Visvesvaraya Technological University, Belagavi

A Project Report
On

"Design and Fabrication of Quad-Plane for All Terrain Applications"

Submitted in partial fulfilment of the requirements for the award of degree of

BACHELOR OF ENGINEERING

In

MECHANICAL ENGINEERING

By

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Accredited by NBA, New Delhi & NAAC with 'A' Grade
Gokulam 3rd Stage, Mysuru – 570 002
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CERTIFICATE

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bonafide students of **Vidyavardhaka College of Engineering** in partial fulfillment for the award of "**Bachelor of Engineering**" in **Mechanical Engineering** of the **Visvesvaraya Technological University, Belagavi** during the year 2021-2022. It is certified that all corrections/suggestions indicated for internal assessment have been incorporated in the report. The project report has been approved as it satisfies the academic requirements in respect of Project work prescribed for the Bachelor of Engineering Degree.

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Declaration

We the members of the project team, studying in the VIII semester of Mechanical Engineering, Vidyavardhaka College of Engineering, hereby declare that the entire project entitled **"Design and Fabrication of Quad-Plane for All Terrain Applications"** has been carried out by us independently under the guidance of **Dr. Ashok B C**, Professor, Dean Corporate and International Affairs, Department of Mechanical Engineering, Vidyavardhaka College of Engineering. This project work is submitted to the Visvesvaraya Technological University, Belagavi, in partial fulfillment of the requirement for the award of the degree of **Bachelor of Engineering** in **Mechanical Engineering** during the academic year 2021-2022.

This dissertation has not been submitted previously for the award of any other degree or diploma to any other institution or university.

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Place: Mysuru

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APPENDIX I: LIST OF SYMBOLS

Re	Reynolds number
W_L	Wing loading
W	Maximum Take-off weight (MTOW)
ρ	Density
λ	Taper ratio
c	Wing chord
C	Control surface chord
C_{tip}	Tip chord
C_{root}	Root chord
C_V	Chord of vertical stabilizer
C_H	Chord of horizontal stabilizer
B	Wing span
B_V	Wing span of vertical stabilizer
B_H	Wing span of horizontal stabilizer
S	Wing planform area
S_V	Vertical stabilizer planform area
S_H	Horizontal stabilizer planform area
AR	Aspect Ratio
AR_V	Vertical stabilizer aspect ratio
AR_H	Horizontal stabilizer aspect ratio
Vt	Turning velocity
μ	Dynamic viscosity of air
T	Thrust force
L	Lift force
D	Drag force
C_L	Coefficient of lift
C_D	Coefficient of drag
ADASEA	Aircraft Design: A Systems Engineering Approach book by Mohammad H. Sadraey.

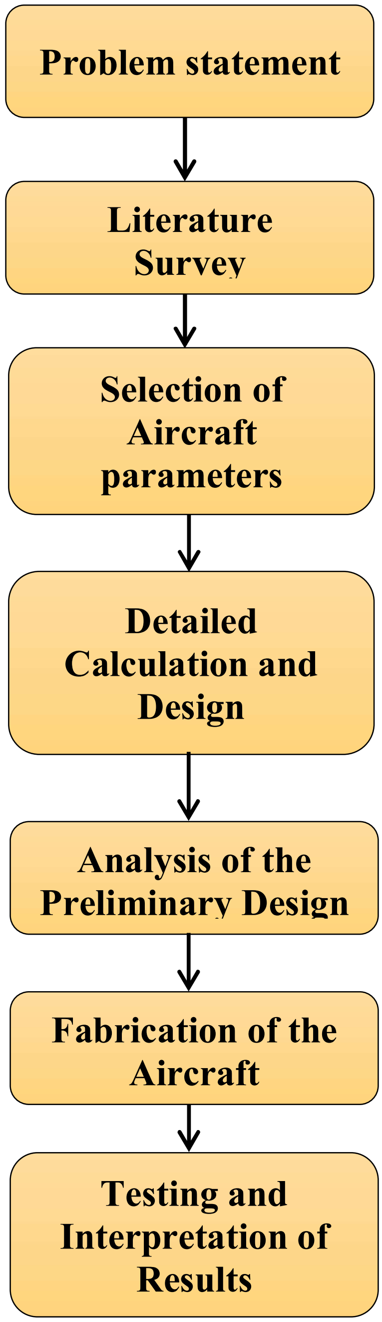
Abstract

This project presents the design of a fixed-wing Vertical Take-Off and Landing (VTOL) heavy-duty UAV "Quad Plane". The VTOL is one of the most rapidly growing technology in the field of unmanned aerial vehicle, with VTOL the aircraft can achieve longer flight time and range and able to take-off/land on any terrain without any requirement of runaways with a maximum payload of 3Kg. The design of the fixed wind VTOL UAV is similar to that of a conventional quadcopter along with the usage of ducted propellers, after take-off to a certain altitude the quadcopter motors stop to function and the power is directed to the motor mounted on the front of the body to achieve forward flight.

The study carried out is on the flight characteristics, such as roll, pitch, and yaw. XFLR5 software is used to understand the aerodynamic characteristics. This project will also give a better understanding of how it transits from a quad mode to a perpendicular motor borne flight mode.

The usage of ducted propellers leads to efficient flight, thereby increasing the flight time and also helps in covering more distance in limited amount of time. The usage of technologies such as rapid manufacturing greatly helps in manufacturing the necessary components in short amount of time and with utmost geometric accuracy.

FLOWCHART OF OUR PROJECT



CHAPTER 1

INTRODUCTION

1. INTRODUCTION

In the present industrial revolution in aerospace sectors/industries drones are the most common technology which are used worldwide either in the military purpose or even for the common man usage. Unmanned Aerial Vehicle (UAV) commonly known as Drone is an aircraft without any human passengers or crew members on board the aircraft. UAVs come under a division of Unmanned Aircraft Systems (UAS) which include a ground-based controller and a system of communication.

Our project the "Quad-Plane" will work by using 5 propellers as it is a combination of working principle of Quadcopter and forward movement of Airplane hence the name "Quad- Plane". The basic principle of quadcopter is it uses 4 motors with a pair of motors rotating in clockwise direction and the second pair rotating in counter clockwise direction. The uniqueness of our project is the usage of ducted propellers which is responsible for concentrating the air flow around the propellers to one single point resulting in efficiency of thrust generated by the body to generate lift.

One propeller will be mounted in front of the Quad-Plane to enable it to propel forward upon reaching a certain altitude.

1.1 Objective of the project

- To design an efficient and high payload carrying aircraft.
- To analyze the aerodynamic characteristics of the aircraft using XFLR5.
- To build and test the aircraft in variable weather conditions.
- To design a cost-effective vertical take-off and landing (VTOL) aircraft.

1.2 Problem Statement

- Even though measures are taken to reach people during emergencies, the materials do not reach in time and sometimes it is also difficult to locate them.
- The cost of present-day air delivery systems are very high and leaves higher carbon footprint.
- 49% of all fatal aircraft accidents happen during the final descent and landing phases. Conventional UAV designs require a considerable amount of runway to either take off or land.

1.3 Scope of the project

- Unmanned Aerial Vehicles.
- Usage of clean and green energy for operation of aircrafts.
- Delivery of emergency supplies.
- Long range, efficient flight missions.
- Mapping and extraction of digital data for surveillance, weather forecasting and other purposes.
- Improved stability in comparison to conventional UAV, can be used in extreme weather conditions.

CHAPTER 2

LITERATURE SURVEY

2. LITERATURE SURVEY

[1] Yacoubi Moaad et al. has 3D printed propellers for both clockwise and counterclockwise configurations and tested the same for minidrones controlled by electric ducted fans to attain VTOL capabilities. He has drawn conclusions based on electricity consumed vs thrust generated by these propellers.

[2] Hugo F. Bento et al.in his paper, he has compared the performance of two ducted propeller designs, namely square and circular ducted propellers. In-depth research shows the interaction of these propellers with air using steady and unsteady RANS CFD simulations. The square duct corners were found to be prone to separation, and to contribute towards the generation of strong vortices. Furthermore, due to the reduced leading-edge suction on the square duct, the square ducted system was found to be 4.5% less efficient than the circular ones.

[3] Ashraf M Kamal et al. presents a preliminary design methodology for transitional UAVs especially tiltrotor aircraft. The proposed approach is a simple and straightforward methodology to generate a graphical tool for selecting the preliminary sizing parameters. By using the proposed mathematical model, the performance constraints of the fixed wing, rotorcraft, and transition flight modes are integrated into a single tiltrotor design chart.

[4] Bacchini et al. a comparison about different configurations of turboshaft powered VTOLs tested in the fifties and sixties, detailing advantages, disadvantages, and problems of each one have been made. The recent eVTOL prototypes categories have then presented under the classification proposed by the American Helicopter Society. They have concluded that short-range missions are best performed by multirotors because they have better hover performances. Long-range missions cannot be accomplished by multirotors because their range is not enough.

[5] Harmon, Frederick G et al. have discussed the maneuvering advantage of a multirotor UAV stating the ability to travel fast to reach a further distance. The design methodology and fabrication method are discussed, followed by a number of flight tests to prove the concept. The proposed UAV is equipped with quadcopter motors and a horizontal thrust motor for vertical and horizontal flight modes respectively.

[6] Win Ko ko et al. have discussed the approach for a VTOL UAV system to be designed,

built, and flown in tricopter and aircraft modes, to be considered for use in military or commercial applications. These applications have developed the appropriate operating procedures required to be incorporated into the design. The wing design is selected and the dynamic stability of the aircraft is calculated and verified in real-time.

[7] Serdar Yilmaz et al. in this paper, performance characteristics and velocity field of a ducted propeller in hover and axial flight conditions are investigated experimentally. Five different circular duct shapes have been tested. Effect of duct geometry is studied by means of measurements at various flow conditions. Velocity field upstream and downstream of the propeller, axial force acting on each component of the propulsive system, rotor speed and torque are measured. Pressure distribution on duct inner and outer surfaces is also investigated. Experimental results obtained for open and ducted propellers are compared.

[8] Yasir Ashraf Abd Rahman et.al. their study proposes the implementation of hybrid VTOL UAV which has the maneuvering advantage of a multirotor UAV while having the ability to travel fast to reach a further distance. The design methodology and fabrication method are discussed, which are followed by a number of flight tests to prove the concept. The proposed UAV is equipped with quadcopter motors and a horizontal thrust motor for vertical and horizontal flight modes respectively

[9] Ozlem Armutcuoglu et al. have proposed a new autonomously controlled tilt-duct vertical takeoff and landing uninhabited aerial vehicle concept. This design combines the vertical flight capability of a helicopter and forward flight performance of a fixed-wing conventional aircraft. The advantages and disadvantages of the ducted propellers are discussed. A conceptual design study is performed including airfoil and geometry selection, initial sizing calculations, estimation of stability and control parameters.

[10] S.S Rao et al. in the paper explain about the requirements and applications of the technology to provide optimal answer for surveillance, weather prediction and border infiltrations. The author utilized various data, ergonomics and economics into the prototype built. Furthermore, made mathematical analysis and verified the results with the theoretical values giving answer to the question of limitation of UAV platform.

[11] Chandrakantha Sharma B V et al. in their paper have designed and built an unmanned autonomous aircraft system which is aimed to be weather proof of all terrain system capable of countering rough and harsh conditions. The aircraft uses location data to drop relief material to stranded people who are far from reach. The aircraft gets the input from the

transmitter to the mounted receiver on the system that processes the signal to control the motor, ailerons etc. Numerous tests on prototypes with lot of surveys and discussion on the final model is given. This is further checked with analysis and testing, which showed the data regarding capabilities and limitations of UAV.

CHAPTER 3

DESIGN METHODOLOGY

AND

PRINCIPLE PARTS

3. DESIGN METHODOLOGY AND PRINCIPLE PARTS

3.1 Stability and Controls

The team aimed to achieve stable flight and maneuvers for the autonomous aircraft. Stable flight requires both static and dynamic stability, which means that after a disturbance the aircraft returns to its equilibrium state for static stability, or its trim condition for dynamic stability. The team analyzed controls and aerodynamics of the aircraft to calculate desired conditions for aircraft stability.

- Static Stability

The first step toward achieving stability in a moving aircraft is to consider the equilibrium state and static stability. A statically stable aircraft has a positive static stability. To achieve a positive static stability, the aircraft must respond to a disturbance from its equilibrium state by naturally returning to its equilibrium position without pilot input. This occurs when the neutral point of the aircraft is located behind the aircraft's CG. By definition, the neutral point is the CG location which would cause the aircraft to have a neutral or "zero" stability. In this case, the aircraft would neither return to nor be driven away from its equilibrium position following a disturbance. This location is determined by considering all the pitching moments about the CG, independent of the change in angle of attack. It is calculated from the horizontal tail volume ratio, the lift curve slopes of the wing- body and the tail, and the aerodynamic centre of the wing which is approximated at the quarter length of the wing's MAC. The location of the neutral point stays relatively constant during flight and will only vary slightly at different flight speeds due to the change in lift coefficient and lift curve slopes for the wing and tail.

- Dynamic Stability

Balancing the moments about the centre of gravity of the aircraft in flight is crucial for dynamic stability during level, steady trim flight. A total of zero applied moment is required to balance the aircraft based on the location of the centre of gravity. A nose-heavy aircraft would usually require a down lifting tail. An aft located centre of gravity usually requires an uplifting tail. All the force-induced moments applied such as the lift and weight forces as well as the moments about the aerodynamic centre of the wing and the tail must be taken into calculation.

- Control Surfaces

Control surfaces are portions of the wing and tail stabilizers that the pilot can manipulate independently in order to control the motion of the aircraft. The geometry and movement of these control surfaces affect the aircraft's maneuverability and its ability to evade large disturbances. The primary factors that influence the design of the control surfaces are the forces that the control surfaces must overcome in order to alter the aircraft's flight path.

Control surfaces are important for both longitudinal and lateral stability. The most common types of longitudinal-axes control surfaces are elevators, flaps, while ailerons and rudders influence lateral stability.

Elevators, generally located on the tail of an aircraft, control the aircraft's pitch. These change the wing's angle of attack and can assist in turning and changing altitude. Elevators also manage the airplane's pitch trim. Integration of aps and slats provide additional longitudinal control. Flaps work to increase lift at high angles of attack and hence also known as high lifting device.

Fixed to the trailing edge of the wing, ailerons are used to control the roll of the airplane. This allows the aircraft to bank and turn by changing the angle of the lift vector from the wing. The rudder gives the airplane yaw control to keep the aircraft in line during a banked turn. The main objective of the project is to design and develop an autonomous aircraft which could deliver relief material to stranded people during natural calamities.

3.2 Airfoil

Initial approximations and required flight characteristics:

- Payload 1.5-2 kg (from market study and weight of emergency medicinal supplies)
- Maximum take-off weight (MTOW) = 3 kg
- As it is a cargo aircraft it should have slow fly characteristics and very good controllability.

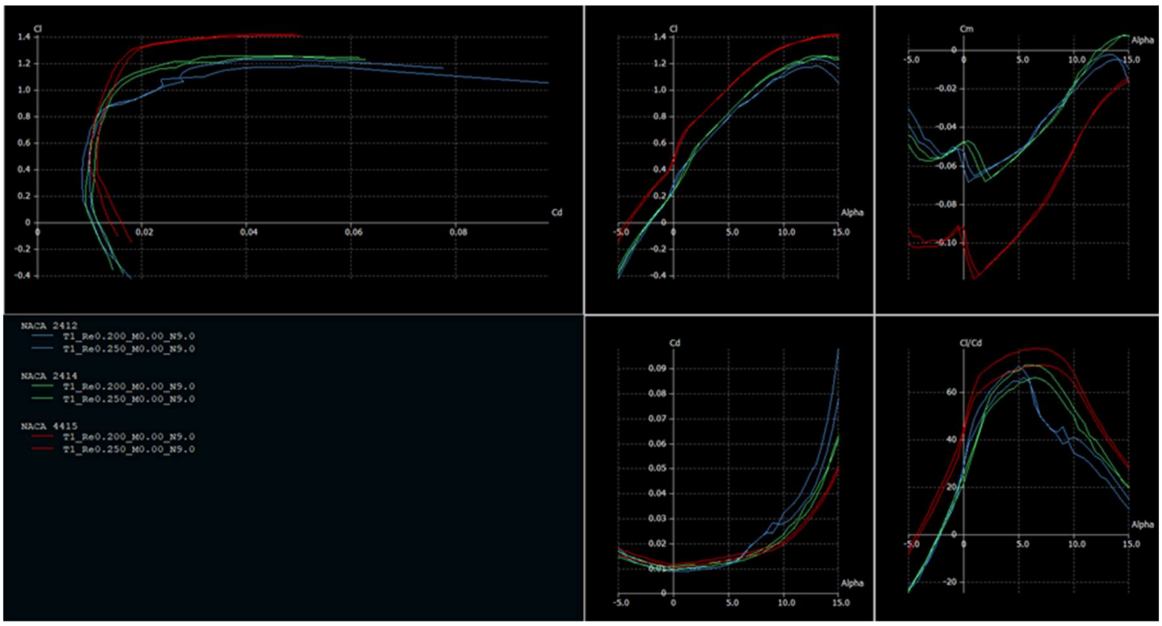


Figure 3.2.1: Airfoil Analysis – XFLR5

- The primary function of wing is to generate lift force. This will be generated by a special wing cross-section called airfoil.

The plot contains airfoils chosen, having medium lift and medium camber with Reynolds Number (Re) within the range 2,00,000-2,50,000.

For a consistent comparison, the team evaluated all three airfoils at a 2,00,000 and 2,50,000 Reynolds number using the XFLR5 XFoil Direct Analysis tool. In this analysis, XFLR5 simulated a viscous flow across the airfoil as the airfoil angle of attack varied and five graphs were generated (Figure 3.2.1).

The airfoil profile taken for the model construction is NACA-4415 which is a four-digit cambered airfoil. Referring to the above plot, NACA-4415 showcases much better performance in the aspects of low drag (C_D), high lift (C_L) during various angles of attack (AoA).

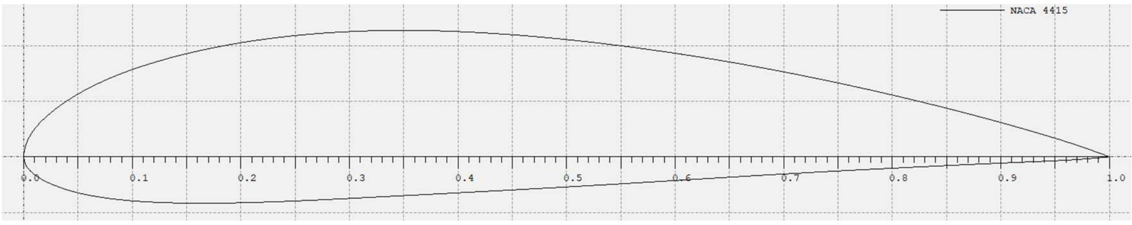


Figure 3.2.2: NACA 4415 Airfoil.

3.3 Wing Properties

Using the estimated dimensions, the team used XFLR5 to model and evaluate the aerodynamic performance of two different wing shapes. The 2 wing shapes tested were rectangular, 1:2 trailing edge taper (Backward Swept).

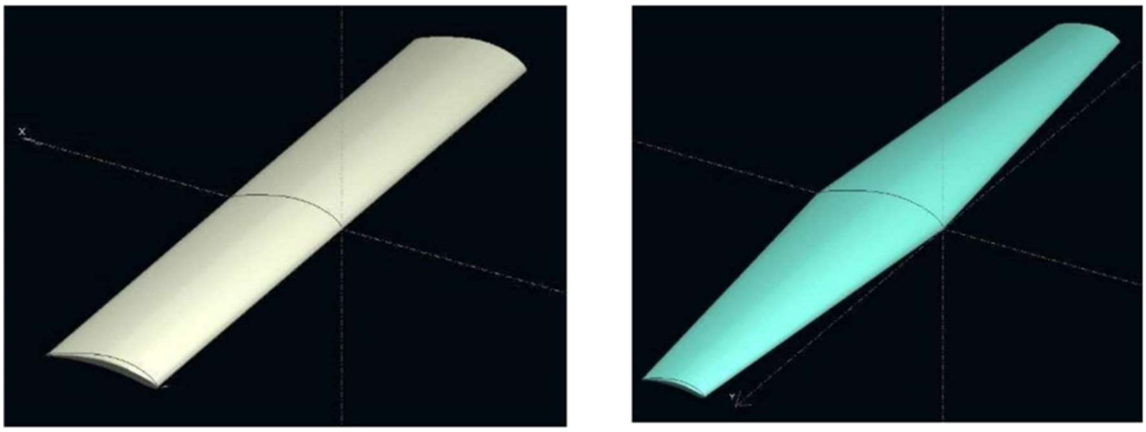


Figure 3.3.1: Rectangular and Backward Swept Wing.

Upon further analysis and comparison, the rectangular wing proved to produce optimum lift coupled with very limited drag when compared with the backward-swept tapered wing. As the rectangular wing has the best characteristics, the team decided to consider rectangular wing a possibility. Due to its favorable aerodynamic properties and ease of manufacturing, the team decided that rectangular wing to be the most ideal shape for the aircraft wing

In aeronautics, the Aspect Ratio of a wing is the ratio of its span to its mean chord. It is equal to the square of the wingspan divided by the wing area. Thus, a long, narrow wing has a high aspect ratio, whereas a short, wide wing has a low aspect ratio. Aspect Ratio is calculated to be 4.4, which equally balances the aircraft between a glider and a fast-flying aircraft.

3.4 Tail Properties

Finding the optimal size for the tail was crucial for static stability. Horizontal and vertical stabilizer dimensions were designed to achieve longitudinal and lateral stability, respectively. For an aircraft with the propeller at the front of the fuselage, an aft horizontal and tail is most effective.

The team considered both the conventional aft tail and t-tail designs for the aircraft. The conventional tail is the most commonly used tail design, as it is simple, efficient at achieving stability, and easy to analyze for aerodynamic and control properties. The T-tail is also lightweight and efficient, and due to the horizontal tail being located above the main wing, it has a larger moment arm and experiences reduced airflow disturbance effects from the main wing.

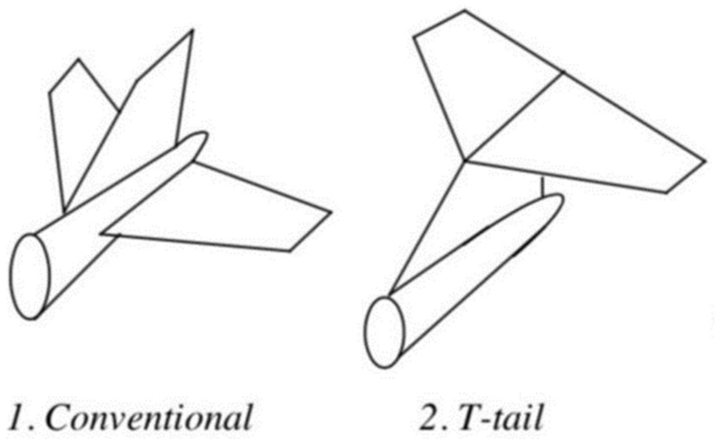


Figure 3.4.1: Tail Configurations.

However, aircraft with T-tails are at risk of entering a “deep stall", which can occur when the aircraft pitches to an angle of attack where the horizontal stabilizer is in the wake of the main wing. The airflow over the horizontal stabilizer is turbulent and reduces the effectiveness of the horizontal stabilizer and control surfaces, so any small disturbance can cause the aircraft to suddenly pitch to an angle of attack well above the stall angle of attack, leading to a potentially irreversible stall condition. Due to this instability of the T-tail, the team chose the conventional aft tail configuration for the aircraft design.

The horizontal and vertical tail airfoils should be symmetrical and non-lifting. The team wanted the airfoil to be thin and lightweight, but thick enough so that it could be easily manufactured and would maintain structural integrity. The team identified the NACA 0015 standard airfoil as an appropriate airfoil for both the horizontal and vertical stabilizers.

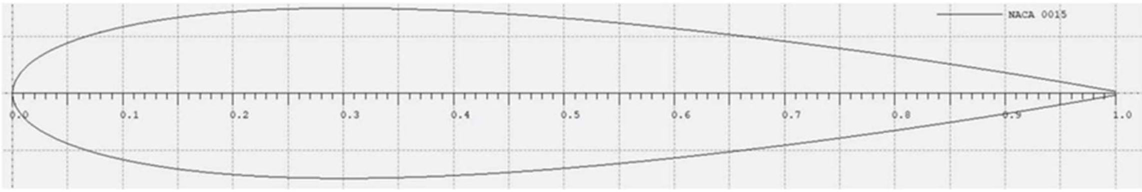


Figure 3.4.2: NACA 0015 Airfoil.

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CHAPTER 4

DESIGN CALCULATIONS

4. DESIGN CALCULATIONS

The following data was assumed based on the book ADASEA,

- Aspect Ratio of Wing = 4.4 (justified in 3.3)
- Wing Loading (W_L) = 11 kg/m^2

In aerodynamics, wing loading is the total weight of an aircraft divided by the area of its wing. It was selected from ADASEA.

- Taper ratio (λ) = $\frac{Ctip}{Croot} = 1$
- Using these values Reynolds number (Re) was found out
- Re = $\frac{\rho \times vt \times c}{\mu}$
- Re = $\frac{1.225 \times 15 \times 0.2}{1.875 \times 10^{-5}}$ = 2,11,164

For the Obtained Reynolds Number, three airfoils were tested for a range of 2,00,000 - 2,50,000 and out of those NACA 4415 was selected. ×

4.1 Wing

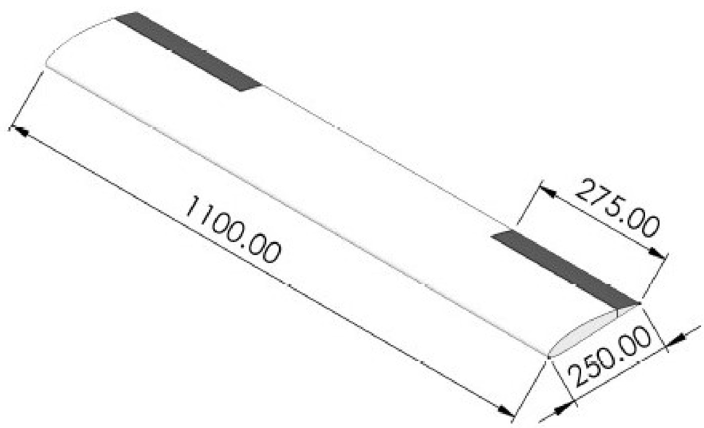

Figure 4.1.1: Aircraft Wing.

Planform Area equation is formulated as,

- Planform Area (S) = $\frac{W}{W_L}$ = 0.27 m^2
- Aspect Ratio (AR) = $\frac{B^2}{S}$ = 4.4
- Wing Span (B_w) = $\frac{S}{C_w}$ (Equation 5.19 from ADASEA)

Using the two equations, it was found out that:

Wing span (B_w) = 1.1 m

Wing Chord (C_w) = 0.25 m

- Taper ratio (λ) $\frac{C_t}{C_r} = \frac{0.200}{0.200} = 1$ (Equation 5.24 from ADASEA)
- Mean Aerodynamic Chord (C_{MAC}) = $\frac{2}{3} \times C_r \times \frac{(1+\lambda+\lambda^2)}{1+\lambda}$ = 0.25 m

(Equation 5.26 from ADASEA)

- YMGC - Location of Mean Centre of Gravity in Semi-Span = $\frac{b}{6} \times (\frac{1+2\lambda^2}{1+\lambda})$

= 0.275 m

(Equation 5.27 from ADASEA)

- Aileron Span (B_a) = 0.25 × B_w = 0.275 m
- Aileron Chord (C_a) = 0.25 × C_w = 0.0625 m

(From ADASEA)

4.2 Empennage

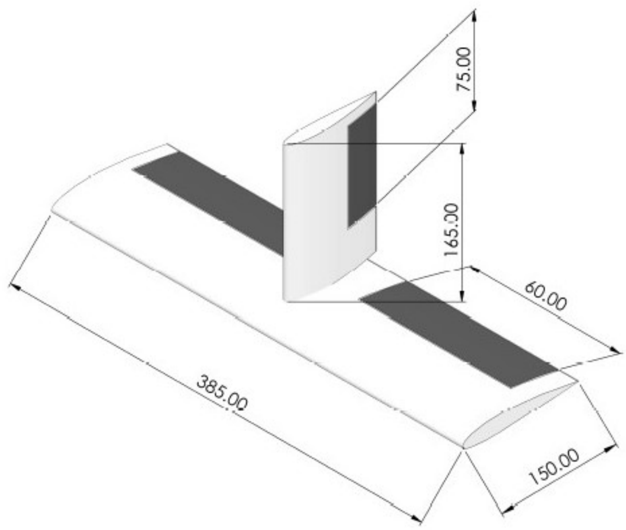

Figure 4.2.1: Aircraft Tail.

Horizontal Tail:

- Aspect Ratio (AR_H) = $\frac{2}{3} \times AR\ (Wing)$ = 3 (Equation 6.59 from ADASEA)
- Span (B_H) = 0.35 × B_w = 0.385 m
- Chord (C_H) = 0.6 × C_w = 0.15 m
- Elevator Chord = 0.4 × C_H = 0.06 m
- Elevator Span = 0.385 m

Vertical Tail:

- Span (B_T) = 0.15 × B_w = 0.165 m
- Chord (C_T) = 0.6 × C_w = 0.15 m
- Rudder Chord = 0.4 × C_T = 0.075 m
- Rudder Span = 0.165 m

4.3 Fuselage

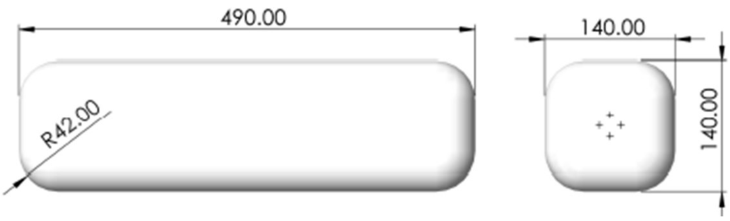

Figure 4.3.1: Aircraft Fuselage.

- Length of the fuselage = 0.49 m
- Square Cross-section = l × b = 0.14× 0.14 = 0.0196 m^2

4.4 Duct

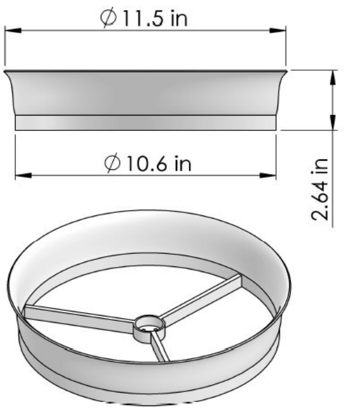

Figure 4.4.1: Quad-Plane Duct.

- Inlet diameter = 11.5 in
- Outlet diameter = 10.6 in
- Height of the duct = 2.64 in
- Total reduction in area = 7.8 %

4.5 Propulsion

As per mission requirement, the aircraft Maximum Take Off Weight (MTOW) is 3kg and thrust produced by the motor should be minimum of 25% of the MTOW of aircraft for quad motors as per ADASEA. The weight and the wing loading were considered to decide the motor and propeller. The motor selected was giving appropriate thrust for 3 cell configurations of battery. After going through various options available in the market it was decided the best option for the given budget and finalized the following:

Table 4.1: Motor thrust variation for different voltage and propeller.

Prop (inch)	Voltage (V)	Load Current(A)	Pull (g)	Power (W)	Efficiency (g/W)
10×45	11.1	13.2	870	146.5	5.93
10×47	10	11.2	720	112	6.42
11×45	11.1	17.2	960	190.9	5.02

- Brushless Motor: 1000 KV (A2212), 1500KV (Avionic C3536)
- Propeller: 10×45 (Since we needed more speed and efficient flight, 10×45 prop is selected)
- ESC: 30A
- Number of battery cells: 3
- Battery voltage: 11.1
- Peak discharge of battery: 25C
- Battery discharge plug; XT60

CHAPTER 5

XFLR5 AIRCRAFT ANALYSIS

5.1 XFLR5 AIRCRAFT ANALYSIS

5.1 XFLR5 Analysis

XFLR5 is an analysis tool for airfoils, wings and planes operating at low Reynolds numbers. It includes:

- XFoil's Direct and Inverse analysis capabilities.
- Wing design and analysis capabilities based on Lifting Line Theory, Vortex, Lattice and 3D Panel Methods.

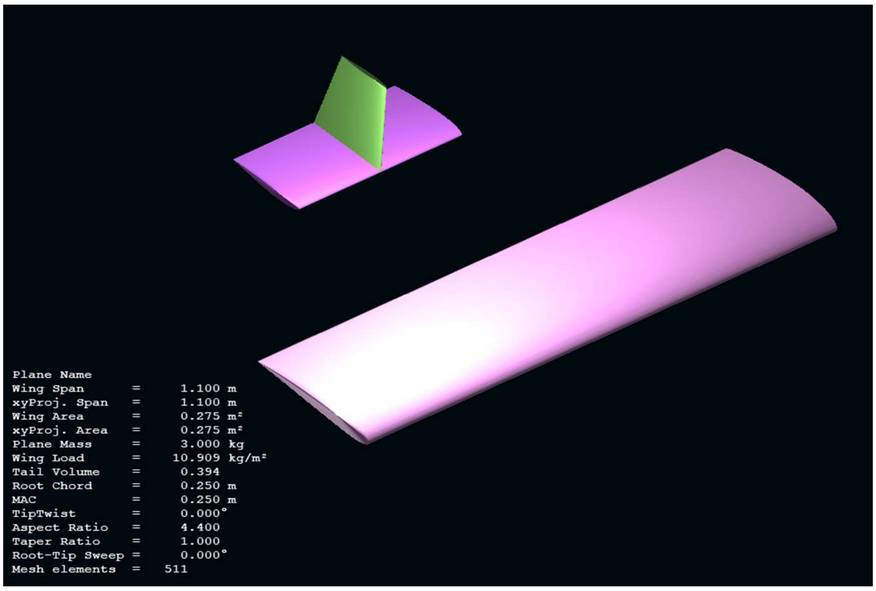

Figure 5.1.1: Aircraft designed inside XFLR5 for required dimensions.

The calculated aircraft dimensions were designed inside XFLR5, particularly wing and empennage as XFLR5 performs better without the fuselage. The figure below shows the aircraft with ailerons and different airfoils used.

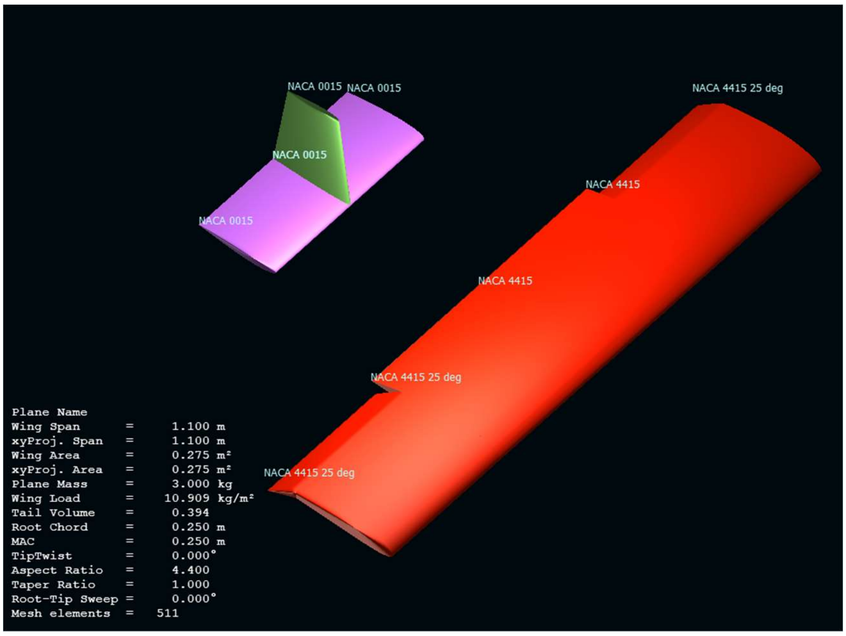

Figure 5.1.2: Aircraft showcasing various airfoils used.

The aircraft is tested for Reynolds Number ranging from 2,00,000 to 2,50,000 across angle of attack (AoA) ranging from -5 to +15 degrees. The speed of the aircraft is considered to be 15 ms^{-1} during all testing conditions.

5.2 Coefficient of Pressure

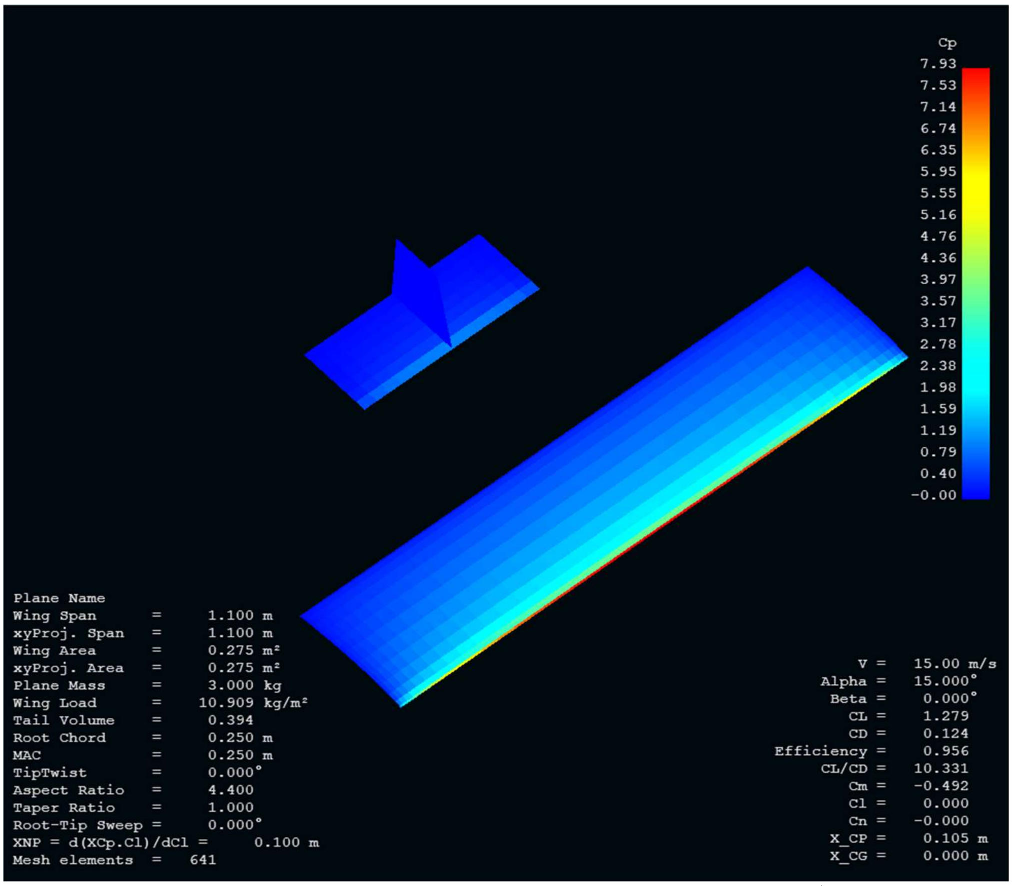

Figure 5.2.1: Shows Cp of the aircraft at a speed of 15 ms^{-1}

The Figure 5.2.1 shows the pressure coefficient of the airfoil and it is observed that the airfoil's upper surface experiences C_p in the range of 2 to 0 , thus the lift force of the airfoil is in the upward direction.

Larger the attack angle, greater is the difference of pressure coefficient between the lower and upper surface. The maximum coefficient of pressure of 7.93 was observed at the leading edge of the wing and least coefficient of pressure was observed at edges of aileron and the tail. Between -5° and 15° the highest lift was observed at 15° with the magnitude of coefficient of lift 1.279 and $\frac{C_L}{C_D}$ ratio of 10.331.

5.3 Airstream analysis.

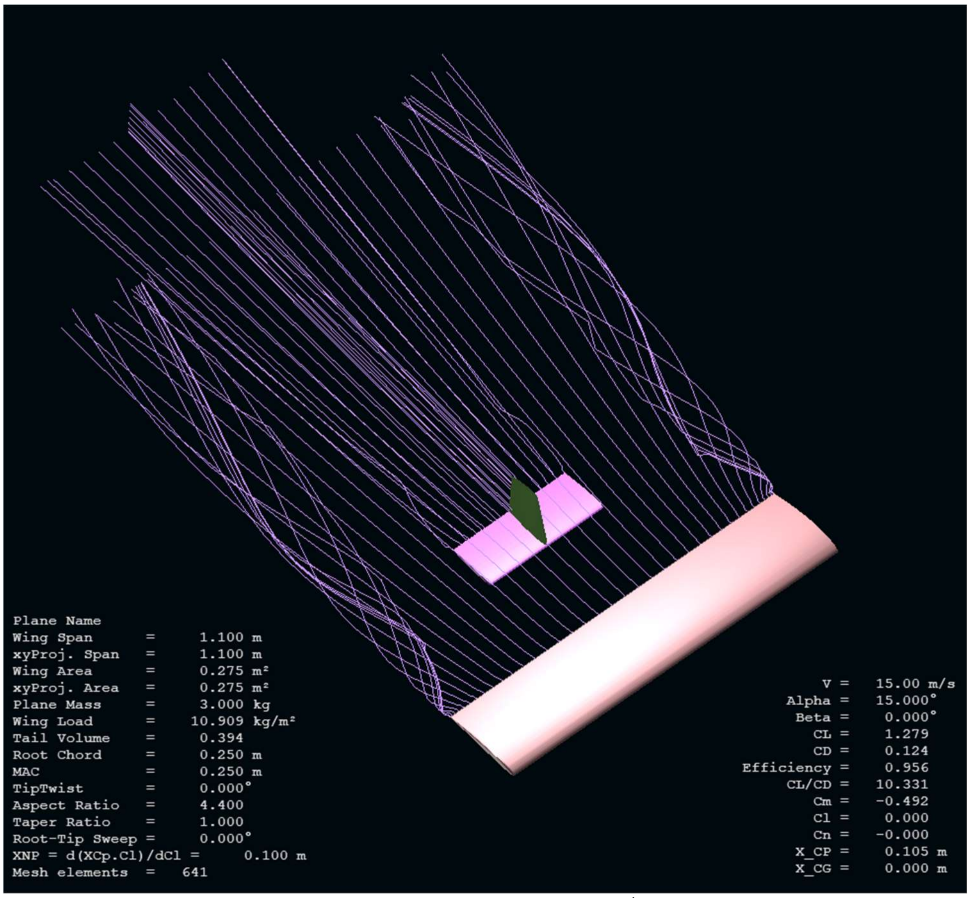

Figure 5.3.1: Airstream of the aircraft at a speed of 15 ms^{-1} and 15° AoA without ailerons.

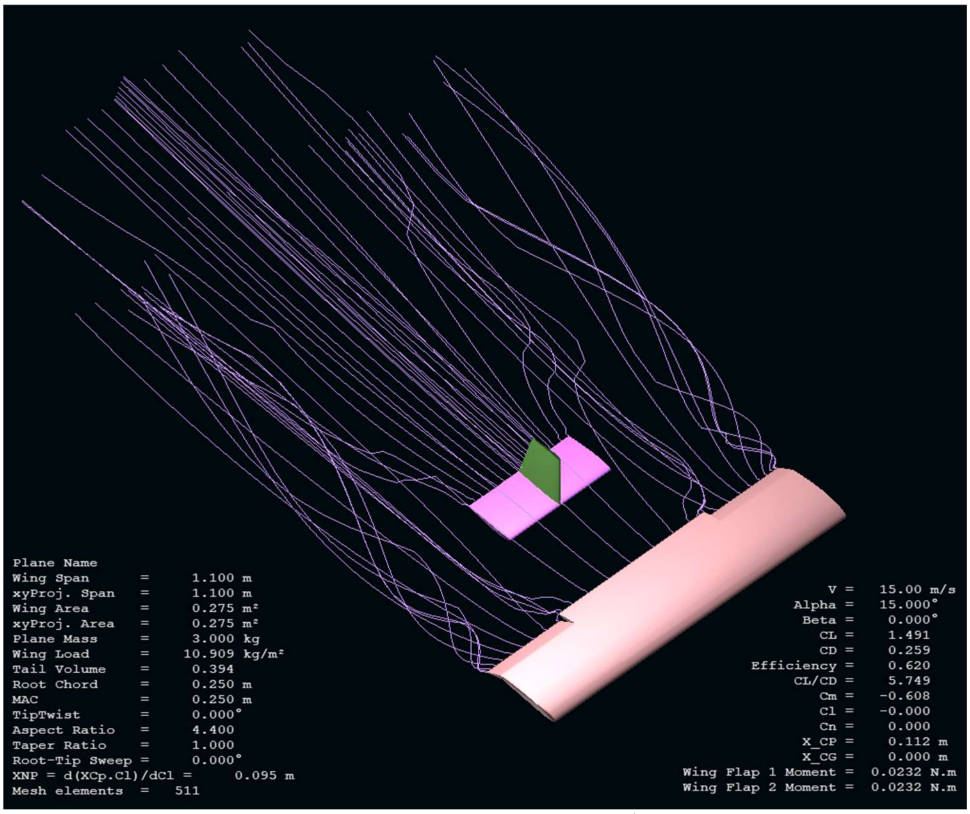

Figure 5.3.2: Airstream of the aircraft at a speed of 15 ms^{-1}, 15° AoA with ailerons at 25°.

In the Figure 5.3.1, the analysis for airstream was conducted for an aircraft speed of 15m/s and it observed that, when the ailerons are not actuated, there is minimal mixing of high and low-pressure air at the tips of the wings, which results in loss of lift and drag. This can be reduced by adding winglets, but the drag is very minimal and usage of winglets for such scaled down aircrafts is not feasible.

In the Figure 5.3.2 the analysis for was conducted at an aircraft speed of $15ms^{-1}$ and it is observed that for actuation of 25° of ailerons, the mixing of air is more as there are numerous tips in trailing edge of the wings, this results in high drag. This is unavoidable and also produces high lift due to actuation of ailerons, which is necessary during take-off and landing.

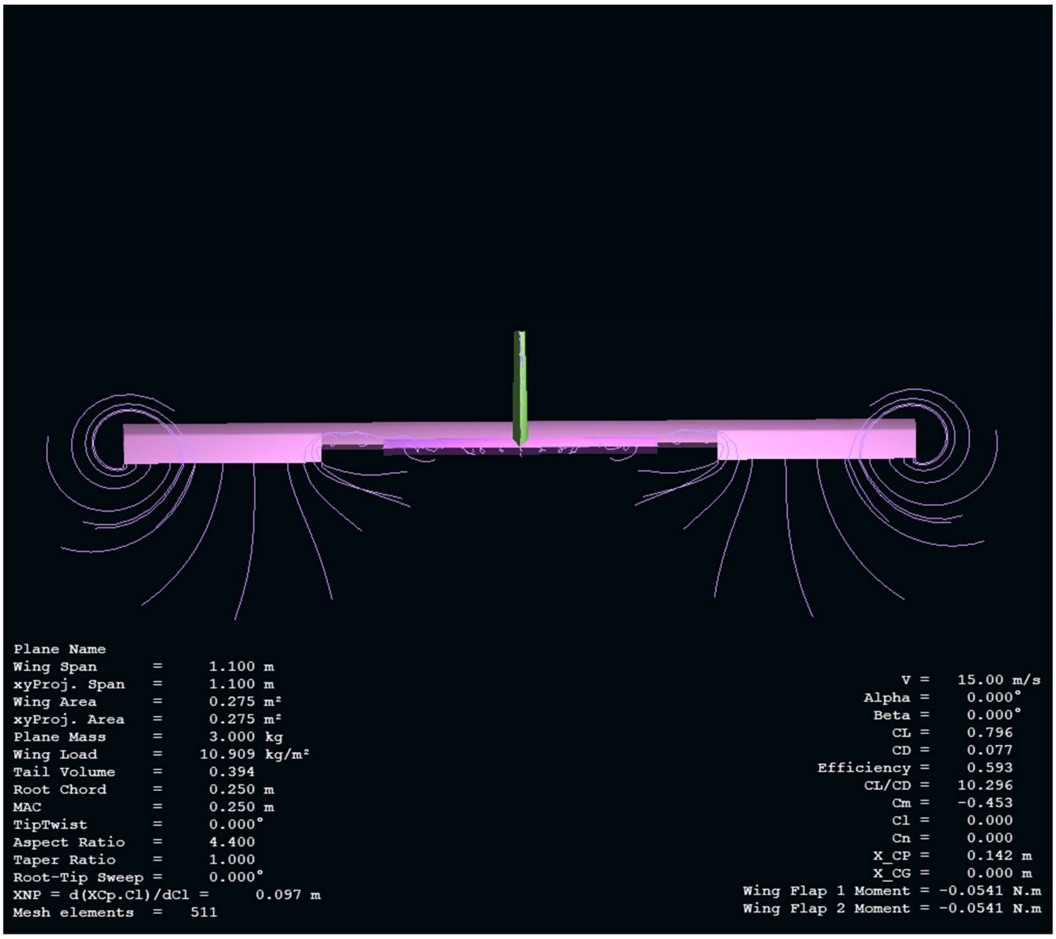

Figure 5.3.3: Airstream analysis of aircraft with 25° flap condition (rear view).

5.4 Aircraft Induced Drag analysis

In the Figure 5.4.1 it is seen that the Induced drag is an inevitable consequence of lift and is produced by the passage of an airfoil (e.g., wing or tailplane) through the air. Air flowing over the top of a wing tends to flow inwards because the decreased pressure over the top surface is less than the pressure outside the wing tip. Below the wing, the air flows outwards because the pressure below the wing is greater than that outside the wing tip. The direct consequence of this, as far as the wing tips are concerned, is that there is a continual spilling of air upwards around the wing tip a phenomenon called 'tip effect' or 'end effect'. The Figure 5.4.1 clearly represents the effect and location of drag with a C_D of 0.022 and $\frac{C_L}{C_D}$ ratio of 25.117 at 4° angle of attack (AoA).

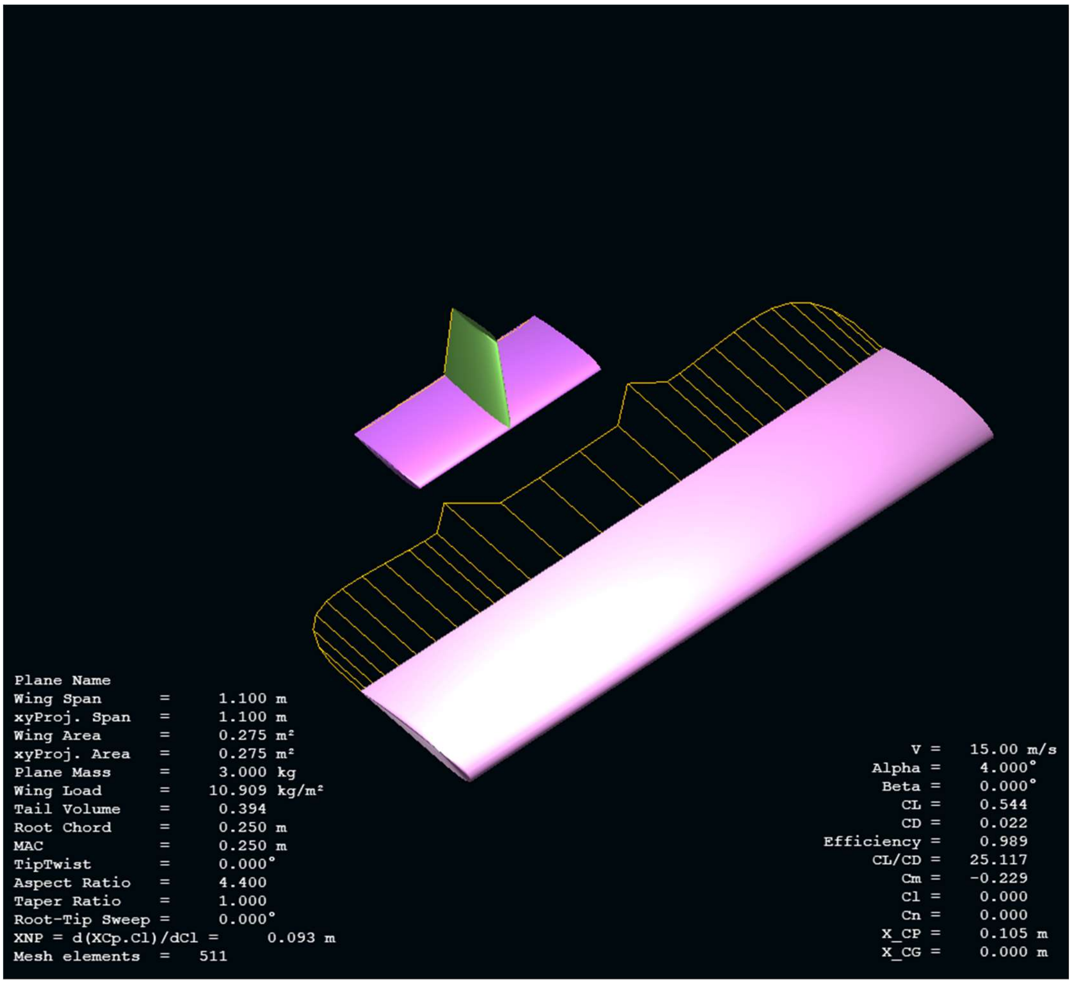

Figure 5.4.1: Aircraft induced drag analysis for no flap condition.

5.5 Aircraft Viscous Drag analysis

In the Figure 5.5.1 viscous drag is shown by purple lines lagging behind the aircraft. A body moving through a fluid experience an opposing force similar to a box sliding over the ground experiences friction is known as viscous drag. Drag is highest where the high-pressure air is leaking into low-pressure air that is the near the tips and parts where flap end. Viscus drag is also high in flap region as the airfoil shape is creating more lift with flap, this in-turn induces more drag as the air needs more time to travel on the airfoil shape. There is very less drag in the empennage section as symmetric airfoil (NACA-0015) is used.

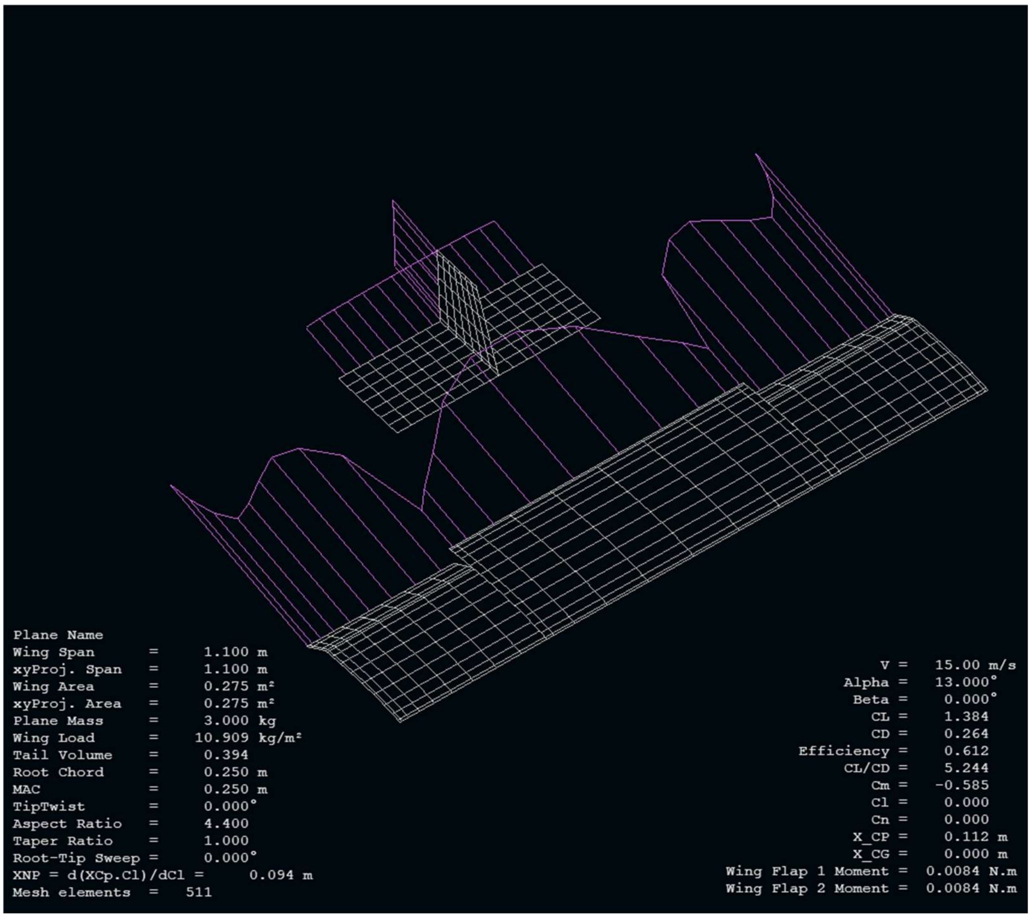

Figure 5.5.1: Aircraft viscous drag analysis for 25° aileron and 13° AoA condition.

The magnitude of C_D is much higher, at 0.264 when compared to Figure 5.3.3 where C_D is 0.077 at an angle of attack of 0° and 25° aileron actuation.

CHAPTER 6

FLIGHT SYSTEM AND COMPONENTS

6. FLIGHT SYSTEM AND COMPONENTS

6.1 Block Diagram of the flight system

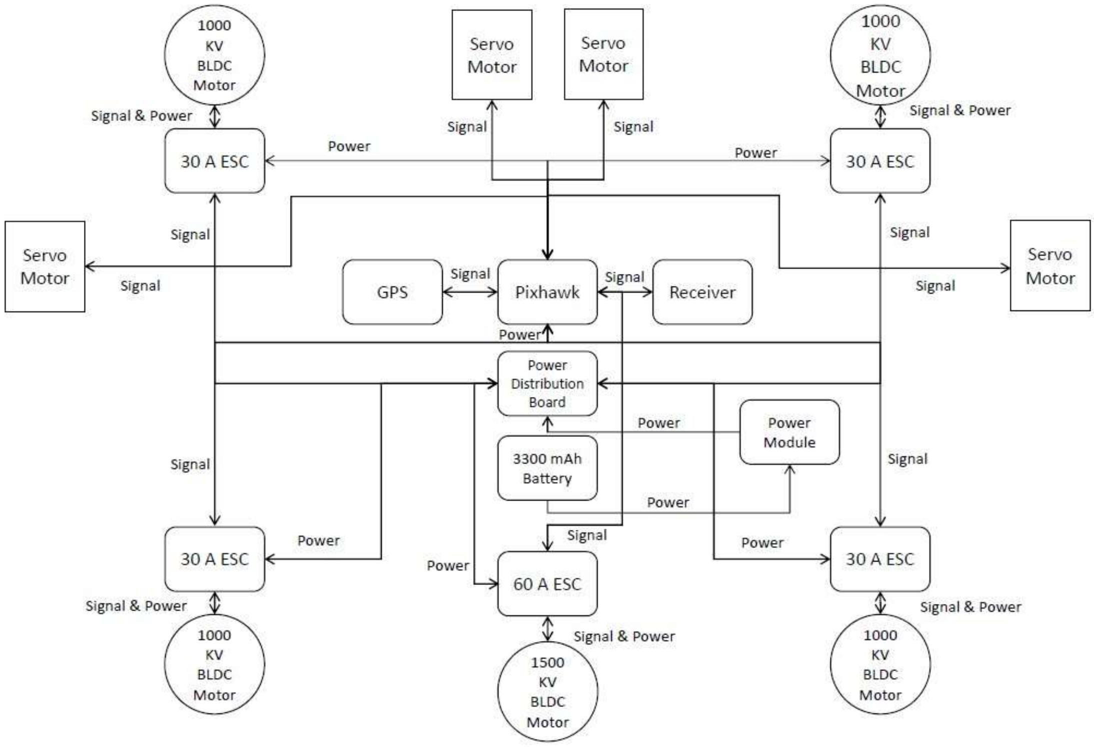

Figure 6.1.1: Flight System block diagram.

In the above Figure 6.1.1, all the components of the flight control system are shown with their connections.

In the next section, individual components are explained in detail.

6.2 Battery

Batteries are one of the most vital parts of the drone as they supply power for the drone to function. This project utilizes Lithium Polymer battery commonly known as LiPo battery. LiPo batteries prove to be one of the most efficient energy storage devices with a very long discharge time, which is best suited for our aircraft. The specification of the battery is 3300mah 3S, 25C having 3 Cells in series arrangement with the total capacity of the battery denoted by ‘C’ comes to a value of 25.

Figure 6.2.1: Orange 3300 mAh LiPo battery.

6.3 Propellers

A propeller is a device with a rotating hub and radiating blades that are to generate a linear thrust upon rotation. In this project the specification for propellers in 2 bladed types with 10-inch x 4.5 inch, which infers that the total area covered upon the rotation of propeller is 10 inches and the pitch distance covered per rotation of propeller is 4.5 inches either forward or backward. 5 propellers are the requirement for this project.

Figure 6.3.1: 10 X 4.5 inch propellers.

6.4 Brushless DC Motors

For quadcopter, Brushless DC motors are the mostly used due to the fact that they need to have faster rotation without anything in between to cause friction, which could cause a major problem in motors by generating heat. To avoid the heat generated by friction, these types of motors are incorporated into our project. Total of 4 A2212 1000KV BLDC motors and 1 Avionic C3536 1500KV motor is used in this aircraft.

Figure 6.4.1: BLDC Motors.

6.5 Servo Motor

A servo motor is a rotary actuator that allows for precise control in terms of linear control or angular control. Servo motors are controlled by Pulse Width Modulation (PWM). For our project servo motors are used to control the direction of fin movement which is present at the tail of the quad-plane.

Figure 6.5.1: Metal gear servo motor.

6.6 Electronic Speed Controllers (ESC)

Electronic Speed Controllers are the devices that can regulate the speed of rotation in motors by varying the level of voltage required for the motor to be in running condition. They come in various ranges from 10A to even 40A, but for our project we will be using 4 ESCs of 30A by Simonk and one 60A ESC for the front motor by Flightline.

Figure 6.6.1: Electronic Speed Controllers.

6.7 Flight Controller

Flight controllers are the heart and soul of any drone in the world, these play an important role in monitoring all values ranging from motor rotation speed, regulating ESC to allow variation in motor speed, controlling servo motor, GPS and many more activities can be controlled by these flight controllers. The flight controller which will be used for our project is the Pixhawk flight controller.

Figure 6.7.1: Pixhawk 2.4.8.

6.8 Sun board sheets

Sun board is a very strong, light and easily cut sheet material used for mountings and other common radio-controlled aircraft applications. The material primarily consists of PVC and foaming agent. The internal slots present makes them the best material for ailerons, rudders and elevators.

Figure 6.8.1: Sunboard sheets.

6.9 3D Printed Components

PLA, also known as polylactic acid or polylactide, is a thermoplastic made from renewable resources such as corn starch, tapioca roots or sugar cane, unlike other industrial materials made primarily from petroleum. Due to its more ecological origins this material has become popular within the 3D printing industry.

The quad-rod mounts and the ducts are 3D printed, as 3D printing gave us the freedom to design and manufacture the component without any design constraints. Also, manufacturing these components through conventional methods would not be economical and consumes lot of time.

Figure 6.9.1: 3D printed components.

Ducted drone propellers are actually similar to the conventional drone propellers. The only difference lies in the amount of thrust produced in these two cases; the ducted propellers can increase the efficiency of the drone by nearly 20% by concentrating the airflow to one point thereby providing more downward thrust leading to increase in upward lift [2].

This is the most unique feature of our project as we are incorporating the usage of ducted propellers for VTOL (Vertical Take-Off and Landing) RC drones.

6.10 Transmitter and Receiver

Radio transmitters and receivers are electronic devices; that manipulate electricity resulting in the transmission of useful information through the atmosphere or space. The transmitter sends a signal over a frequency to the receiver. The transmitter has a power source that provides the power for the controls and transmission of the signal.

Figure 6.10.1: Transmitter and Receiver.

CHAPTER 7

PROPOSED DESIGN

7. PROPOSED DESIGN

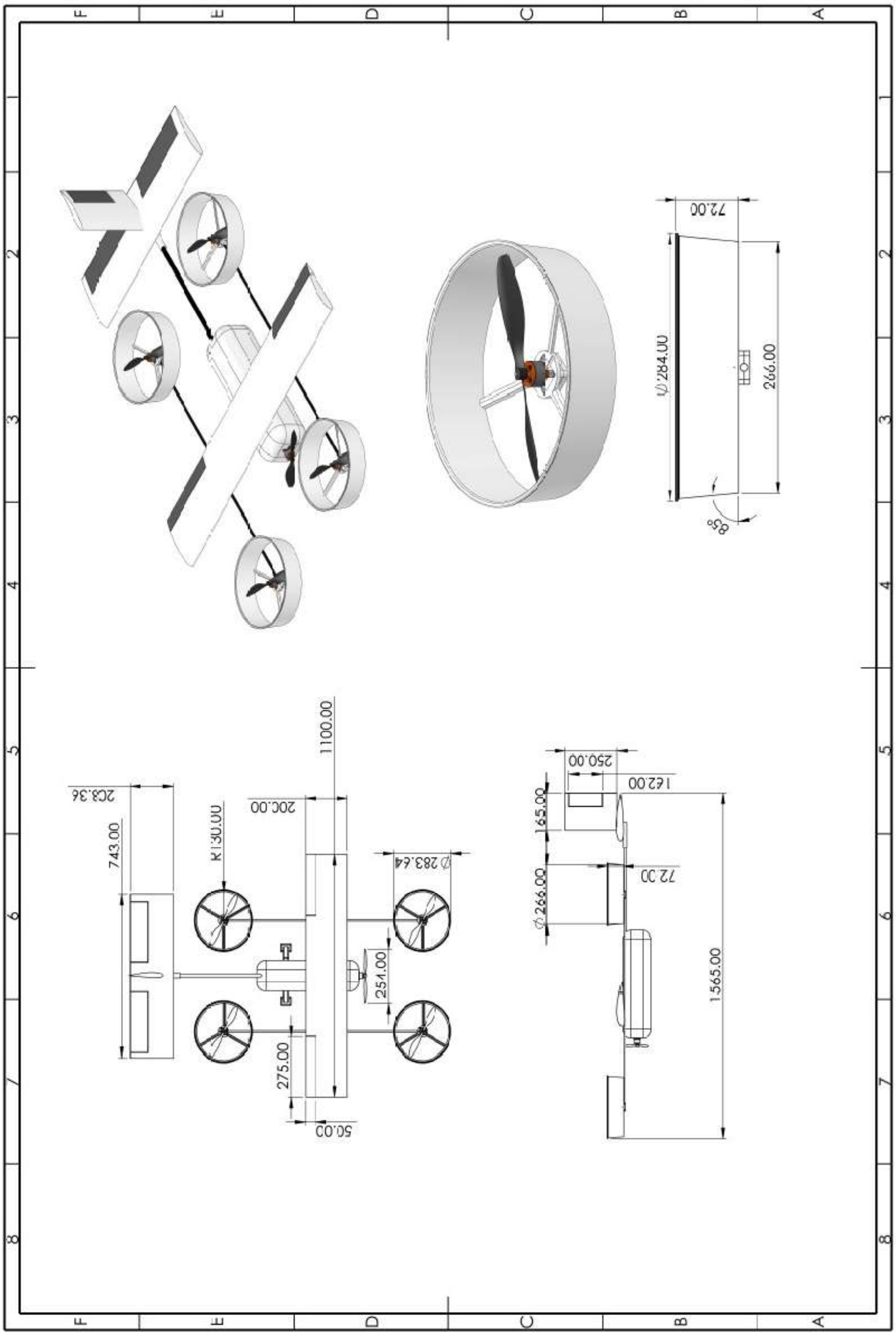

Figure 7.1: Proposed Sketch of Quad-Plane.

CHAPTER 8

FABRICATION AND TESTING

8. FABRICATION AND TESTING

8.1 FABRICATION

It is important to bear in mind that the aircraft will undergo multiple test flights in variable weather conditions. Keeping in mind the structural integrity and ease of rebuilding the aircraft, wing and the fuselage were fabricated using hardened thermocol, as it possesses desirable material properties such as good strength and light in weight and is economical.

Since the critical parts such as the quad-rod connectors and the ducts cannot be manufactured through conventional processes, proper design and manufacturing processes need to be employed to ensure desirable outcome. Hence, all the components are designed using CAD software and these files are converted into .stl files, which is a 3D printer readable file format.

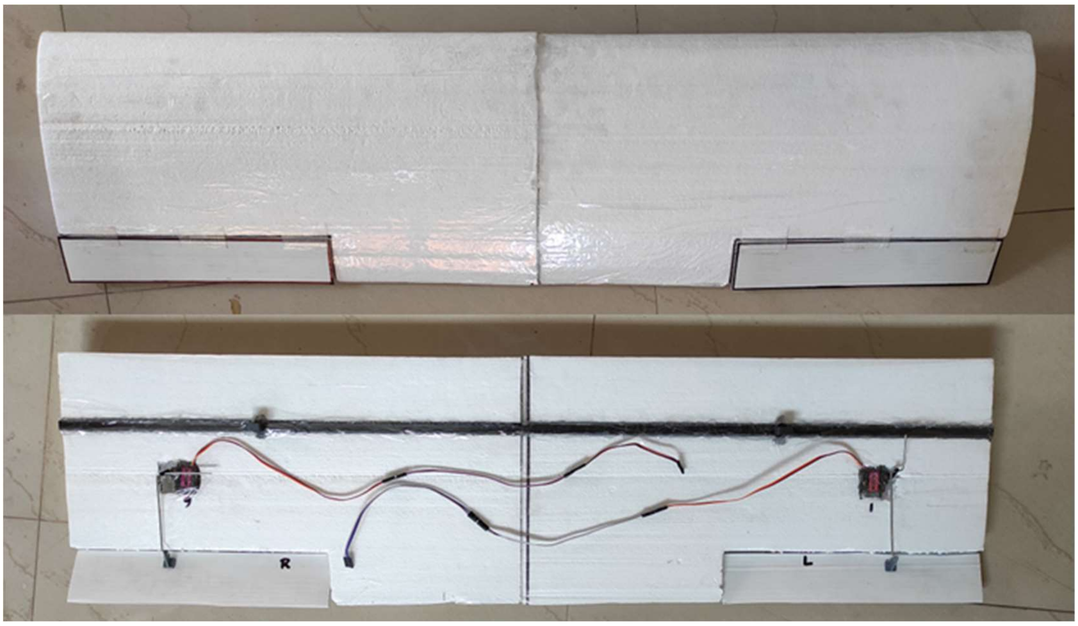

Figure 8.1.1: Wing – Top & Bottom Views.

The Hardened thermocol was purchased and prepared for further processing. The first part to manufacture was the wing. The airfoil shapes were cut on chlorofoam sheets lined with aluminium tape to ensure heat resistance. These airfoils were placed on sides of Hardened thermocol. Hot wire cutter was used to cut the wing by following along the airfoil profile. Slots for the carbon fiber spar was also made using the same procedure. This resulted in smooth and accurate wing with good surface finish. The wing consists of 2 splits, joined together with a carbon fiber spar running throughout the length of the wing.

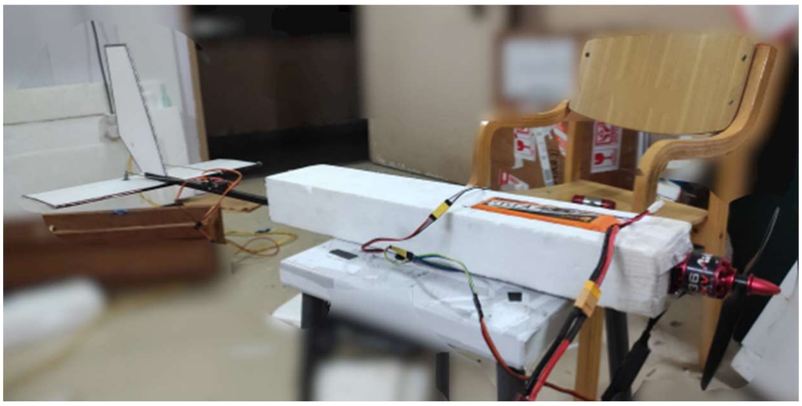

Figure 8.1.2: Fuselage with motor and electronics mounted.

The fuselage of the aircraft, being a simple cuboid is fabricated using hot wire cutter, by marking the required dimensions on the thermocol block and cutting through them. The slots required for placement of battery, power distribution board were made by hand, as usage of hot wire cutter for the same is not possible. Further, a slot was made at the bottom for placement of tail boom using hot wire cutter.

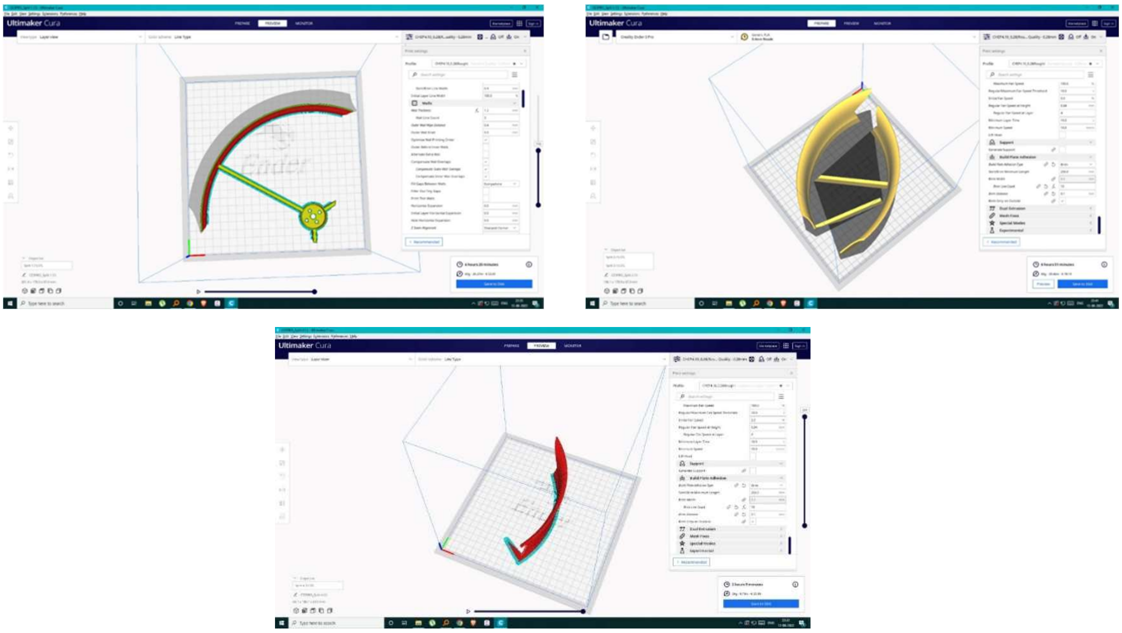

Figure 8.1.3: 3D Printing Bed Setup

Wing and quad rod connectors and the ducts are 3D printed using PLA (Poly Lactic Acid) as this method gives the freedom for fabrication of complex structures without compromising the overall strength.

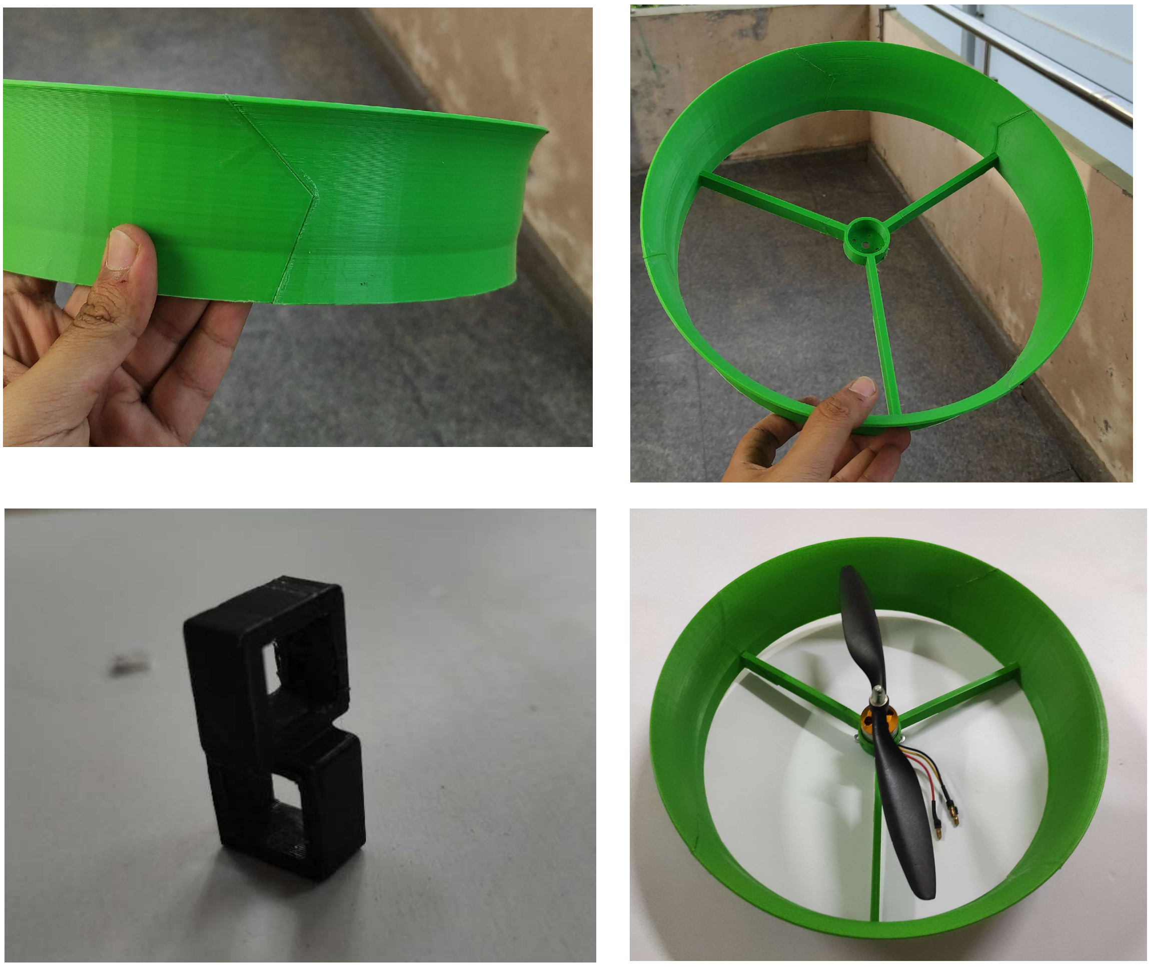

Figure 8.1.4: (a) Assembled 3D printed Duct (b) 3D printed Quad-Rod connector.

The print time of the duct was 14 Hours per duct, totaling to 56 hours of 3D printing time and the part was split into 4 individual pieces due to printing bed constraints. The ducts are assembled together using super strong quick bonding adhesive.

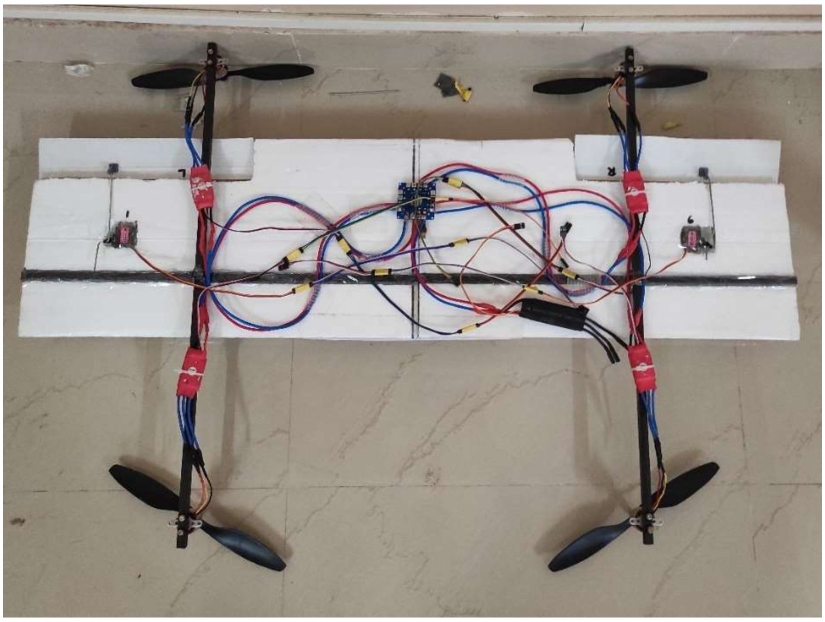

Figure 8.1.5: Flight system wired as shown in section 6.1.

Figure 8.1.6: Assembled Quad-Plane.

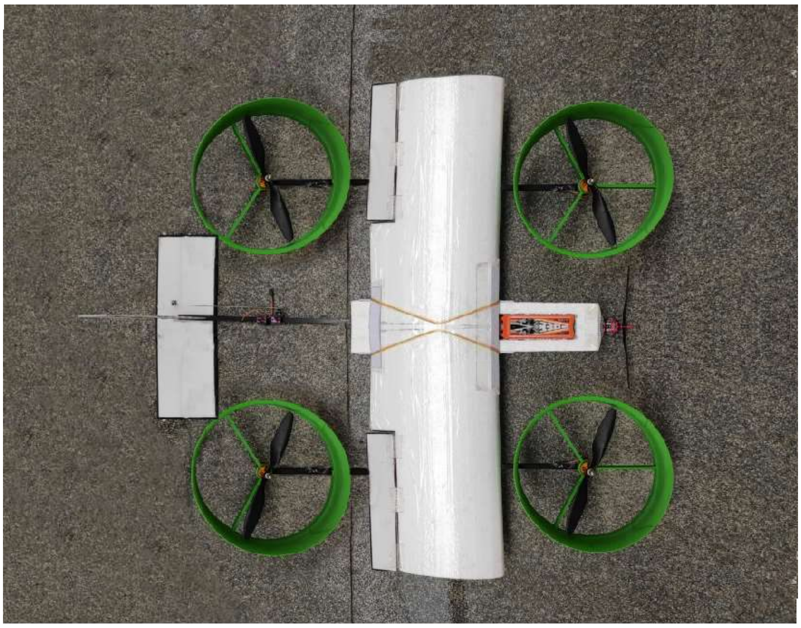

Figure 8.1.7: Assembled Quad-Plane with 3D printed ducts.

The quad-plane was assembled first without ducts. After ensuring if everything fits perfectly, ducts were attached to the quad motors and armed for further testing.

8.2 TESTING

8.2.1 Thrust test

The 1000 KV BLDC quad motors are rated for 800 grams of thrust at full throttle for a configuration of 3 cell battery & 10X45 propeller.

BLDC Brushless Motor – A2212/13T 1000KV

BLDC Brushless Motor Specifications:-

KV: 1000
No load Current : 10 V : 0.5 A.
Current Capacity: 12A/60s
No Load Current @ 10V: 0.5A
No. Of Cells: 2-3 Li-Poly
Motor Dimensions: 27.5 x 30mm
Shaft Diameter: 934;3.17mm
Shaft diameter : 3.175mm.
Minimum ESC Specification: 18A (30A Suggested)
Thrust @ 3S with 1045 propeller: 800gms approx
Thrust @ 3S with 0945 propeller: 475gms approx
Thrust @ 3S with 0845 propeller: 475gms approx

Figure 8.2.1.1: A2212 Motor rating under ideal testing conditions

During the testing phase with the duct in Figure 8.2.1.2, the motor showcased improved thrust values, rating at 856 grams of thrust for a configuration of 3 cell battery & 10X45 propeller.

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Figure 8.2.1.2: A2212 Motor rating during testing conditions using duct.

We conclude that, usage of ducts produces an overall extra thrust of 224 grams from all 4 quad motors and it increases the efficiency of the whole aircraft by 7% under ideal testing conditions.

8.2.2 Power Consumption test

Figure 8.2.2.1: Current and Watt rating for motor (a) with duct and (b) without duct

Figure 8.2.2.1 show a comparison of current drawn between quad motors with and without duct at 50% throttle over a period of time. The reduction is due to the fact that the duct reduces turbulent flow of air and concentrates the air into the duct with decreasing dia. This increases the exit velocity of air due to Bernoulli's Principle and also the efficiency of the motor.

The reduction in current drawn is estimated at 34% under ideal testing conditions, which drastically increases the flight time of the aircraft.

CHAPTER 9

RESULT

9. RESULT

The flight controls depend on the flight controller being used, Pixhawk in this case. The following modes were employed to test and analyze the aircraft.

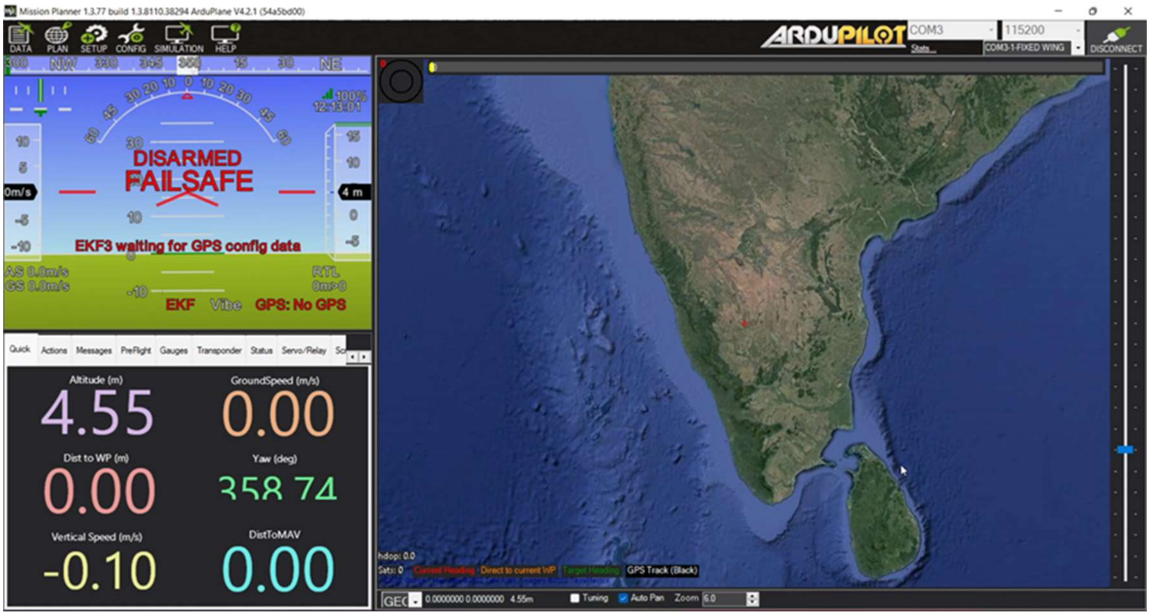

Figure 9.1: Mission planner - interface for Pixhawk by Ardupilot.

- QSTABALIZE
    - When roll and pitch sticks were released, the vehicle automatically leveled itself.
    - Regular input of roll and pitch commands were required to keep the vehicle in place as it was pushed around by the wind.
    - The yaw input controls the rate of change of the direction of flight. When the yaw stick is released, the aircraft maintain its current direction of flight.
    - The throttle input controls the average motor speed, this means that constant adjustment of the throttle is required to maintain altitude. When the throttle stick is put down completely, the motors go to their minimum rate of movement and hover at a particular point.
- QHOVER
    - In QHOVER mode, Quad-plane maintained a consistent altitude while allowing roll, pitch, and yaw to be controlled normally. This means that, the plane moves, turns, rolls while holding itself into a particular altitude.
    - This is particularly important because higher the altitude, lesser the density of air, the more disadvantage to a propeller-based aircraft and also keeping in mind urban terrain while performing missions, it is crucial to fly at a constant altitude.

- QLOITER
    - This mode automatically maintained the current location, direction of flight of the aircraft. When the sticks are released, the plane stops at a particular point, in the direction of its flight and gradually starts descending holding the current location based on pre-determined hovering motor speeds.

The aircraft is tested within its cruising altitude (100 m) and at its cruising speed (10 ms^{-1}) with a maximum take-off weight of 3 kg.

CHAPTER 10

BILL OF MATERIALS

10. BILL OF MATERIALS

Table 10.1: Cost breakdown of the project.

Particulars	Specification	Quantity	Price (₹)
Battery	LiPo 3300 mAh Orange	1	2,500
Propellers	10 X 4.5”	5	445
Motors	Brushless DC motors	5	2,000
Electronic Speed Controllers	Simonk 30A & Flightline 60A	5	2,250
Servo Motors	9-gram metal gear servos	4	495
Power Distribution Board	6 ports	1	120
3D printing	3D printed	-	5000
Transmitter and Receiver	TS832 48CH 5.8GHz RC + IA10B Radio receiver	1	4100
Frame	Sunboard sheets, Hardened Thermocol	1	660
Carbon Fiber Rods	8 mm X 1000 mm	4	1700
Flight Controller	Pixhawk 2.4.8	1	9000
Miscellaneous Expenses	-	-	1700
Total Cost			₹ 30,000/-

CHAPTER 11

CONCLUSION

11. CONSLUSION

This project showcases the design, manufacturing, and testing of an experimental vertical take-off and landing aircraft with a very specific feature of employing ducted propellers to increase the overall efficiency. Some of the major achievements of this study include determination of aerodynamic characteristics of aircraft, performance analysis of the ducts and overall efficiency enhancement of the aircraft.

The aircraft has been successfully assembled and tested under required conditions. The objective of the project has been achieved by designing and fabricating a cost-effective and efficient VTOL aircraft which is capable of carrying considerable amount of payload.

Ducts prove to improve the overall efficiency of the aircraft. This is verified by using thrust and power consumption tests. Even a minute increase in aircraft efficiency plays a major role in overall functioning of the aircraft. A 56-gram increase in thrust amounts to 7 percent increase in performance in each ducted propeller.

Some of the major challenges faced throughout the fabrication process is the difficulty to manufacture complex parts. This has been made possible by 3D printing these components. 3D printing has allowed designers and engineers to think and design freely, without keeping the manufacturing constraints in mind. Manufacturing of these components and their incorporation into this project would not have been possible and economically feasible without the application of 3D printing technology.

There is still a lot of room for improvement to be more efficient in this project. Utilization of BLDC motors with much higher capacity and compact in design ca significantly reduce weight of both the aircraft and duct to be designed. The propellers utilized can be upgraded to Tri-Prop with reduction in diameter for more thrust generation. Battery pack can be upgraded for better flight performance and increased flight time. Lastly, fabricating the fuselage with much more sturdy and hollow material would give lot of space for proper placement of battery, flight control systems, payload etc.

Overall, this project demonstrates the capabilities of vertical take-off and landing aircraft with ducted propeller capable of carrying considerable amount of payload in variable weather consition.

CHAPTER 12

SCOPE FOR FUTURE WORK

12. SCOPE FOR FUTURE WORK

There is still a lot of scope for improvement in this project. We have just scratched the surface in usage of ducted propellers for VTOL aircrafts.

- Data such as geographical characteristics, surveillance etc. can be gathered using these types of aircrafts. As this aircraft can take-off and land in any location, it will play a crucial part in surveying remote regions.
- Fully autonomous missions can be planned and executed with employment of telemetry and setting up a ground control station. This is particularly helpful in helping people in disaster-stricken areas, e-commerce delivery systems etc. Coupling these with technologies such as artificial intelligence and machine learning allows for an increased reach to solve problems and flight capability advancement.
- The battery technology can be improved and usage of the latest technologies such as Graphene batteries can prove beneficial. Increased cycle time and rate of discharge increases the life of the battery by a substantial amount.
- The aircraft is tested in ideal weather condition at a fixed altitude. Ducts also prove to reduce any disturbances in airflow to the propellers, which in turn plays a major role in functioning of the aircraft in variable weather condition. Necessary improvement, if made to the aircraft after testing in such weather conditions, will prove to be highly beneficial and increases the area of application of the aircraft.
- Ecologically friendly, sustainable technology and materials such as composites of natural fibers and utilizing solar power to power some components of the aircraft can also pose a vast area of opportunity for overall aircraft improvement.

CHAPTER 13

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13. REFERENCES

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Appendix II

Programme Outcomes (POs)

And

Programme Specific Outcomes (PSOs)

I. PROGRAM OUTCOMES (POs)

1. Engineering knowledge: Apply the knowledge of mathematics, science, engineering fundamentals, and an engineering specialization to the solution of complex engineering problems.

2. Problem analysis: Identity, formulate, review literature, and analyze complex engineering problems reaching substantiated conclusion using first principles of mathematics, natural sciences, and engineering sciences.

3. Design/development of solutions: Design solutions for complex engineering problems and design system components or processes that meet the specified needs with appropriate consideration for public health and safety, and the cultural, societal, and environmental considerations.

4. Investigate complex problems: Use research-based knowledge and research methods including design of experiments, analysis, and interpretation of data, and synthesis of the information to provide valid conclusions.

5. Modern tool usage: Create, select, and apply appropriate techniques, resources, and modern engineering and IT tools including prediction and modelling to complex engineering activities with an understanding of the limitations.

6. The engineer and society: Apply reasoning informed by the conceptual knowledge to access social, health, safety, legal and cultural issues and the consequent responsibilities relevant to the professional engineering practices

7. Environment and sustainability: Understand the impact of professional engineering solutions in a societal and environmental context, and demonstrate the knowledge of, and need for sustainable development.

8. Ethics: Apply ethical principles and commit to professional ethics and responsibilities and norms of engineering practice.

9. Individual and teamwork: Function effectively as an individual, and as a member or leader in diverse teams, and in multidisciplinary settings

10. Communication: Communicate effectively on complex engineering activities with the engineering community and with society at large, such as being able to comprehend and write effective reports and design documentation, make effective presentations, and give and receive clear instructions.

11. Project management and Finance: Demonstrate knowledge and understanding of the Engineering and Management principles and apply these to one's work, as a member and leader in a team, to manage projects and in multidisciplinary environments.

12. Life-Long learning: Recognize the need for, and have the preparation and ability to engage in independent and lifelong learning in the broadcast context of technological change.

II. PROGRAM SPECIFIC OUTCOMES (PSOs)

1. Applied principles of basic science, mathematics, machine design, manufacturing, thermal engineering and management to solve real-life mechanical engineering problems.

2. Use professional engineering practices and Strategies for the development, operation and maintenance of mechanical system/ processes.

Table A: POs and PSOs.

PO1	PO2	PO3	PO4	PO5	PO6	PO7	PO8	PO9	PO10	PO11	PO12	PSO1	PSO2
3	-	-	-	-	-	-	2	3	3	3	3	2	-

Correlation: 3-High, 2- Medium, 1-Low.