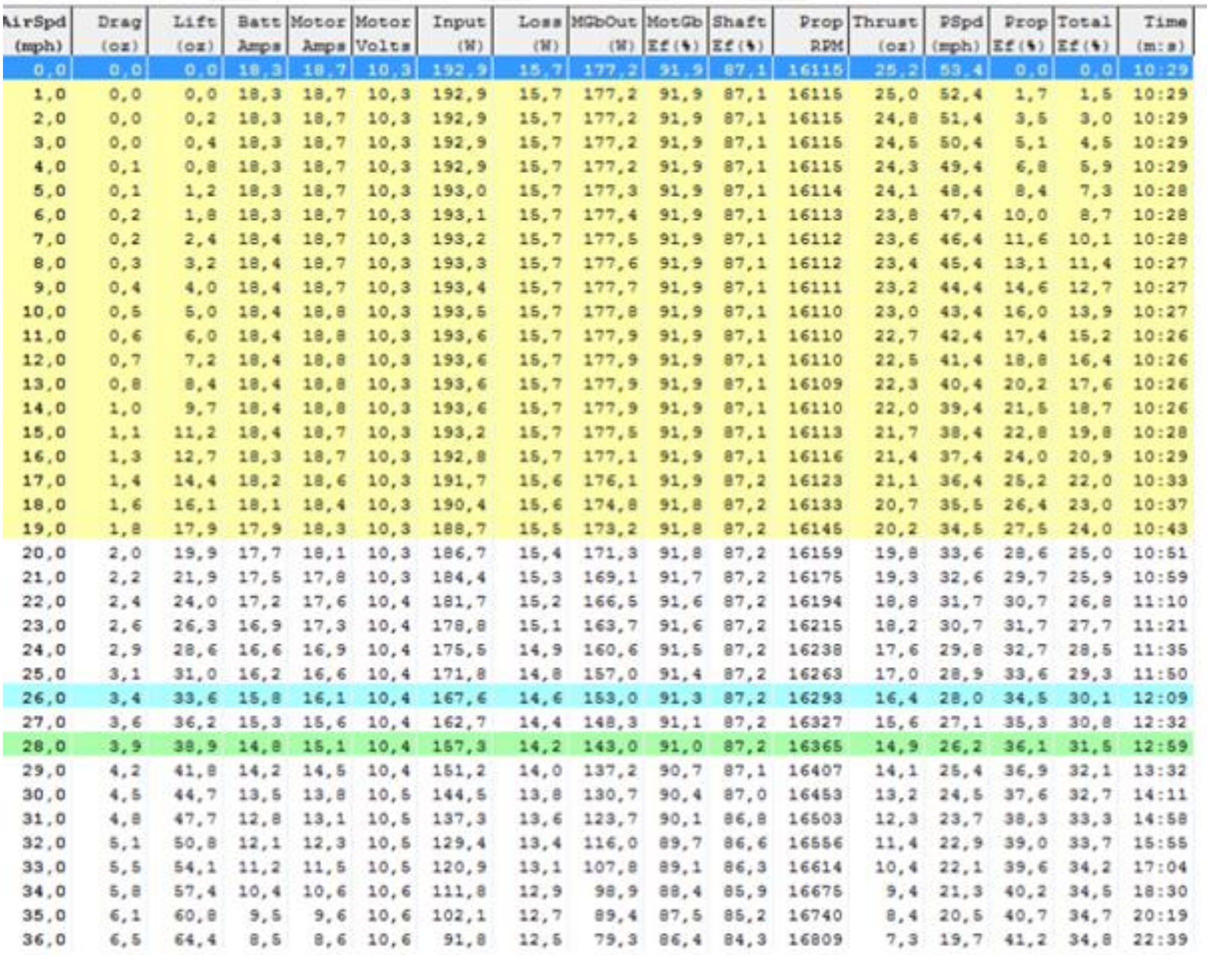
1. • Power on the laptop computer and load the Virtual Cockpit software.
2. •Power on the RC controller
3. •Set the throttle stick to 0 throttle
4. •Switch the channel 5 (landing gear) to the PIC position (away from the pilot)
5. •Power on the ground station hardware
6. •Power on the autopilot
7. •Verify communications with the ground station by checking the Communications indicator
8. •Verify the autopilot is in PIC mode by checking the Autopilot Mode indicator
9. •Aircraft should be located where the GPS receiver has a clear view of the sky
10. •Check the control surfaces and propulsion system

The aircraft can be landed using the Land command or in PIC mode. To land the aircraft, simply upload a Land waypoint command. After the aircraft lands, use caution when retrieving the aircraft as it may enter a lost communication fail-safe mode which could cause the propeller to turn on. This can happen when the landing area is not in line of sight with the ground station, causing a loss of communication with the ground station. To land the aircraft manual in PIC mode, flip to PIC mode and land the aircraft. Keep the autopilot in CIC mode until the power is removed to ensure the propeller does not spin up.

8. RESULT AND DISCUSSION

8.1. Simulation Result

Result and discussion of this work can be divided into two parts. First, the author tested all parameters according to the preliminary design and estimation. A simulation software named *motocalc* was used in that purpose. The early estimation of the power and propulsion systems has been tested here. In result, motor and propeller performances, battery efficiency, airspeed, drag, thrust, power and losses have come out. The simulation results were then counted safe parameters and helped to design an error free aircraft. Second, the proposed aircraft was built and tested in real time environment.



AirSpd (mph)	Drag (oz)	Lift (oz)	Batt Amps	Motor Amps	Motor Volts	Input (W)	Loss (W)	MGbOut (W)	MotGb Ef(%)	Shaft Ef(%)	Prop RPM	Thrust (oz)	PSpd (mph)	Prop Ef(%)	Total Ef(%)	Time (m:s)
0,0	0,0	0,0	18,3	18,7	10,3	192,9	15,7	177,2	91,9	87,1	16115	25,2	53,4	0,0	0,0	10:29
1,0	0,0	0,0	18,3	18,7	10,3	192,9	15,7	177,2	91,9	87,1	16115	25,0	52,4	1,7	1,5	10:29
2,0	0,0	0,2	18,3	18,7	10,3	192,9	15,7	177,2	91,9	87,1	16115	24,8	51,4	3,5	3,0	10:29
3,0	0,0	0,4	18,3	18,7	10,3	192,9	15,7	177,2	91,9	87,1	16115	24,5	50,4	5,1	4,5	10:29
4,0	0,1	0,8	18,3	18,7	10,3	192,9	15,7	177,2	91,9	87,1	16115	24,3	49,4	6,8	5,9	10:29
5,0	0,1	1,2	18,3	18,7	10,3	193,0	15,7	177,3	91,9	87,1	16114	24,1	48,4	8,4	7,3	10:28
6,0	0,2	1,8	18,3	18,7	10,3	193,1	15,7	177,4	91,9	87,1	16113	23,8	47,4	10,0	8,7	10:28
7,0	0,2	2,4	18,4	18,7	10,3	193,2	15,7	177,5	91,9	87,1	16112	23,6	46,4	11,6	10,1	10:28
8,0	0,3	3,2	18,4	18,7	10,3	193,3	15,7	177,6	91,9	87,1	16112	23,4	45,4	13,1	11,4	10:27
9,0	0,4	4,0	18,4	18,7	10,3	193,4	15,7	177,7	91,9	87,1	16111	23,2	44,4	14,6	12,7	10:27
10,0	0,5	5,0	18,4	18,8	10,3	193,5	15,7	177,8	91,9	87,1	16110	23,0	43,4	16,0	13,9	10:27
11,0	0,6	6,0	18,4	18,8	10,3	193,6	15,7	177,9	91,9	87,1	16110	22,7	42,4	17,4	15,2	10:26
12,0	0,7	7,2	18,4	18,8	10,3	193,6	15,7	177,9	91,9	87,1	16110	22,5	41,4	18,8	16,4	10:26
13,0	0,8	8,4	18,4	18,8	10,3	193,6	15,7	177,9	91,9	87,1	16109	22,3	40,4	20,2	17,6	10:26
14,0	1,0	9,7	18,4	18,8	10,3	193,6	15,7	177,9	91,9	87,1	16110	22,0	39,4	21,5	18,7	10:26
15,0	1,1	11,2	18,4	18,7	10,3	193,2	15,7	177,5	91,9	87,1	16113	21,7	38,4	22,8	19,8	10:28
16,0	1,3	12,7	18,3	18,7	10,3	192,8	15,7	177,1	91,9	87,1	16116	21,4	37,4	24,0	20,9	10:29
17,0	1,4	14,4	18,2	18,6	10,3	191,7	15,6	176,1	91,9	87,2	16123	21,1	36,4	25,2	22,0	10:33
18,0	1,6	16,1	18,1	18,4	10,3	190,4	15,6	174,8	91,8	87,2	16133	20,7	35,5	26,4	23,0	10:37
19,0	1,8	17,9	17,9	18,3	10,3	188,7	15,5	173,2	91,8	87,2	16146	20,2	34,5	27,5	24,0	10:43
20,0	2,0	19,9	17,7	18,1	10,3	186,7	15,4	171,3	91,8	87,2	16159	19,8	33,6	28,6	25,0	10:51
21,0	2,2	21,9	17,5	17,8	10,3	184,4	15,3	169,1	91,7	87,2	16175	19,3	32,6	29,7	25,9	10:59
22,0	2,4	24,0	17,2	17,6	10,4	181,7	15,2	166,5	91,6	87,2	16194	18,8	31,7	30,7	26,8	11:10
23,0	2,6	26,3	16,9	17,3	10,4	178,8	15,1	163,7	91,6	87,2	16215	18,2	30,7	31,7	27,7	11:21
24,0	2,9	28,6	16,6	16,9	10,4	175,5	14,9	160,6	91,5	87,2	16238	17,6	29,8	32,7	28,5	11:35
25,0	3,1	31,0	16,2	16,6	10,4	171,8	14,8	157,0	91,4	87,2	16263	17,0	28,9	33,6	29,3	11:50
26,0	3,4	33,6	15,8	16,1	10,4	167,6	14,6	153,0	91,3	87,2	16293	16,4	28,0	34,5	30,1	12:09
27,0	3,6	36,2	15,3	15,6	10,4	162,7	14,4	148,3	91,1	87,2	16327	15,6	27,1	35,3	30,8	12:32
28,0	3,9	38,9	14,8	15,1	10,4	157,3	14,2	143,0	91,0	87,2	16365	14,9	26,2	36,1	31,5	12:59
29,0	4,2	41,8	14,2	14,5	10,4	151,2	14,0	137,2	90,7	87,1	16407	14,1	25,4	36,9	32,1	13:32
30,0	4,5	44,7	13,5	13,8	10,5	144,5	13,8	130,7	90,4	87,0	16453	13,2	24,5	37,6	32,7	14:11
31,0	4,8	47,7	12,8	13,1	10,5	137,3	13,6	123,7	90,1	86,8	16503	12,3	23,7	38,3	33,3	14:58
32,0	5,1	50,8	12,1	12,3	10,5	129,4	13,4	116,0	89,7	86,6	16556	11,4	22,9	39,0	33,7	15:55
33,0	5,5	54,1	11,2	11,5	10,5	120,9	13,1	107,8	89,1	86,3	16614	10,4	22,1	39,6	34,2	17:04
34,0	5,8	57,4	10,4	10,6	10,6	111,8	12,9	98,9	88,4	85,9	16675	9,4	21,3	40,2	34,5	18:30
35,0	6,1	60,8	9,5	9,6	10,6	102,1	12,7	89,4	87,5	85,2	16740	8,4	20,5	40,7	34,7	20:19
36,0	6,5	64,4	8,5	8,6	10,6	91,8	12,5	79,3	86,4	84,3	16809	7,3	19,7	41,2	34,8	22:39

Fig. 8.1 Performance calculation of the propulsion system

The test flights were tremendous and the aircraft was totally controllable. While testing the aircraft with raw payloads other than important electronic devices and broadcasting system, the aircraft flight characteristics were different than normal because of center of gravity problem. After the weight distribution correctly, the flights were very smooth and stable. Although the aircraft characteristics were good according to the design but it also has some limitations. The limitations and future work will be discussed at the end of the chapter. The figure 8.1 describes the onboard data of the aircraft in simulation environment. The figure gives us the data of airspeed, power losses, aircraft speed, propeller rotation, efficiencies and other required information. These data were used to calculate for the power system and helped the author to design the aircraft without error.

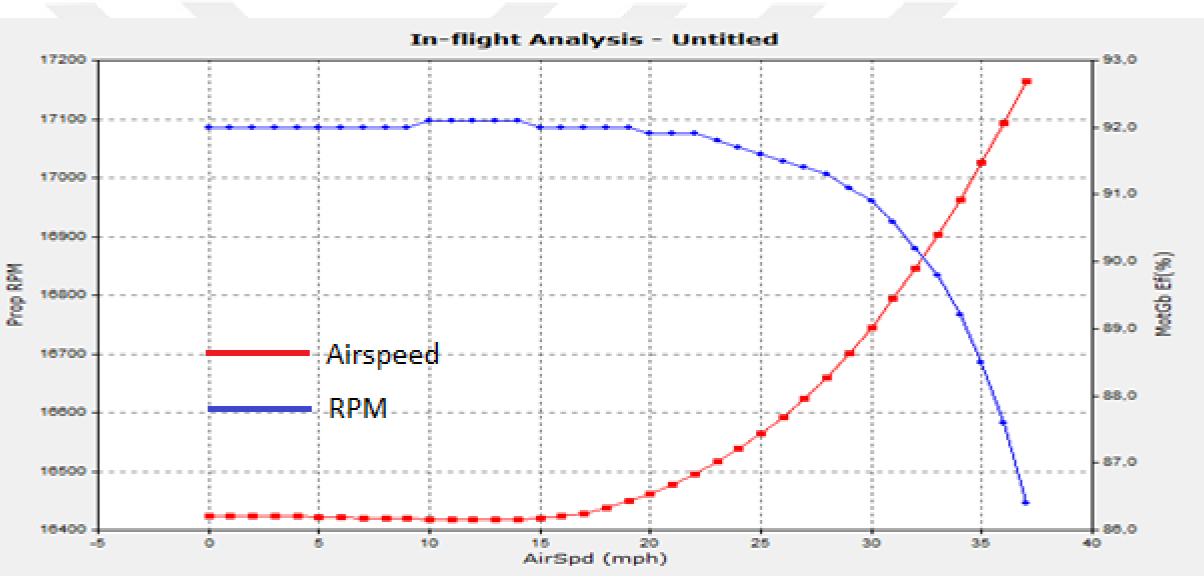


Fig. 8.2 In flight analysis RPM vs airspeed

The figure 8.2 shows the characteristic of the propeller performance according to airspeed and also shows how airspeed effects the RPM thus effects the efficiency of the motor. When the battery is fully charged the motor starts rotating at full speed. The figure shows that at initial condition the propeller rotates with a speed of 17000 RPM. At airspeed 0 to 10 mph the rotation remains same and stable until the airspeed reaches to 20 mph. After that, with increasing of airspeed the rotation decreases slightly. At airspeed 32 mph they intersect each other where the motor efficiency reached to 90%. The thing which has to be understood that increasing airspeed causes more loses. Because the aircraft flies with a certain payloads but more airspeed produces more drag thus more resistance. Thus higher airspeed causes lower rotation and causes more losses.

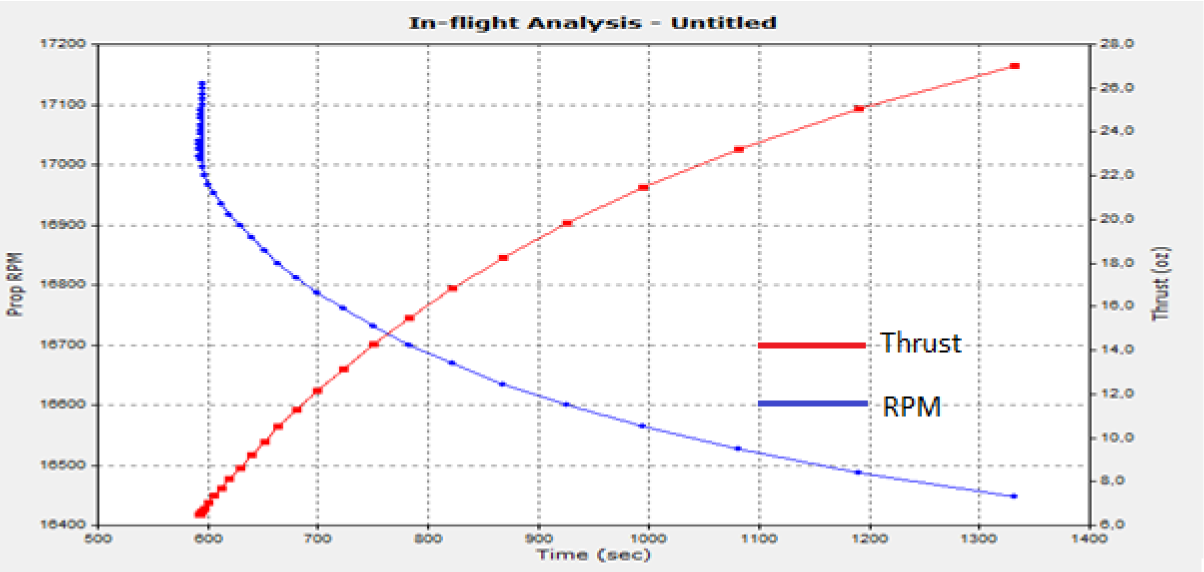


Fig. 8.3 In flight analysis RPM vs Thrust (oz)

The figure shown 8.3 above describes the ration between the thrust and propeller rpm. As we see thrust increases with the propeller speed of rotation and vise-versa. The thrust also increases with time after the initial the condition.

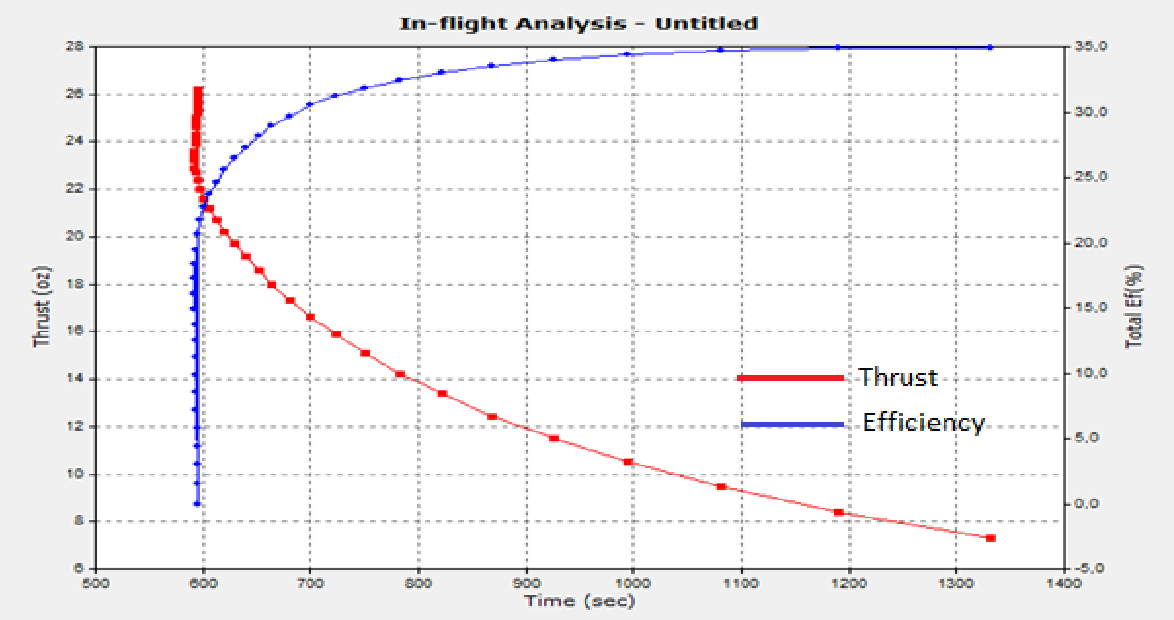


Fig. 8.4 In flight analysis thrust vs efficiency

The efficiency of the total propulsion system also depends on the thrust. As the thrust increases with time the total efficiency also increases and vice-versa shown in figure 8.4. It can be noted that before taking off the aircraft faces more drag, as it flies drag decreases and thrust increases which causes the frequency increment.

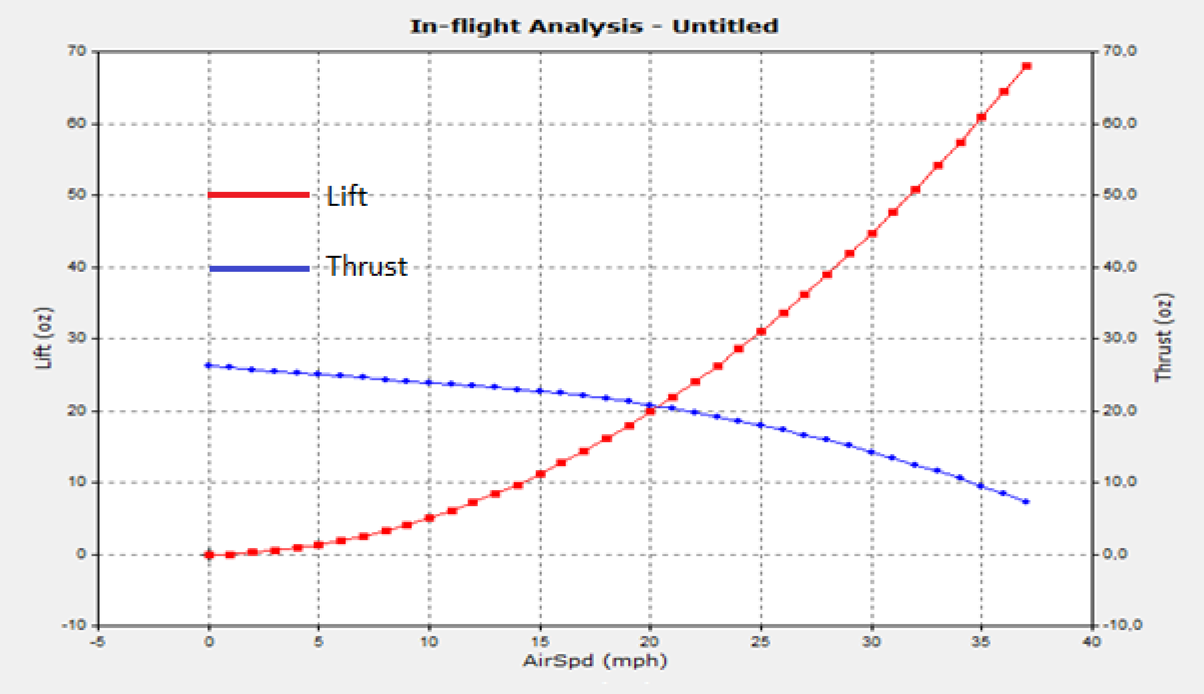


Fig. 8.5 In flight analysis thrust vs lift

The figure 8.5 gives a graph to compare lift, airspeed and thrust. Increasing of thrust increases the lift. Therefore, aircraft climbs higher. The elevator of the aircraft gives enough lift when it has enough thrust. Also, when the rpm of the aircraft decreases or the when aircraft tries landing the elevator can produce small lift to maintain its position. One interesting thing is, if you have a small or lighter UAV with a good aspect ratio wing and you lost your engine or motor not very far from ground you can able to land your aircraft without any damage. In that case, your wing will keep your aircraft on sky and your elevator will produce small lift so that you can able to control lift without producing any thrust by its motor.

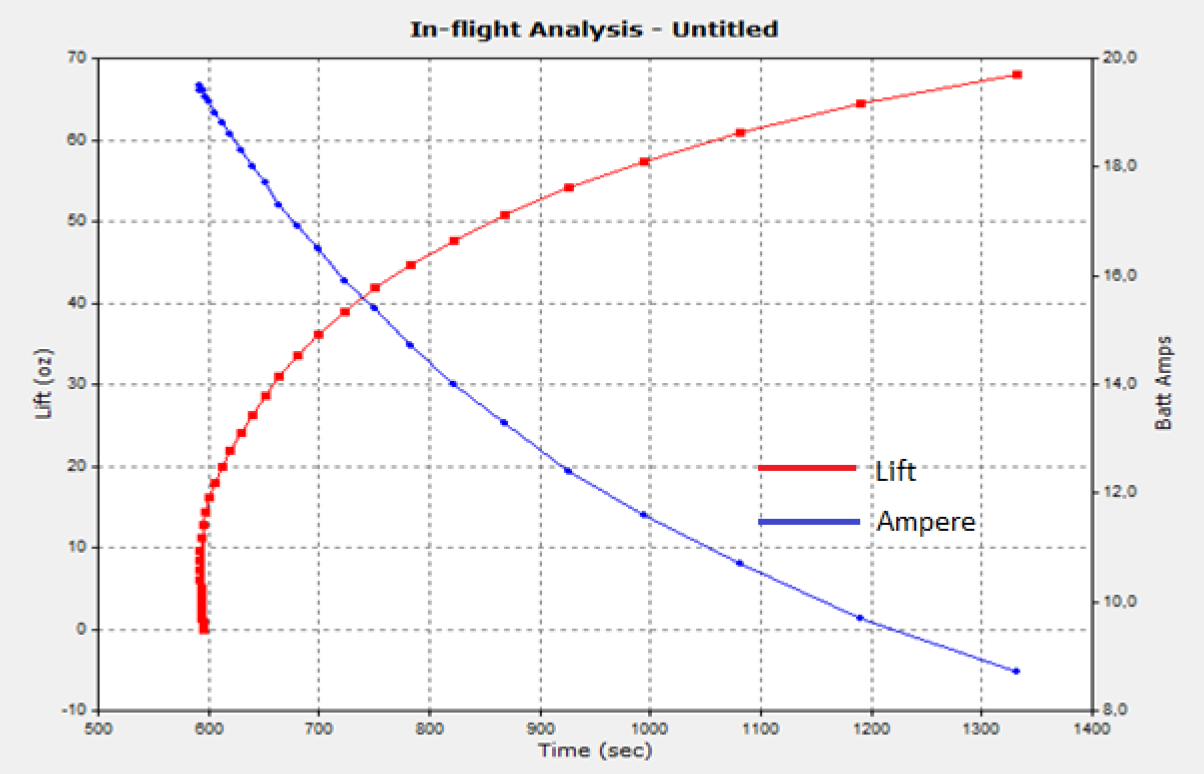


Fig. 8.6 In flight analysis lift vs current

The discussion of the graphs clearly show that to produce more lift the aircraft needs more speed. To give more speed the motor should run faster. As the motor runs fast its propeller produces more currents shown in figure 8.6. So we can say the higher the Amps the higher the lift and vice-versa.

8.2. Real-Time Result

The real-time result of the aircraft was not so different than the simulation result. Before building the aircraft the parameters and propulsion system was tested with *motocalc* simulation software. After that the systems of the aircraft estimated and finally the aircraft constructed. The aircraft then was ready for its first fly. Unfortunately the first flight was not succeeded. The aircraft was a little heavier and its center of gravity was not at the exact position. Finding these problems were not easy. But a series of test and experiments helped to come with a stable aircraft. A number of test flights were taken place of the aircraft. In every case, something different was tested. As the work was more emphasized on aerodynamic contribution a number of wings were tested to give the aircraft more strength against airspeed. Although the aircraft is a fixed wing aircraft but its wings are able to give aerobatic rotation with full control. Thus the author contributes to design a fixed wind unmanned aircraft with full aerodynamic control which is more stable even in a bad weather condition and able to fly using short distance.

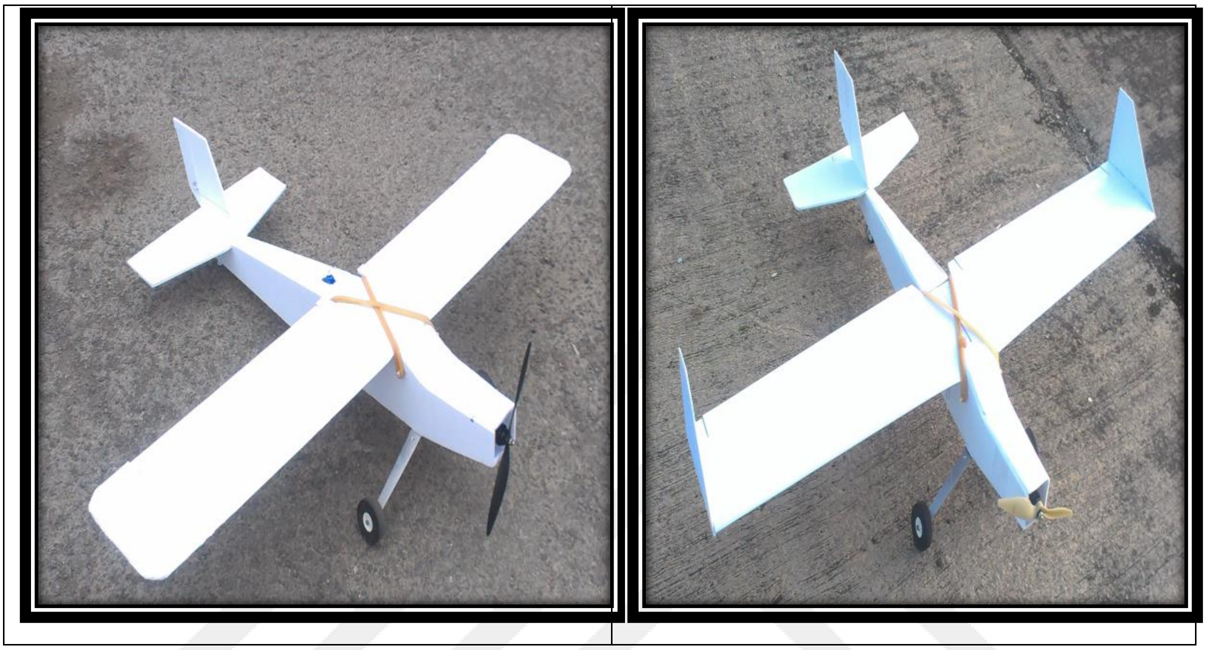


Fig. 8.7 Aircrafts on runway (a)

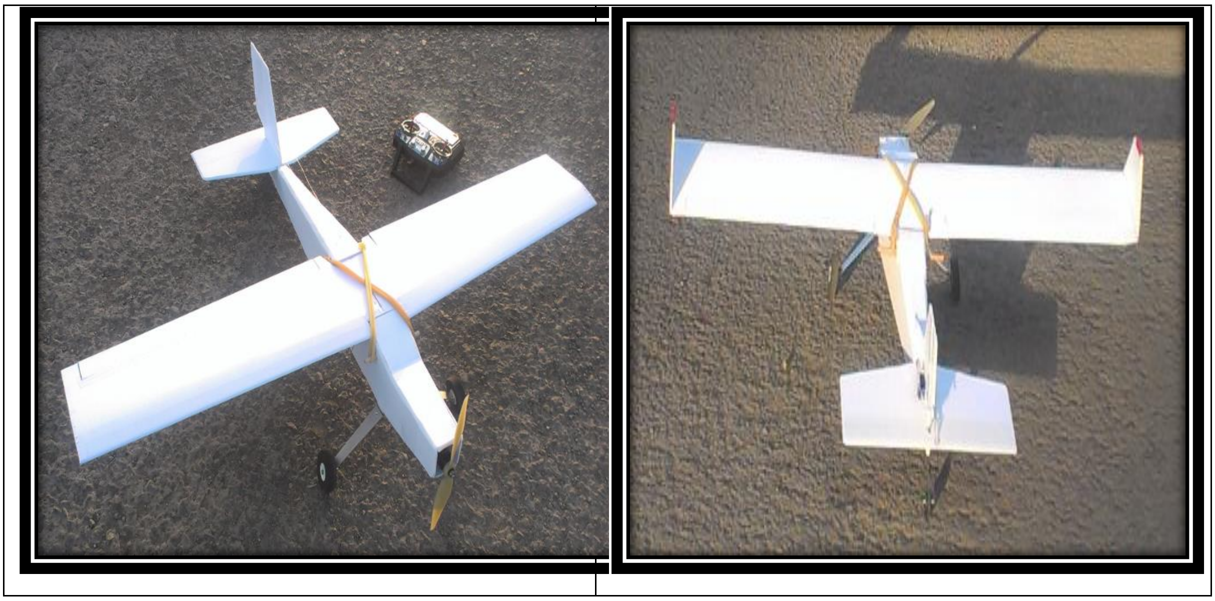


Fig. 8.7 Aircrafts on runway (b)

In figure 8.7 we can see four different wings of the aircraft. The first one without tips is lighter among them. Its wing is completely flat and 1^0 dihedral angle. It can take off with less thrust and take short distance to fly. The second aircraft has an aerodynamic wing with tips. This aircraft is very efficient to fly in bad weather. Its tips help the aircraft to control easily. The tips works as gyros and help the aircraft to maintain its position automatically. The third aircraft is a super aerobatic aircraft instead of having an upper fixed wing. This aircraft is the fastest among them. Its total efficiency is also high. The dynamic aerobatic design of the aircraft makes it superior among others. Finally, the fourth one has a heavy wing with tips. It was tested to carry heavy payload and the tips were added to control the aircraft easily. Although tips produce more drug thus efficiency becomes less but it helps the aircraft from complete damage. All the aircrafts gave expected result and flied good. A real time video payload system was used to capture images from planned area. The mission was succeeded and the aircraft returned safely to the base completing pre-planned mission.

Fig. 8.8 Flying of the aircrafts

The figure 8.8 shows the flying bird on the sky. An aircraft with tips and without tips were tested. From the figure it is quiet understable the stability of the aircrafts when flying. The figure 8.9 shows images that was taken by the UAV. To take the images a real-time video payload system was used. An area was planned before the flight which had be covered by the aircraft. The aircraft successfully covered the area according to pre-planned mission and sent the videos to the base.

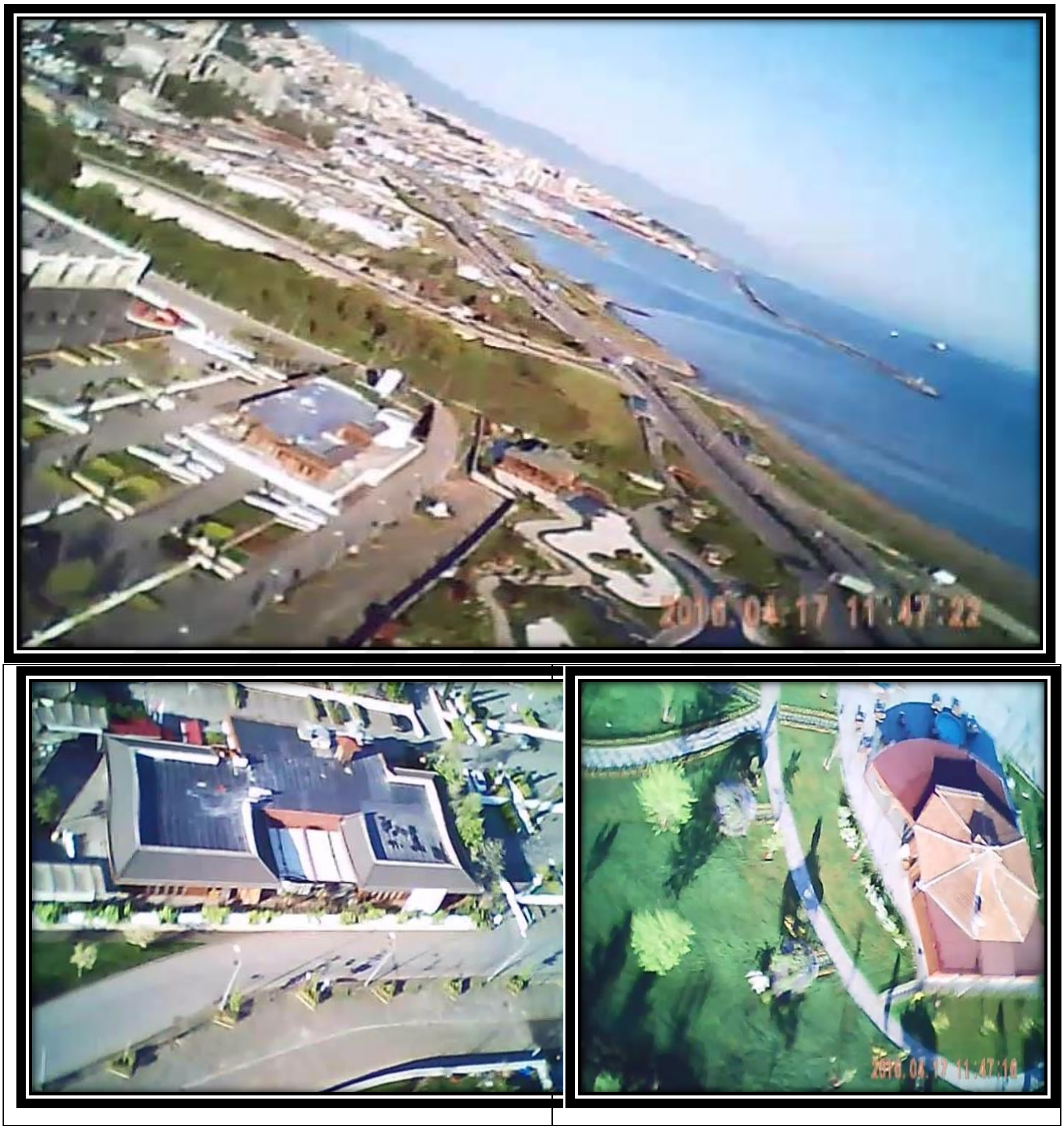


Fig. 8.9 Mission images of the aircraft

The images of the figure 8.9 shows the mission success of the aircraft. Actually the payload camera sent video signals to the base and the images are collected from the video file. The mission area was near the Black Sea. The Forum Trabzon and the 100. Yil Park were covered under the mission. First, the author pointed some areas and flied the aircraft according to the plan. The aircraft flied really well on the Black Sea even the airspeed was high. The flight was counted approximately 15 minutes and returned to the base after successfully completing its mission. The aerobatic flying capacity was also tested during its fly with full load. It can fly like a fighter jet. Although it can spin 360^0 and able to fly backward direction but the aircraft is totally controllable under every condition.

8.3. Limitation

Although the project was successful but it has some limitations. From the beginning of the project until the end every system worked so well. The aircraft system, designs, aerodynamic modeling, different wings for different reasons and video system have passed according to desires. In spite of describing a total autopilot system the autonomous flight of the aircraft was not so successful. The hilly area and high rise buildings were the reasons for radio failure.

8.4. Future Work

Many new developments are taking place every day in unmanned aircraft systems. Technologies have come out to improve power-plants, materials and sensors. In the past, UAV systems gained through the technology spin-off from other endeavors, now much research into new technology is being addressed purely to advance UAV systems. Vertical takeoff and Landing (VTOL) and collision avoid techniques have the most priorities. The author also trying to develop a parachute system if every safety systems fall. For a small unmanned aircraft power resource always a thinking matter. With batteries it is not possible to fly very long distance. Using solar cells could be a solution but in that case wings size is a problem. Fuel cells and super-capacitors may be thinkable. The author is developing an internet based interface to control the aircraft from everywhere. The application of unmanned aircraft becomes very popular in some developed countries. They use them both civil and military purposes. But the scopes are much wider than we think. Almost every country including the U.S. spend millions of dollars each year patrolling borders with conventional aircrafts. Fire fighting and law enforcement costs are also not less than this. If border agents were equipped with low-cost Micro UAVs, thousands of dollars could be saved, as UAVs cost much less then similarly equipped full-size aircraft. In the private sector, there also exists a range of surveillance applications for UAVs. One example is use by the media. Newscasters spend millions of dollars on helicopters to cover breaking news stories. Micro UAVs could be carried by news crews and launched over a breaking story to gather aerial footage immediately. The Micro UAVs would also pose less risk to the civilian population than low-flying full sized helicopters. It is likely that as Micro UAVs become available, they will be employed in many more applications to cut cost and improve coverage. One objective of this thesis was also to show the scope and future of the unmanned aircrafts. It can be now easily understood their possibilities in operation in various sectors. The author now working on sense and avoid technology and the VTOL operation. Using extra motors on wings can be a solution of VTOL flight. A pilot controlled parachute system can be implemented also to save the aircraft in the worst condition. These systems including fully autonomous flight of the aircraft will be published as scientific papers.

9. REFERENCES

1. Barton, J., Fundamental of Small Unmanned Aircraft Flight, Johns Hopkins APL Technical Digest, 31,2 (2012) 132-149.

2. Koldaev, A., Non Military UAV Applications, Research, 2007.

3. Mueller, T., and Delaurier, J., Aerodynamics of Small Vehicles, Fluid Mechanics, 89 (2003) 89-111.

4. Deschenes, A., Brown, K., Sobin, A. and West, G., Design, Construction, and Testing of RC Aircraft for a Hybrid Propulsion System, 49th AIAA Aerospace Sciences Meeting including the New Horizons Forum and Aerospace Exposition, January 2011, Orlando, Florida.

5. Aircraft Components and Subsystems, Anderson 2000.

6. Vural, M., Estimating RC Model Aerodynamics and Performance, NMAE, Illinois Institute of Technology, U.S.A, 2010.

7. Jayabalan, N., and Leng, G., Reverse Engineering and Aerodynamic Analysis of a Flying Wing UAV, Aeronautical Engineering Group, National University of Singapor, 2010.

8. Selig, M., Modeling Full-Envelope Aerodynamics of Small UAVs in Realtime, AIAA Atmospheric Flight Mechanics 2010 Conference, Toronto, Ontario, Canada. 2010.

9. Chattapadhyay, N. and Khan, K., Design, Analysis and Fabrication of Experimental Aircraft: A challenge for pioneers, Proceedings of the World Congress of Engineering, July 2013, London, U.K.

10. Siwaraju, A., Design and Fabrication of Small Scale Trainer Aircraft, Bachelor Degree Report, Pahang Univeristy, Malaysia, 2010.

11. Krishna, N., Design, Fabrication and System Integration of a Medium Range Low Altitude Fixed Wing UAV, Bachelor Degree Project, Hindistan College of Engineering, Chennai, India, 2010.

12. Gallart, M., Development of a Design Tool for Aerodynamic Shape Optimization of Airfoils, Master Thesis, University of Victoria, 2004.

13. Mullen, G., Aircraft Parameter Identification Using MATLAB, College of Aeronautics Report, Cranfield University, England, 2000.

14. Statzer, M., Low Cost Expandable UAV project, Final Design Presentation, Virginia, 2003.
15. Dutta, S., Design/Build/Fly The Evolution of a Model Airplane, Tennessee Research and Creative Exchange, University of Tennessee, Knoxville, 2008.
16. Raymer, D., Aircraft Design: A Conceptual Approach, American Institute of Aeronautics and Astronautics Inc., Washington, 2002.
17. Manske, C., Unmanned Airlift, Cadre Paper, Air University, Air University Press, 2004.
18. Scholz, D., Aircraft - From Conceptual Design to Flight Testing, Presentation for EWADE, Hamburg University of Applied Science, Germany, 2007.
19. Kumar, P., Design of an Unmanned Aerial Vehicle Using Commercial Off-The-Shelf Components, Project Work, Polytechnic Institute of New York University, Brooklyn, 2008.
20. Roskam, J., Airplane Design, Roskam Aviation and Engineering Corp., Ottawa, 1985.
21. Amadori, K., Geometry Based Design Automation- Applied to Aircraft Modelling and Optimization, Linkoping University, Sweden, 2012.
22. Dansie, J., Model Aircraft Design, Teaching Series, Melbourne, Australia, 2002.
23. Concrete, T., Aircraft Design Report, AIAA Cessna/Raytheon Design/Build/Fly Competition, Massachusetts Institute of Technology, U.S.A., 2008.
24. Mehta, A., Joshi, C., Solanki, K., and Yadav, S., Design and Fabrication of Solar R/C Model Aircraft, International Journal of Modern Engineering Research (IJMER), 3,2 (2013) 752-758.
25. Austin, R., Unmanned aircraft Systems, Design, Development and Deployment, Willey, 2010.
26. Budiyonu, A., Design and Development of Autonomous Uninhabited Air Vehicles at ITB: Challenges and Progress Status, Aerospace Indonesia Meeting, Bandung, Indonesia, 2005.
27. Noth, A., Engel, W and Siegwart, R., Design of an Ultra Lightweight Autonomous Solar Airplane for Continuous Flight, Autonomous Systems Lab,1-12, (2012).
28. Tegeder, T., Development of an Efficient Solar Powered Unmanned Aerial Vehicle with an Onboard Solar Tracker, Master Thesis, Brigham Young University, Utah, U.S.A., 2007.

29. Christiansen, R., Design of an Autopilot for Small Unmanned Aerial vehicles, Master Thesis, Brigham Young University, Utah, U.S.A., 2004.

30. Bappy, A., Design and Development of Unmanned Aerial Vehicle (Drone) for Civil Applications, Bachelor Thesis Project, Brac University, Dhaka, Bangladesh, 2014.

31. Garner, W., Model Airplane Propellers, Documentary, 2009.

32. Julicher, J., RC Aircraft Motor Control, Microchip Technology Inc., 2002.

33. Arslan, Oktay., and Inalhan, G., Design of a decision Support Architecture for Human Operators in UAV Fleet C2 Application, Controls and Avionics Laboratory, Istanbul Technical University, Istanbul, 2009.

34. Bayliss, J., Unmanned Aerial Vehicle, Bachelor Thesis, Florida International University, U.S.A., 2013.

35. Ippolito, C., An Autonomous Autopilot Control System Design for Small-Scale UAVs, NASA Ames Research Center, U.S.A, 2005.

36. Peddle, I., Autonomous Flight of a Model Aircraft, Master Thesis, University of Steelbosch, South Africa, 2005.

37. Valavanis, K., Unmanned Aircraft system, International Symposium of Unmanned Aerial Vehicles, UAV’08, Journal of Intelligent & Robotic Systems, 54,3 (2009)

38. Zaloga, S., Unmanned Aerial vehicles, Robotic Air Warfare, 2007.

39. Htike, T., Ngwe, T., and Myint, Y., Practical Approach to Rudder Control System for UAV using Low Cost MEMS Sensors, World Academy of Science, Engineering and Technology, 42, (2008).

40. Timmons, C., Autonomous RC Aircraft with Collision Avoidance Capabilities, Honors Thesis, Florida State University, U.S.A., 2014.

41. Prime, Z., RC VTOL Model Aircraft, Final Report, The University of Adelaide, Australia, 2005.

BIOGRAPHY

Mehedi Imran HASAN, the author of the thesis was born in July 14, 1990 in Bangladesh. After the secondary school he studied in Military School and graduated from Shaheed Ramiz Uddin Cantonment College in 2008 obtained G.P.A. 4.90 out of 5.00. In January 2009, he was admitted to International University of Business Agriculture and Technology to study for his Bachelor degree in Electrical and Electronics Engineering. He has been awarded as a graduate in 2012 and stood 2nd in the department securing C.G.P.A. 3.84 out of 4.00. During the education period Mr. Hasan won many competitions including Intra University Mastermind Championship. He was a professional cricketer and has been awarded many prizes in different sporting events. In 2013, he got Turkish Government Scholarship and came to Turkey to do Master in Karadeniz Technical University. During his master he has written three papers those are published from three different countries. The first one was about Biomass Energy, published from USAK University, Turkey. Others are about speed control of asynchronous motor published from India and the U.S.A. His stay in Turkey brought him a lot of opportunities to know many important persons around the world. Mr. Hasan is also active with many national and international organizations. During his stay in Trabzon, he was president of the student branch of Karadeniz International Students Organization (KULDER). He attended many International Conferences in Asia and Europe. Mr. Hasan also loves to travel and learn new cultures and languages. He travelled more than 10 countries and know 5 International languages except his mother tongue. He knows English, Turkish, Polish, Hindi and Urdu. During Master he went to Poland achieving Erasmus Scholarship and studied in A.G.H. University of Science and Technology which is one of the most prestigious universities in Europe. Mr. Hasan now working as an Automation Engineer and do program digital relays. He also designs and programs Energy SCADA for Turkish Government’s projects.