SAE ISS AERO DESIGN CHALLENGE 2022

Design Report (Micro-Class)

TEAM NAUTILUS
TEAM ID : ADC20220181

HINDUSTAN INSTITUTE OF TECHNOLOGY & SCIENCE
(DEEMED TO BE UNIVERSITY)
CHENNAI

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STATEMENT OF COMPLIANCE

CERTIFICATION OF QUALIFICATION

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Team No. : 181

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Statement of Compliance

As a faculty advisor we certify that the registered team members are enrolled in the collegiate club and courses. This team has designed and analysed this preliminary design report of UAV (microclass) in accordance with given conditions and guidelines mentioned in the rule book for ADC-2022 which is a design contest, without any direct assistance from the professional engineers, R/C model experts or pilots or any other related professionals.

(G.Dineshkumar)

Signature of the Faculty Advisor **Date : 10/06/2022**

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2. Executive Summary

This document is a design report of Team NAUTILUS of Hindustan Institute Of Technology And Science, India pertaining to the SAE Aero Design Challenge Southern Section 2022 competition, held at Chennai India.

This report contains a complete overview of our design process, analysis of our final design, complete information and a summarization of our expected performance. The main objective of our Team NAUTILUS is to design a lightweight aircraft with maximum possible payload fraction. Our goal is to design and fabricate an UAV type aircraft that is capable of lifting a payload of approximately 1.1 lbs.

Our final design is a top/high wing rectangular type monoplane referred to as VT-MAV which is a single-engine propeller driven aircraft. The aircraft has been constructed using depron sheets, carbon fibre tubes, balsa wood etc. After finalising our theoretical aircraft design, we used several pieces of software for various analyses.

3. Design Process

This section details the team's processes and approaches to design the aircraft such that it needs all the necessary requirements and manages to perform the desired task to win the SAE Aero Design Challenge Southern Section 2022 competition, micro class.

3.1 Literature Review

It begins with the observation of the videos of Micro-Class SAE Aero Design competitions held in the previous subsequent years to get an idea about the competition. Following it, we came up with the plans for airfoil, wing, fuselage, electronics and various other estimations. We also made various blueprints and circuit diagrams to get a better idea about the concept.

3.2 Strategy

Our main aim during the entire design process was

1. To keep the lowest empty weight possible (so that payload with maximum weight can be carried on given thrust)

2. To make the model robust enough without much compromising in weight

So we came up with some light but durable materials like balsa wood, carbon rods etc.

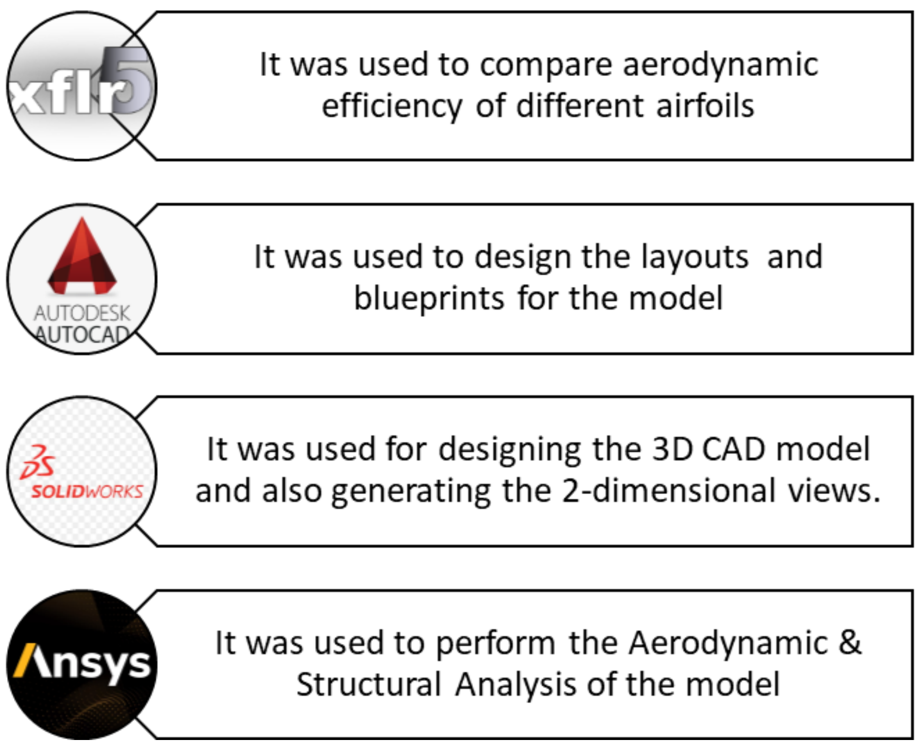
3.3 Design Iteration

The philosophy of this team throughout the team process has centred on developing sound fundamentals to satisfy competition requirements. Therefore, the focal point for the team was to create an UAV model that:

1. Can achieve the highest possible lift.
2. Can minimise drag effects.

3. Maintain longitudinal and vertical static stability.
4. Can provide adequate manoeuvrability.
5. Can possess the necessary structural strength.
6. Has the lowest empty weight.
7. Can carry payload with highest payload fraction.

3.4 Applications Used



3.5 Design Configurations

The final design of VT-MAV consists of a top-mounted wing with SELIG1223 airfoil profile capable of generating the highest possible lift among its rivals. The fuselage consists of a streamlined-box shaped design with a rectangular payload bay embedded inside it. The horizontal and vertical stabilisers consist of a symmetrical NACA0012 airfoil inclined at a definite pitch angle. The electronics system consists of a 14” CFRP propeller, a 750 kV brushless motor, a 2000 mAh 3-cell battery, 40Ampere ESC and a receiver.

3.4.1 Aerofoil Selection

In this design, we have incorporated SELIG1223 airfoil. The primary characteristic of this airfoil is to provide high lift characteristics. We have compared three different airfoils which are majorly used for RC-Planes. They are SELIG1223, EPPLER423 & CH-10. From the lift-drag curves obtained through a program called xflr5 within a predefined range of Reynolds Number.

From the graphs, it is quite clear that we get the highest lift coefficient of $C_L = 2.25$ for the Critical Angle of Attack (θ_{crit}) of $13°$ compared to the other two airfoils.

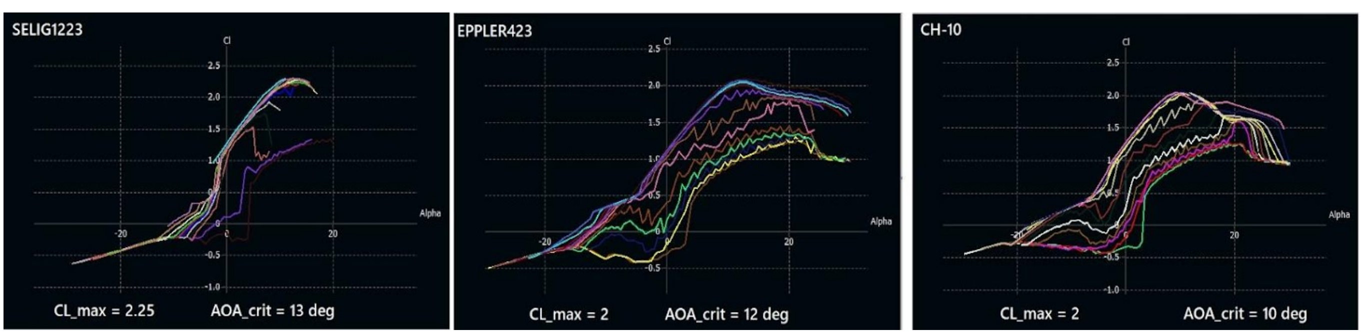


Fig 3.4.1 (a) - Comparison of Cl vs α curves for three airfoils

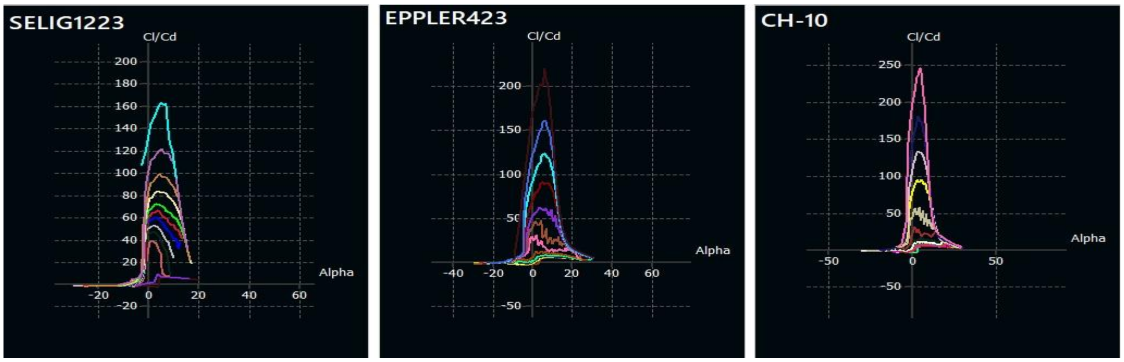


Fig 3.4.1 (b) - Comparison of Cl/Cd curves for three airfoils

With respect to the $\frac{C_L}{C_D}$ vs α curves, we get $\frac{C_L}{C_D} \approx 160$ for the given Reynolds Number which is highest in comparison with the other two airfoils. Hence we decided to proceed with SELIG1223 airfoil for the wing for :

- Highest possible lift.
- Lowest Possible Drag (High L/D ratio for given Re).

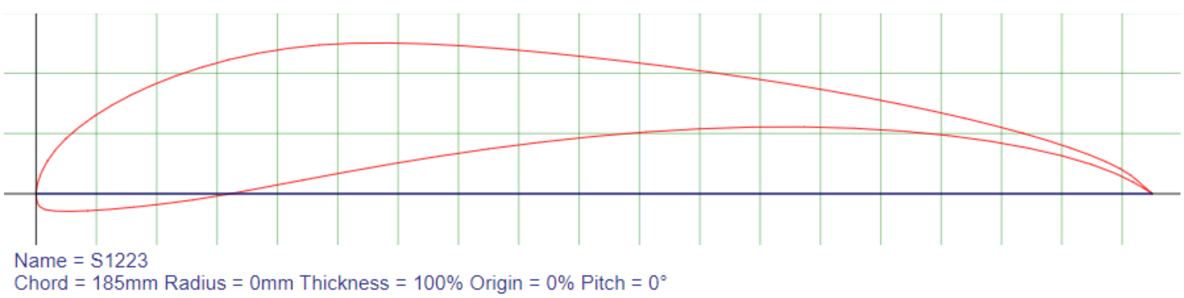


Fig 3.4.1 (c) - Profile for SELIG1223 Airfoil

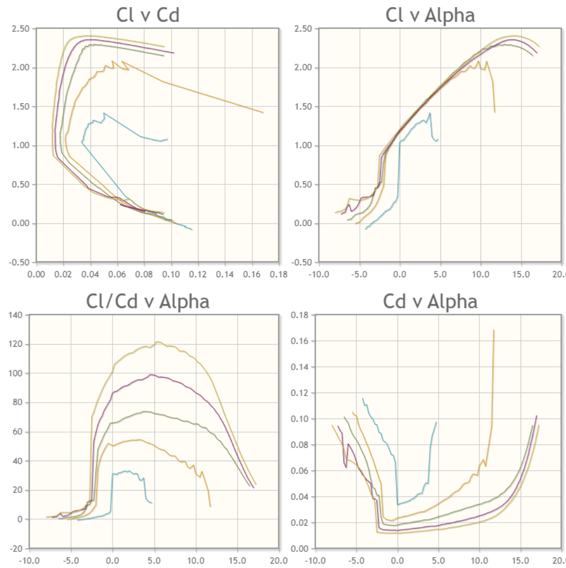


Fig 3.4.1 (d) - Different Aerodynamic Curves for S1223 airfoil.

Airfoil Selection for Horizontal & Vertical Stabilizer

- A symmetrical airfoil profile should always be used for both the horizontal and vertical stabilizer as the net force acting on both will change direction during the course of flight depending on which direction the elevator or rudder is deflected.
- Two common profiles to consider using are the NACA 0010 or NACA 0012 airfoil.

In our design, we have incorporated NACA0012 airfoil for both the horizontal and vertical stabilizer with varying chord length to obtain a tapered shape.

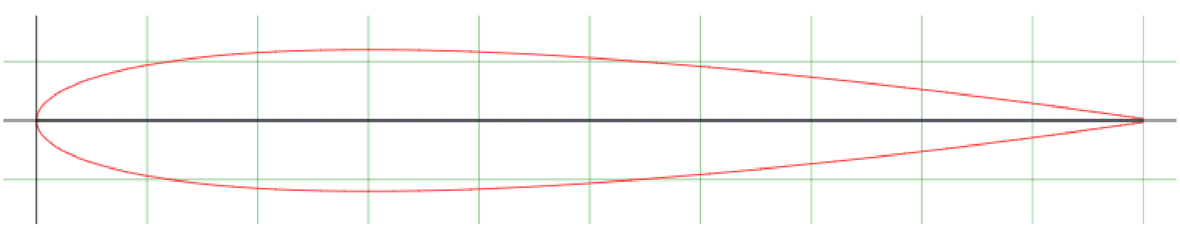


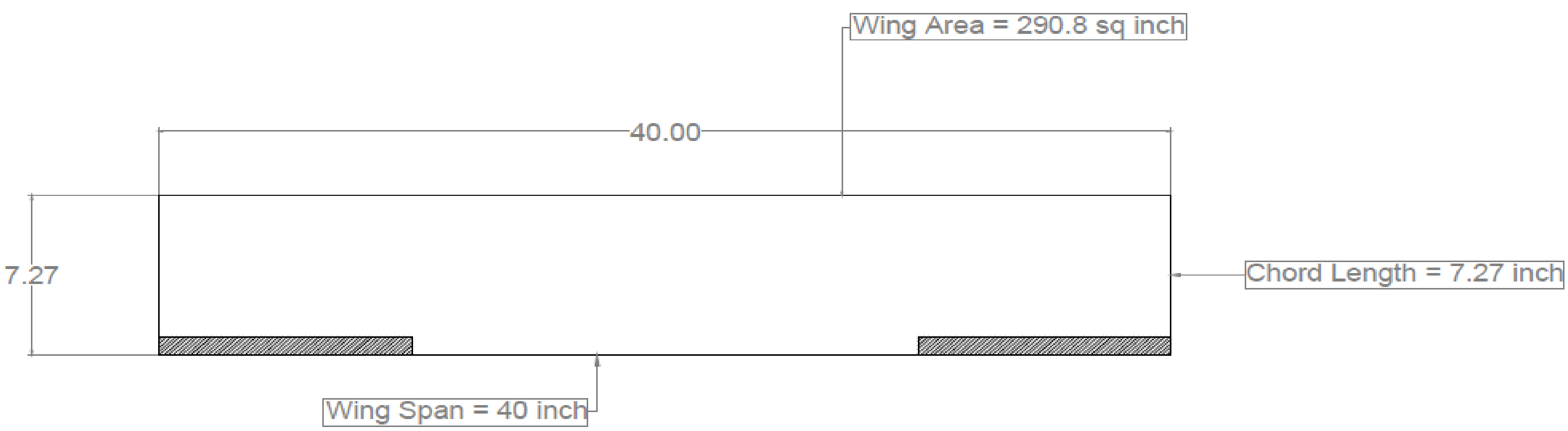
Fig 3.4.1 (e) - Profile for NACA0012 airfoil

3.4.2 Wing Design

- We have assumed an aspect ratio of 5.5 for our design which is an ideal value for the RC-planes according to the experiments.
- We used a combination of formulas and online calculators to calculate the dimensions of wing, fuselage, emphanage and primary control surfaces.

$$Aspect\ Ratio\ (AR) = \frac{b^2}{S} = \frac{40^2}{290.8} = 5.5$$

Fig 3.4.2 (a) - Wing Top-View with necessary parameters indicated.



$$Wing\ Loading\ = \frac{W}{S} = \frac{1.8*9.81}{0.188} = 94\frac{N}{m^2}$$

3.4.3 Sizing of Primary Control Surfaces

According to the thumb rules for the RC-planes:

- The aileron is estimated to be about **25%** of the total wing surface area.

- The horizontal & vertical stabilizers are estimated to be approximately around **15%** of the total wing surface area.
- The elevator accounts for around **20%** of the stabilizer area and the rudder is estimated to be around **33%** of the fin area.

3.4.4 Tail Selection

After a lot of analysis and study, the team decided to go with a conventional type tail configuration as it would be more suitable for the VT-MAV as it would act as an advantage to the model.

3.4.5 Fuselage and Empennage Section

The fuselage is the backbone of an aeroplane. It serves as a connecting piece for the engine, wing and tail fin as well as storing payload and other components. This part of the aircraft is a geometrically large piece of the total system and will experience significant loading during landing. All aerodynamic and structural considerations will be addressed in the design of the fuselage.

- According to the thumb rules for RC-planes, the length of the fuselage for our design is estimated to be equal to 28.11 inches.
- The fuselage has been divided into three modules for the ease of assembling and loading or unloading the payload and other electrical components.

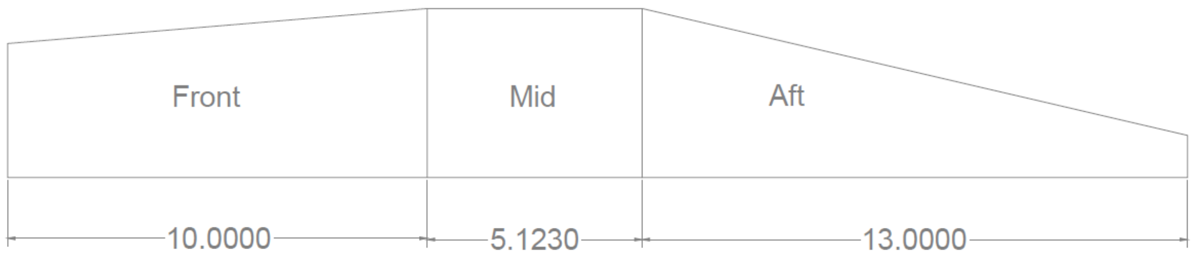


Fig 3.4.5 (a) - Layout of the fuselage

3.4.6 Final Configuration

The final design is a high lift top-wing aircraft with a tapered-box shaped fuselage and the motor integrated at the nose with the conventional configuration of horizontal and vertical stabilizers and the payload bay embedded inside the fuselage in the central portion.

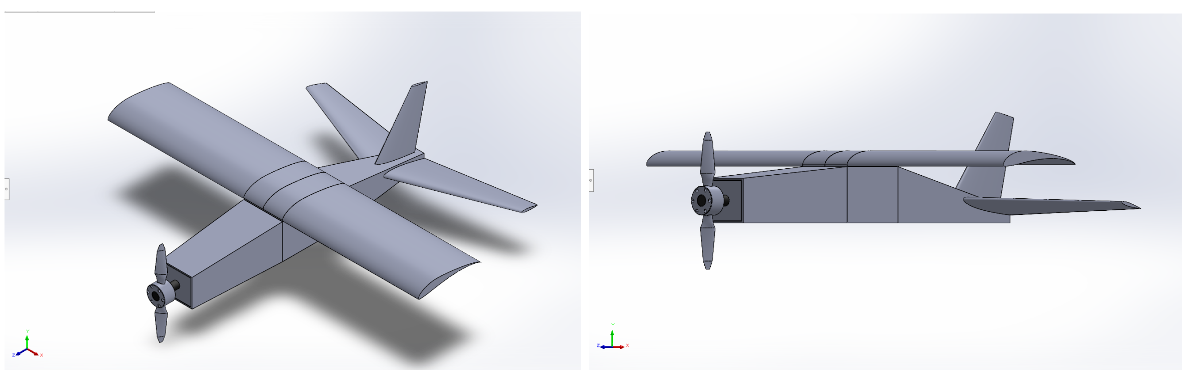
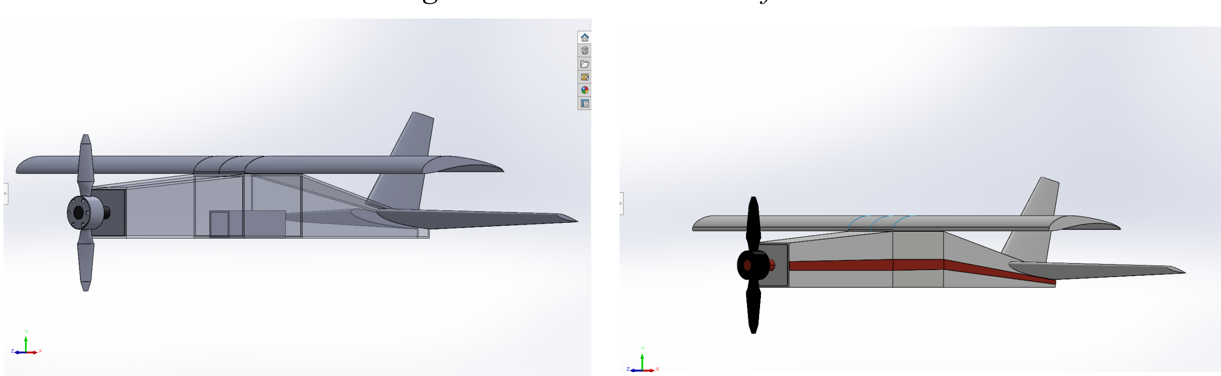


Fig 3.4.6 - Isometric Views of Model



This design would be capable of carrying the payload with the highest payload fraction to meet the competition requirements.

4. Analysis & Calculations

This section of the report consists of the calculation analysis done on the aircraft to test the performances of the individual aircraft components using Ansys Workbench 2020.

4.1 Aerodynamic Analysis

In order to evaluate and finalise on the newly proposed design, the model was simulated, analysed and the performance characteristics were calculated . According to the analysis the S1223 airfoil section provides high lift and low drag profiles at low speed with a $Clmax$ of 2.1. This is a very appreciable and best suited for our aircraft configuration.

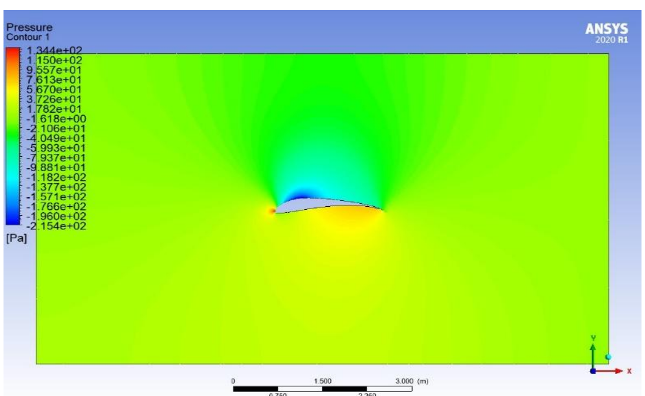


Fig 4.1 (a) - Pressure contour at 0 degree AOA

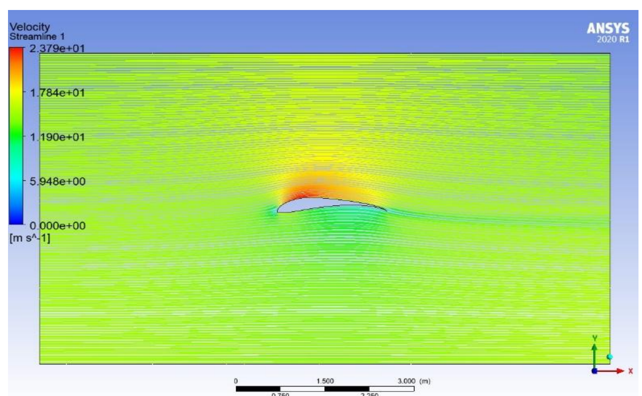


Fig 4.1 (b) - Stream line flow around the airfoil

The pictures show the fluid flow analysis over the SELIG 1223 airfoil at the calculated stall velocity of 7 m/s. The airfoil provides much higher lift at lower reynold’s number which is directly proportional to flow velocity. After the thorough analysis calculations done, it is found that the maximum angle of attack is 13. The flow characteristics as follow gives the maximum lift with minimal drag .

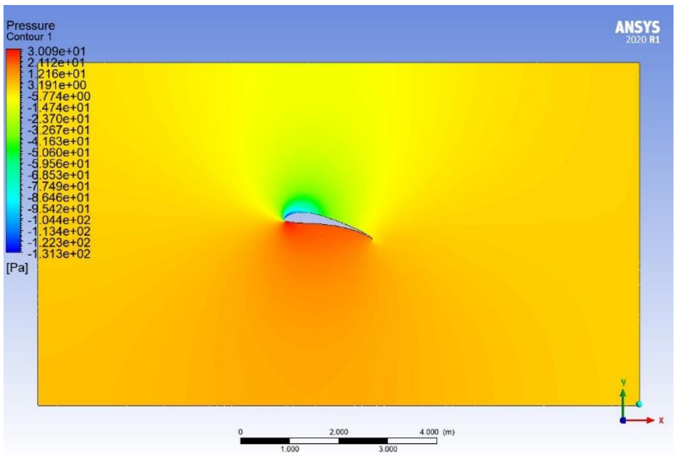


Fig 4.1 (c) - Visualisation of pressure contour at 13 degree AOA

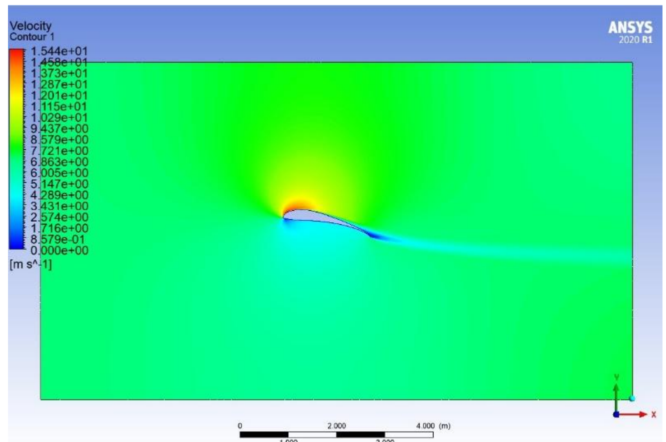


Fig 4.1 (d) - Visualization of velocity contour at 13 degree

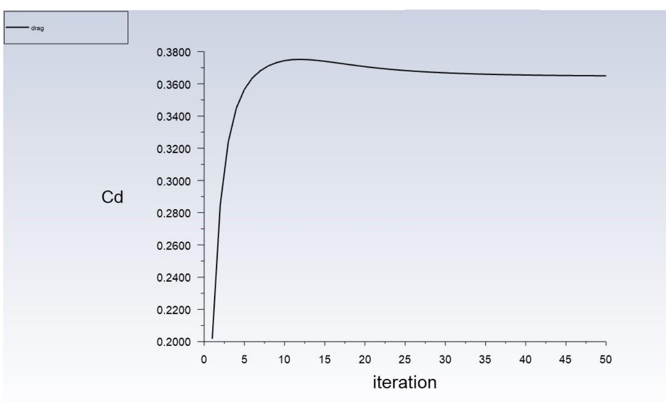


Fig 4.1 (e) - Cd vs iterations for wing analysis

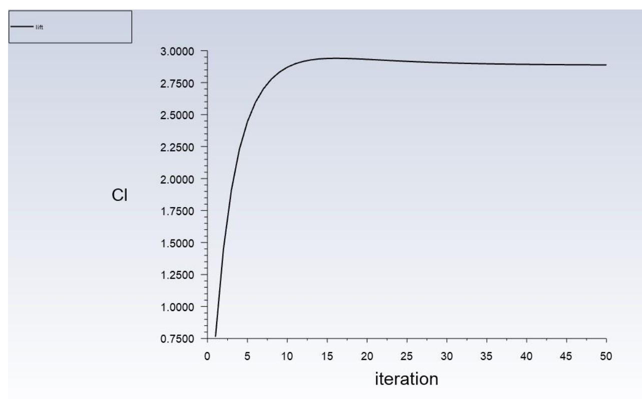


Fig 4.1 (f) - Cl vs iterations for wing analysis

The viscous model used for the CFD analysis is the standard k-epsilon (2 eqn.) with enhanced wall treatment which is the most suitable for low speed analysis. Each part was analysed for its aerodynamic characteristics. First the airfoil was analysed and then the whole wing was analysed

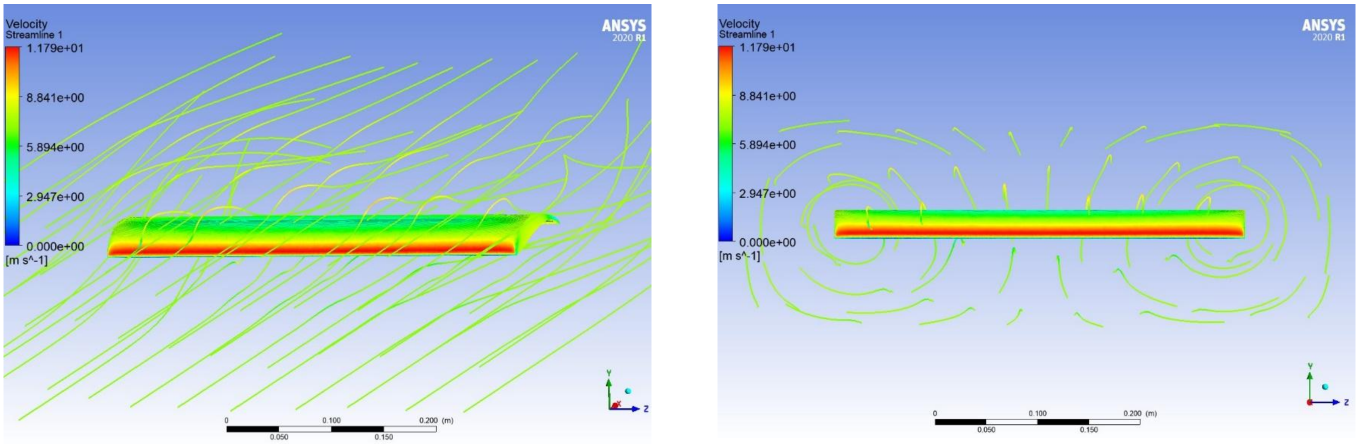


Fig 4.1 (g) - Visualisation of flow over wing from different views.

Using Computational Fluid Dynamics (CFD). The Cp contours and the velocity flow over the entire wing were checked to get finalised results after a number of iterations at various values and as shown as follows. The above graphs of the wing analysis gives the desired value of Cl of 2.8 as estimated and a minimal drag coefficient (Cd) of 0.36. Similarly, the wing was analysed from various views to get its velocity streamline flow where the flow can be properly visualised.

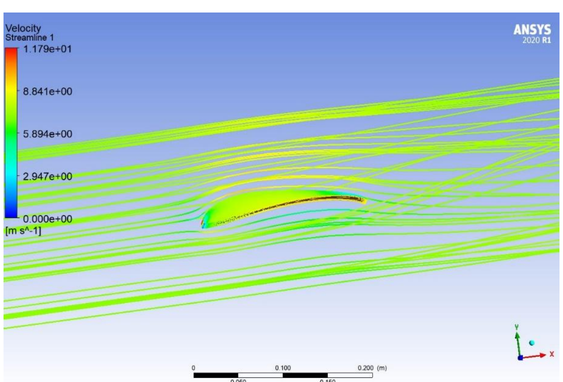


Fig 4.1 (h) - Streamlines over an airfoil

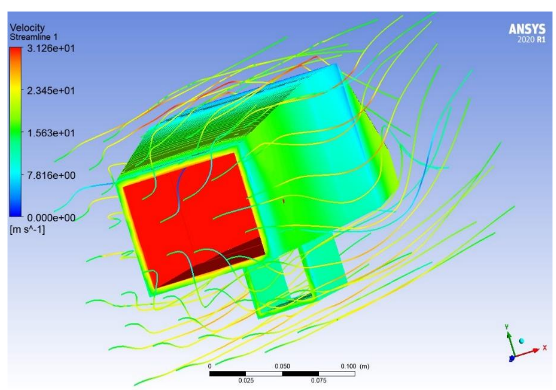


Fig 4.1 (i) - Visualisation of flow over fuselage from front view

Finally, we had to analyse the fuselage as a whole of our aircraft performance had to be determined. Thus, the entire parts of our model were imported to CFD to undergo the flow analysis process in order to know if our design had performance needed for the tasks. The results were successful after a number of iterations in optimum conditions and the results were as follows. Similarly, the rear part of the fuselage was analysed to get its velocity streamline flow where the flow can be properly visualised.

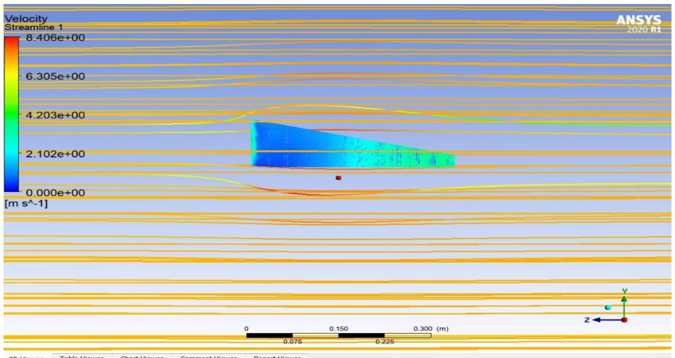
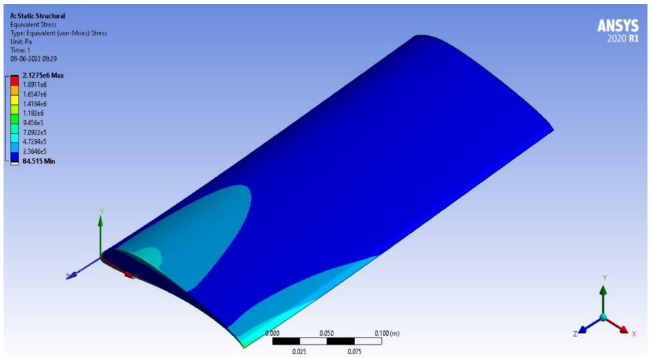


Fig 4 (a) - Simulation of streamlines over aft portion of fuselage

4.2 Structural Analysis

This part highlights the structural strength of various components of the aircraft. The ability to withstand loads is an essential criterion to ensure that no component undergoes failure during the flight of the aircraft .

The wing structure was designed with the help of CAD software. It is designed to be structurally light and sturdy. Due to this it should be able to withstand the bending loads acting on it. To meet These requirements, a rib and spar skeleton structure were designed. Wing used in this model is a rectangular wing which is easy to construct and gives the optimal strength. The wing can be attached and detached from the body of the fuselage by a lock system employed above the fuselage. In order to ease transportation and portability the wing was designed to be detachable and divided in two sections. Those three segments are held together by carbon fibre tubes.



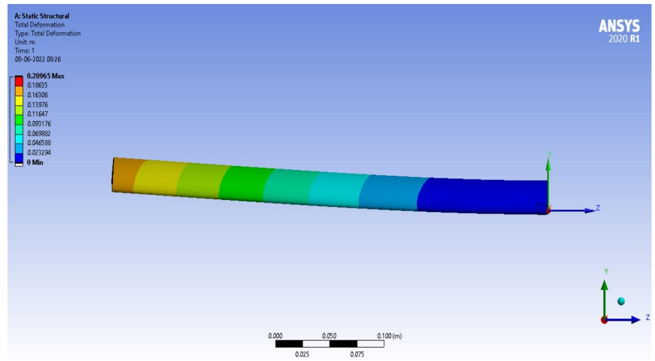


Fig 4.2 (a) - Visualisation of stress on the wing due to load on wing,

Fig 4.2 (b) - Visualisation of Total deformation of wing due to lift produced at load factor 2g

The wing is a cantilever beam and is subjected to a uniform bending load of 16.677 N on each wing at the bottom surface assuming the load factor of 2g. The stress distribution and deflection of the wing are shown below.

4.3 Calculations

Sr No	Component	Dimensions
1	Wingspan (b)	40 inch
2	Wing Aspect Ratio (AR)	5.5:1
3	Avg Wing Chord (c)	7.27 inch
4	Wing Area (S)	290.8 sq inch
5	Aileron Length	10 inch
6	Aileron Width	1.82 inch
7	Strip Aileron Width	0.91
8	Fuselage Length (F)	28.11 inch
9	Fuselage Height (H)	4.5 inch
10	Balance Point from WingLE	2.4 inch
11	Stabilizer Area	43.62 sq inch
12	Stabilizer Width	3.81 inch
13	Avg Stabilizer Length	11.45 inch
14	Elevator Area	8.72 inch
15	Avg Elevator Width	0.76 inch

16	Fin Area	14.39 sq inch
17	Avg Fin Width	2.19 inch
18	Fin Height	6.57 inch
19	Rudder Area	4.75 sq inch
20	Avg Rudder Width	0.72 inch
21	Estimated Empty Weight	1200 g
22	Estimated Payload Weight	500 g
23	Estimated All Up Weight (AUW)	1700 g
24	Wing Loading	90 g/sq dm
25	Stall Speed (V)	8 m/s
26	Landing Distance (approx.)	51 m
27	Touch Down Velocity	9.2 m/s
28	Lift Force (L)	16.5N
29	Payload Fraction (PF)	0.6

Table 1 - List of Various Components/Flight Parameters & their corresponding dimensions/values

Formulas Used :

$$L = \frac{1}{2} * \rho * V^2 * S * C_L$$

$$PF = \frac{M_{empty}}{M_{empty} + M_{payload}}$$

$$D = \frac{1}{2} * \rho * V^2 * S * C_D$$

$$Stabilizer\ Area \approx 15\%\ of\ Wing\ Area$$

$$S_g = \frac{1.21 * \frac{W}{s}}{g * \rho * C_{Lmax} * \left(\frac{T}{W}\right)}$$

$$Elevator\ Area \approx 20\%\ of\ Stabilizer\ Area$$

$$V_{stall} = \left(\frac{2 * W}{\rho * S * C_L}\right)^{0.5}$$

$$Rudder\ Area \approx 33\%\ of\ Fin\ Area$$

$$V_{touchdown} = 1.15 * V_{stall}$$

$$Fuselage\ Height \approx 10 - 15\%\ of\ Fuselage\ Length$$

$$AR = \frac{b^2}{S}$$

$$Location\ of\ CG \approx 25\%\ of\ MAC$$

Thumb Rules for RC-Flying

5. Electronic Systems

A wide variety of electronic components and subsystems are used in the manufacture of unmanned aerial vehicles (UAVs). Electronics make up a significant part of systems such as propulsion mechanisms, take-off and landing, targeting and weaponry, sensors as well as the computers required to control and coordinate an unmanned vehicle’s subsystems. The electronics of VT-MAV also plays an important role in the scoring of the micro class competition. The major components of the electronics are: -

1. Battery
2. ESC (electronic speed controller)
3. Brushless Motor (750 kV)
4. Connecting Wires
5. Propeller
6. Transmitter & Receiver
7. UAV Controller Remote
8. Push Rods

We have kept the battery in such a way that it powers all the control systems like servos, ESC and all other avionics systems. The battery used in our UAV is a 2200 mAh lithium polymer battery which has 3 cell settings and has a C Rating of 30 C. The electronic speed controller (ESC) used in our model is 40 amps. The length of our propeller is about 14 inches. A brushless motor of 750 kV is used. With the above combinations of battery, motor, propeller , the UAV will be able to provide thrust of about 1.5 Kgf or 1500 grams which is the required thrust of sustained flight in the SAE Aero Design Challenge.

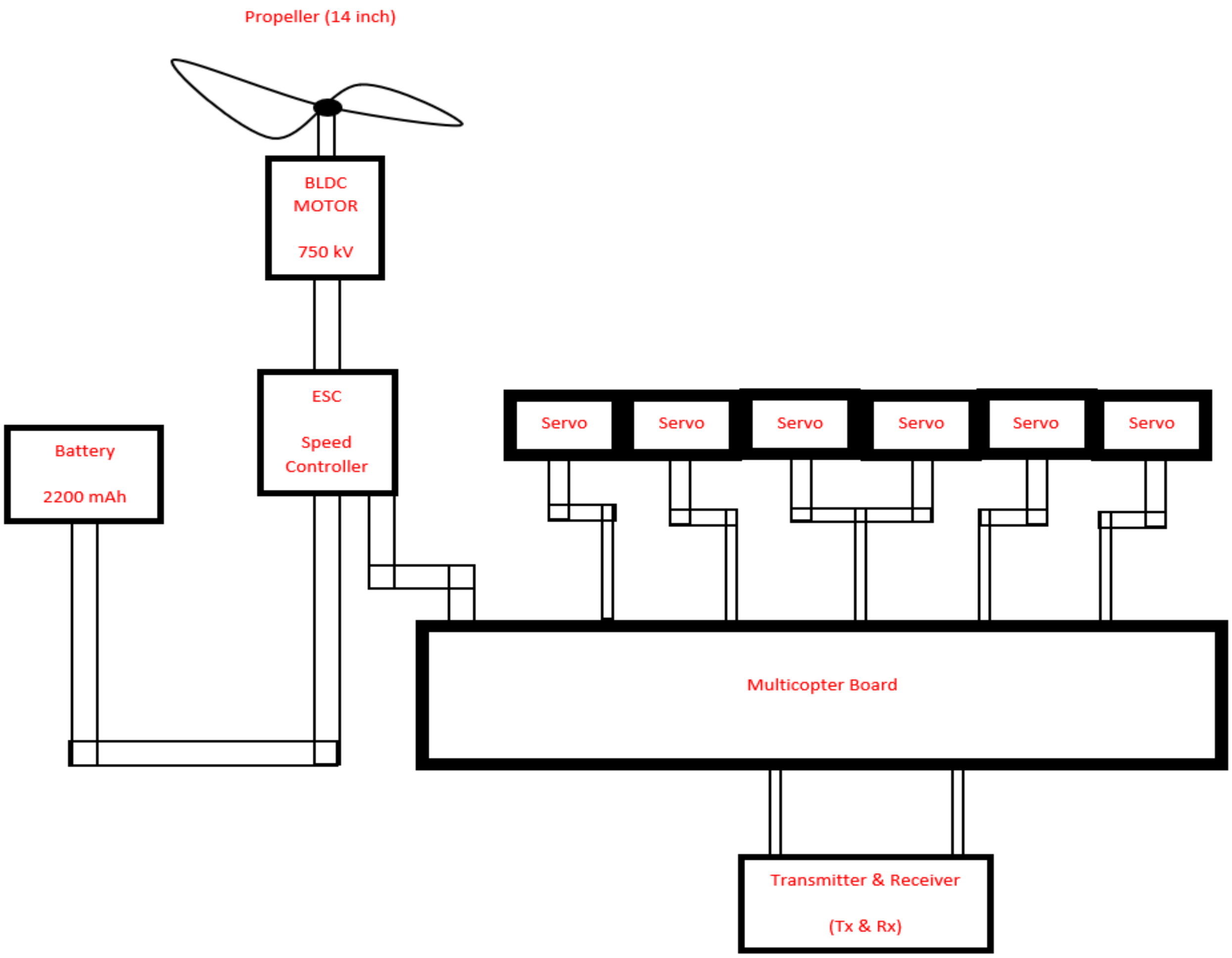


Fig - Electric Circuit

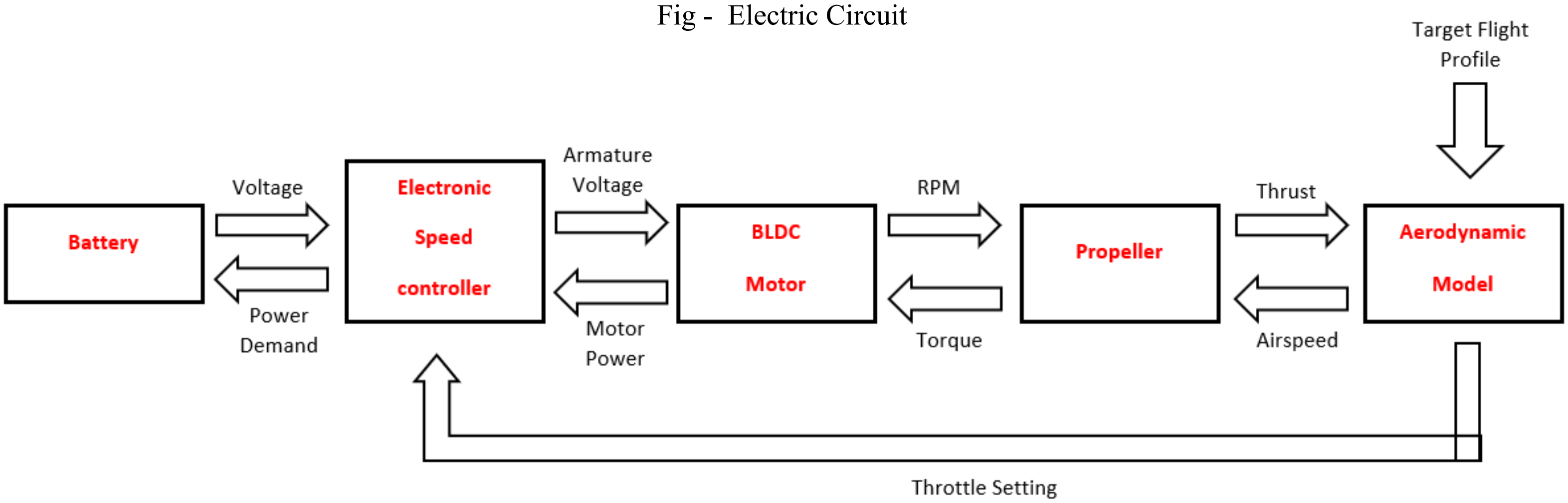


Fig. Propulsion Model Block Diagram

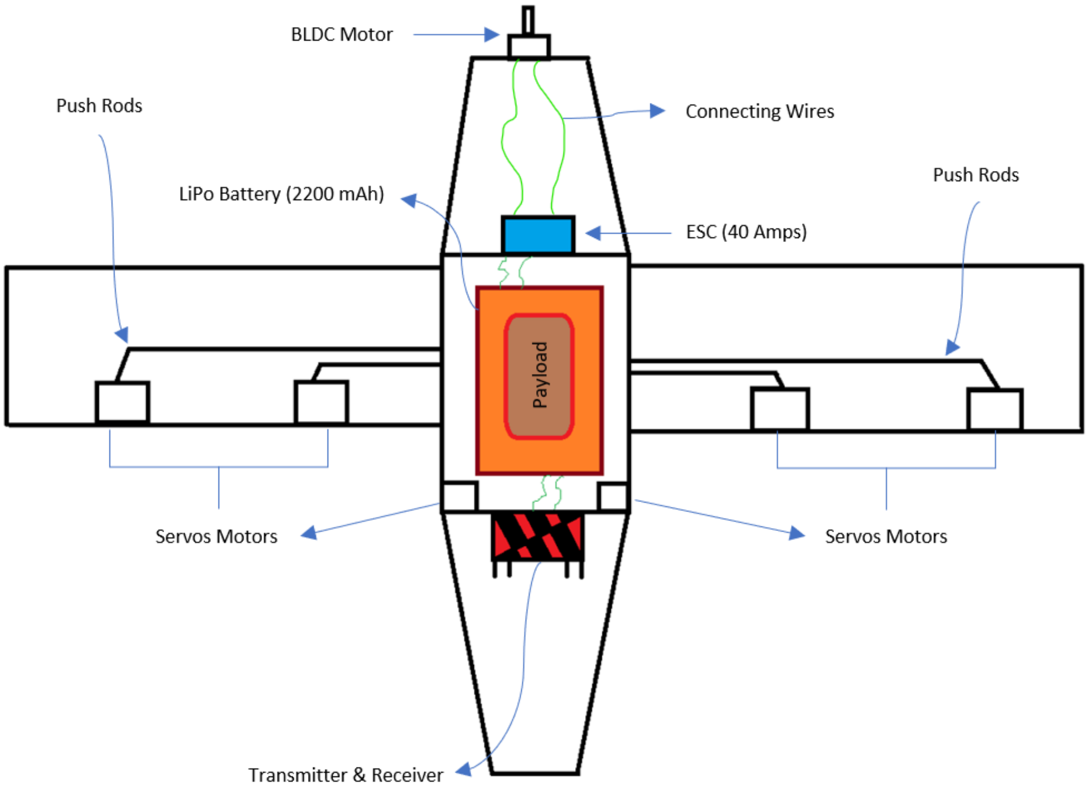
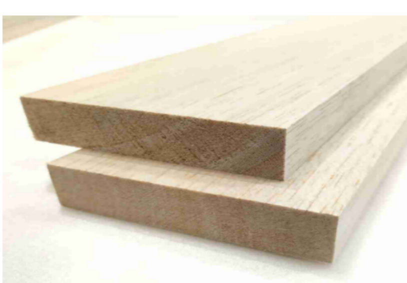


Fig - Mechanical & Electrical Systems Schematic

6. Materials, Fabrication & Construction

6.1 Table of Materials Used

S No	Material Name	Specifications	Design Requirement
1	**Balsa Wood** 	* Balsa sheet is made of high quality wood, offers exceptional durability, rigidity, and stability, it is essential in making model and DIY materials. Enough to stand alone with light sanding, varnishing or staining.	3 sheets of dimension 39” * 4” & 6mm thickness

2	**Depron Foam Sheet** 	* Depron Sheets Made of high quality EVA material, environmental protection, non-toxic, not changeful form, very durable. They have high resilience and resistance to tension, strong toughness, good shockproof and cushioning performance. It is a fantastic medium for building model RC aeroplanes.	5 sheets of dimension 30” * 20” & 5mm thickness
3.	**Carbon Fibre Rods & Tubes** 	* Carbon rods & tubes are corrosion resistant, high vibration attenuation, high heat conductivity, ultraviolet resistance material. * It is used as stringers in RC aircraft models.	8x1000mm – 1 nos 4x1000mm – 1 nos 2x1000mm – 1 nos

Table 2 - Materials used along with their specifications

6.2 Fabrication & Construction

6.2.1 Wing :

Component	Material
Ribs	Balsa Wood
Stringers	Carbon Tubes/Carbon Rods
Skin	Depron Foam

Pasting the airfoil profile printouts on the balsa wood made it easier for cutting and carving the airfoil with exact dimensions. Similar pattern is followed and 8 airfoils are made. To have better finishing and smooth surface, sand papers were used. We have finalised to construct the wing in two different modules, each having a span length of 20 inches. A glimpse of the construction process is as follows :

- Each Wing contains around 6 ribs spaced at approximately 10 cm distance from each other.
- A carbon tube of 10*8 mm diameter is placed from root till around 2/3 of the length of the span. The distance from the leading edge is around 3.66 cm. A carbon rod of 8mm diameter is fixed in the centre portion of the fuselage, extending around 20 cm from both the sides. While assembling, the carbon tube can be integrated inside the rod (rod extends at around 1/3 of the length of span.
- In the similar way, the carbon-tube & carbon-rod integration is done at 7.91 cm from the leading edge. The carbon-tube is 6*4mm diameter, extending till 2/3 length of span from root while the carbon rod has 4mm diameter extending to 1/3 the length of span from root. The same setup is applicable for the wing on the other side.

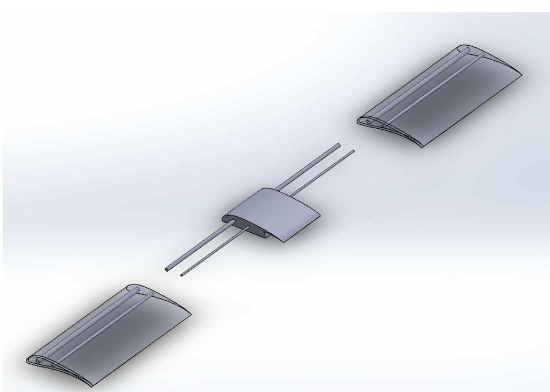


Fig 6 (a) - Construction of Wing (1)

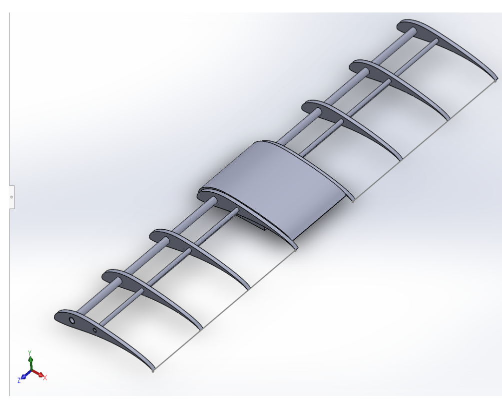


Fig 6 (b) - Construction of Wing (2)

Out of 183 mm chord length, to place the carbon rods at 36.5 mm and 79 mm from the leading edge, two holes were drilled at location mentioned above with 10 mm and 6 mm diameter respectively.

6.2.2 Fuselage :

- The fuselage is split into three different modules namely front, middle & aft part as mentioned in the design process.
- To integrate all we have conceptualised to put four carbon rods/tubes at the corners making a carbon rod-tube combination between the two modules to integrate it as shown in the figure.
- The carbon tube of 4*2mm diameter is fixed at the corners of the forward part using hot glue. Similarly, a carbon rod of 2mm diameter is fixed at the four corners of the forward face of the middle part. Hence, in this way it becomes easy to integrate the forward part with the middle part instantly by embedding the carbon rod inside the carbon tube.
- Similar principle lies behind the integration of the aft part with the middle part.

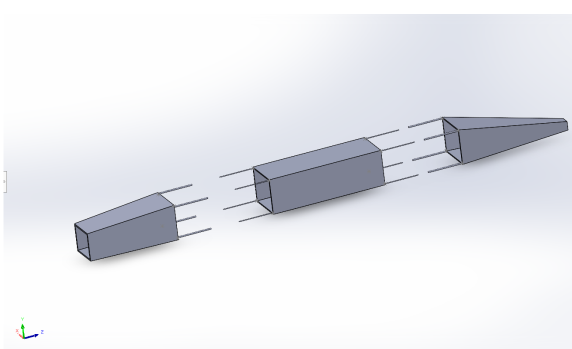


Fig 6(c) - Fuselage Construction

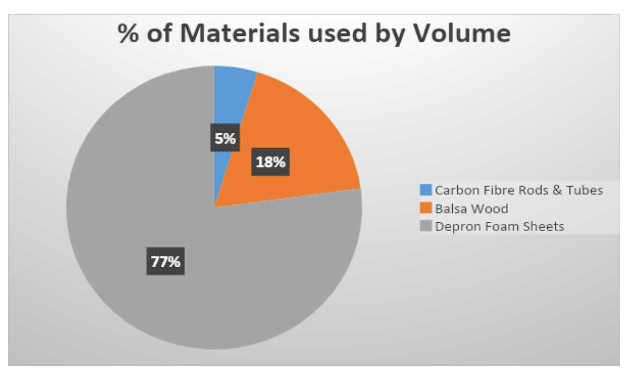


Fig 6(d) - % of Materials used

7. Mechanical Systems

This section of the Design Report depicts the various mechanical systems which help to actuate or move the required parts of the aircraft. Servos are type of components which help to actuate the control surfaces and the drop mechanism for the releasable payload, and the push pull rods which transfers the load to the required component.

7.1 Payload Drop Mechanism :

1. The drop system in our aircraft is manually operated. Our team's objective is to drop the payload at the given target so the drop system plays a prominent role.
2. It is a box made up of balsa wood that is attached inside of the fuselage which consists of an open door. The door is hinged at the bottom and is connected to the servo using a push pull rod.
3. When the servo arm is at neutral position, the door is locked and if it moves to an angle of 90˚, the door is opened and the payload is dropped as a free fall.

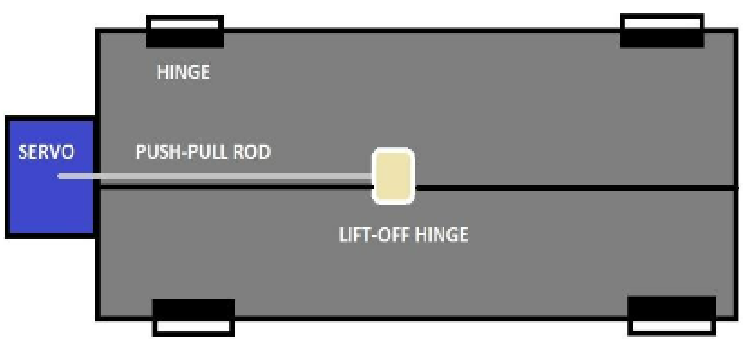


Fig 7 (a) - Schematic of Payload Drop Mechanism

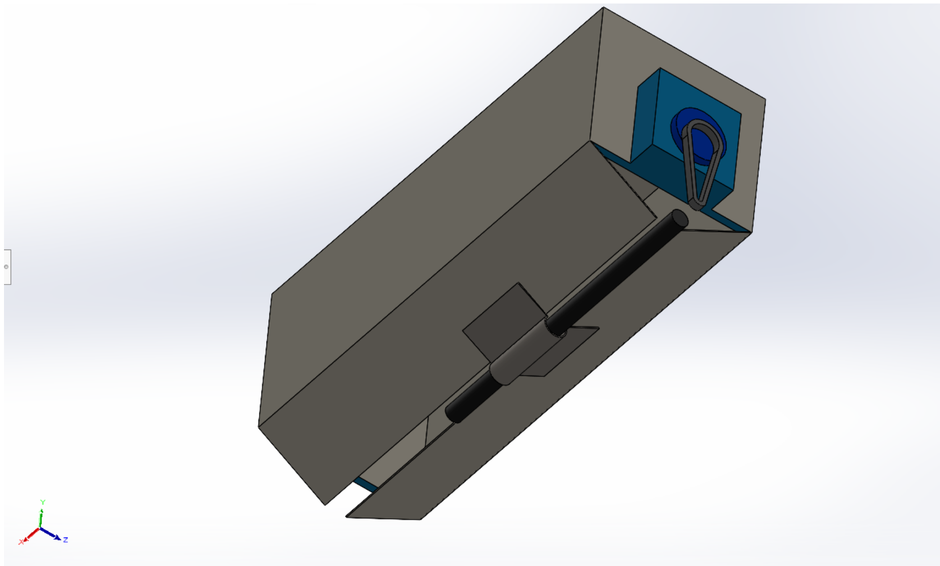
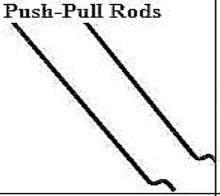


Fig 7 (b) - CAD Model of Payload Drop Mechanism

Table 3 - List of Components used in Payload Drop Mechanism

S.NO	COMPONENT NAME	FUNCTION	WEIGHT
1.	**Servo** 	It produces rotational motion which allows the movement of doors.	20g
2.	**Push-Pull Rods** 	It helps in moving the control surface. (lift-off hinge)	5g
3.	**Lift-Off Hinge** 	It helps in opening the door using a lifting mechanism.	7g
4.	**Hinge** 	It is a joint that attaches the door to the payload bay.	7g

8. Conclusion

Team NAUTILUS believe that our high wing monoplane with conventional type tail configuration is best suited design approach to successfully complete the given task to win the SAE AERO DESIGN CHALLENGE SOUTHERN SECTION, micro class. The use of additive manufacturing techniques was constructed of precise shapes with optimal aerodynamic properties. The first test flight of VT-MAV proved that it can be flown with good stability and control. Furthermore on performance basis VT-MAV can easily lift a payload of up to 1.2 lbs and manage to release the payload within the specified drop zone radius. We would like to thank SAE for the opportunity to showcase our team work, flight skills and design. We would also like to thank our University management and our faculty advisor for supporting us. We look forward to demonstrating our flight configurations to the rest of our competitors.

9. Reference

[1] Fundamental Knowledge : www.rcplanes.online

[2] Airfoil Data : www.airfoiltoolbox.com

[3] Reference Book : “Aircraft Design : A Conceptual Approach” by Daniel Raymer

[4] Materials Procurement : Vortex RC

[5] Design Calculations : www.rcplanes.online/design.htm

Files :

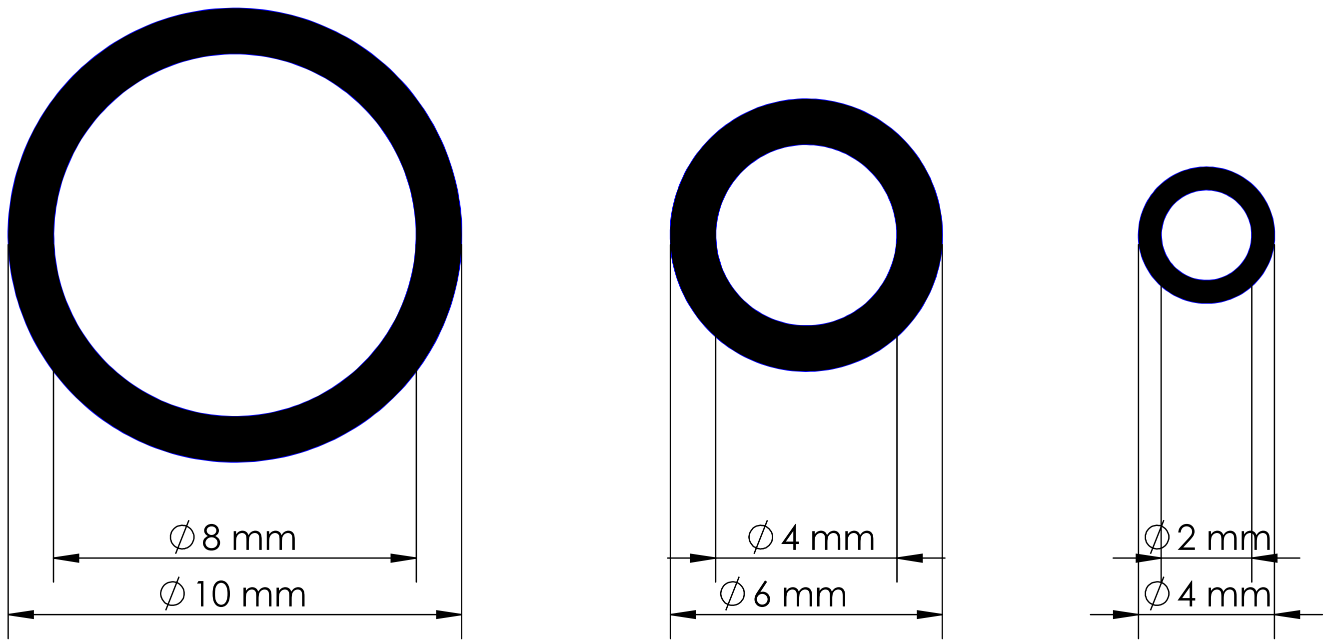
1. 3D CAD MODEL : Click Here
2. Cost Estimation : Click Here
3. Wing Structure Blueprint : Click Here

APPENDIX A : Weight Estimation Sheet (Empty Wt)

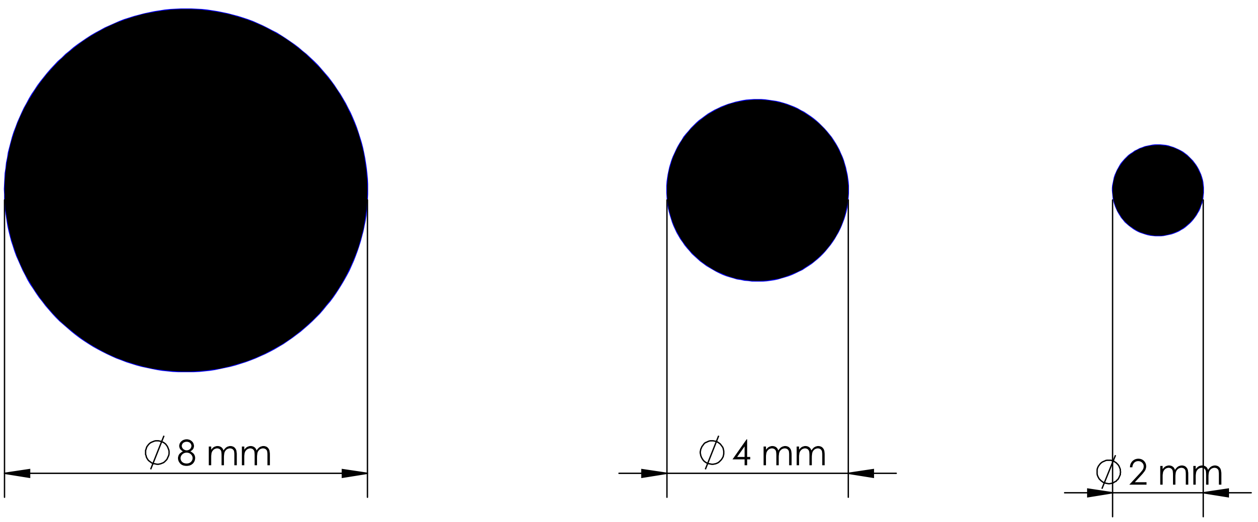
	Sr No	Component	Quantity	Weight
	1	Wing Ribs - Balsa Wood	12	90g
	2	Horizontal Stab Ribs - Balsa Wood	8	72g
	3	Vertical Stab Ribs - Balsa Wood	5	45g
	4	Fuselage Frames - Balsa Wood	10	110g
	5	Wing Skin - Depron Foam	2	210g
	6	Horizontal Stab Skin	2	20g
	7	Vertical Stab Skin	1	10g
	6	Fuselage Skin - Depron Foam	3	30g
	7	Carbon Rod (8mm)	1	40g
	8	Carbon Rod (4mm)	1	20g
	9	Carbon Rod (2mm)	1	6g
	10	Carbon Tube (10mm)	1	42g
	11	Carbon Tube (6mm)	1	24g
Structures	12	Carbon Tube (4mm)	1	14g
	13	Battery	1	175g
	14	Electronic Speed Controller	1	34g
	15	Servo Motors	6	120g
	16	Motor (750 kV)	1	120g
	17	TX & RX	1	50g
	18	Propeller	1	60g
Electronics	19	Pushrods	6	12g
		Total		**1174g**

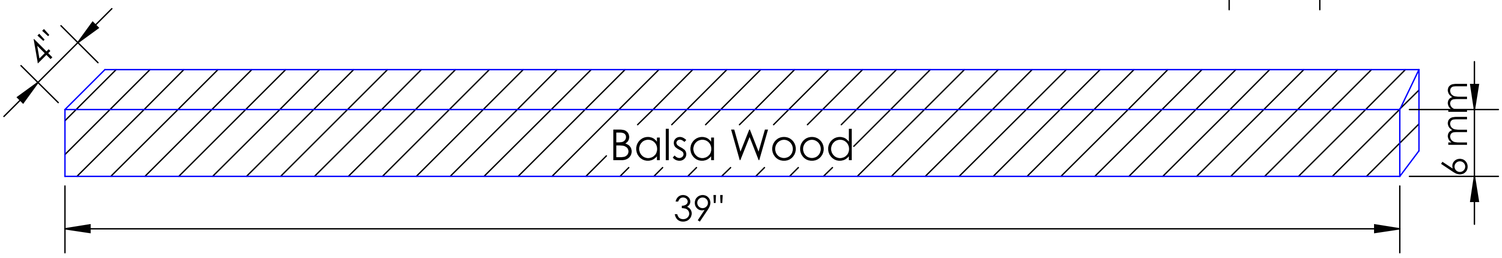
APPENDIX B : Dimensions of Materials Used

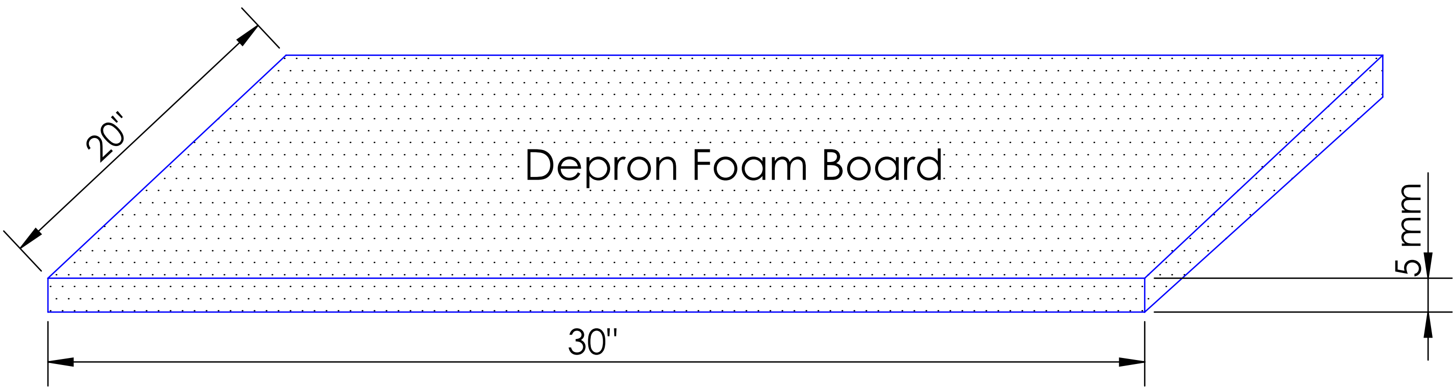
1. Pultruded Carbon Fibre Tubes



2. Carbon Fibre Rods



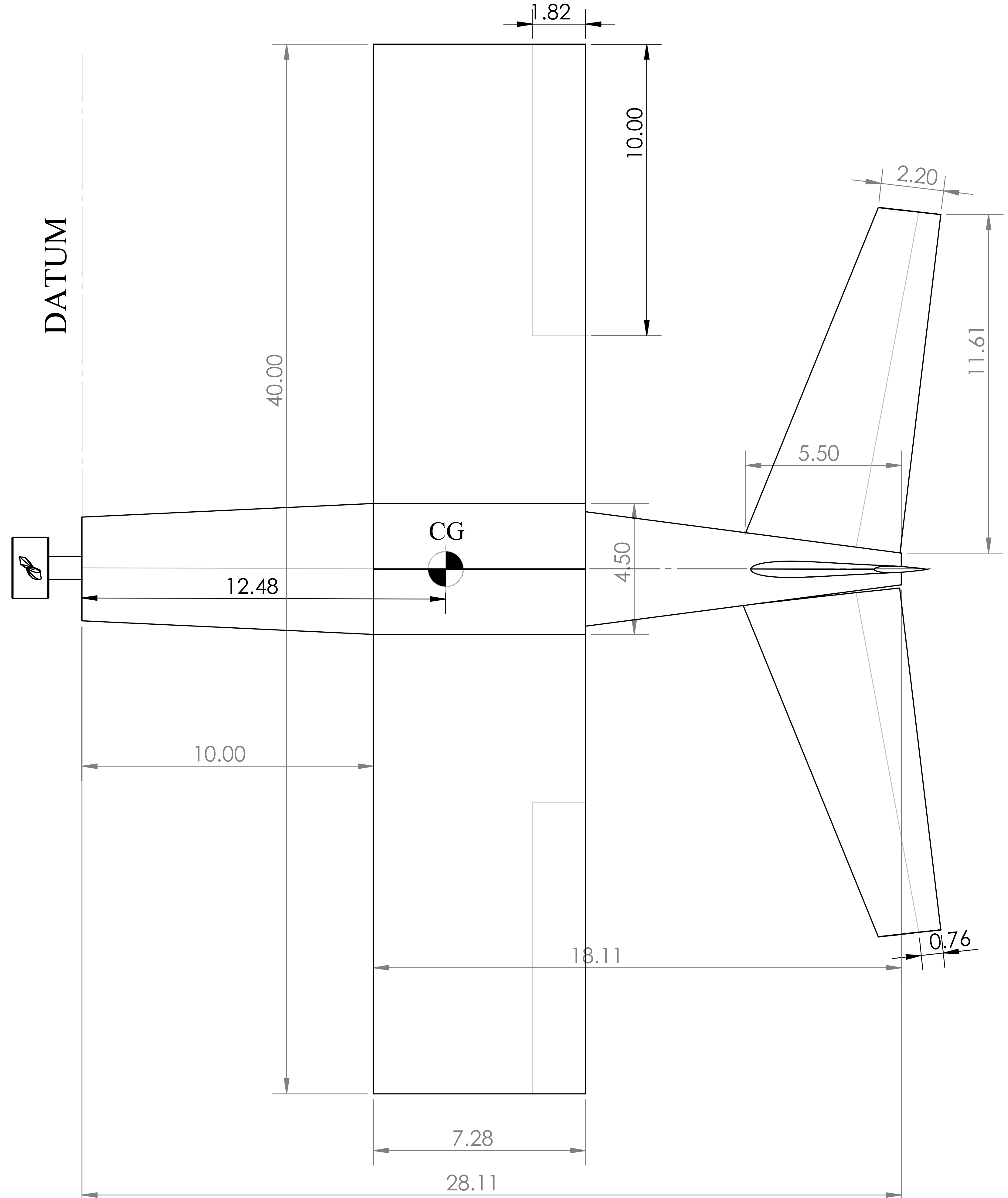




APPENDIX C : 2D Views of Aircraft

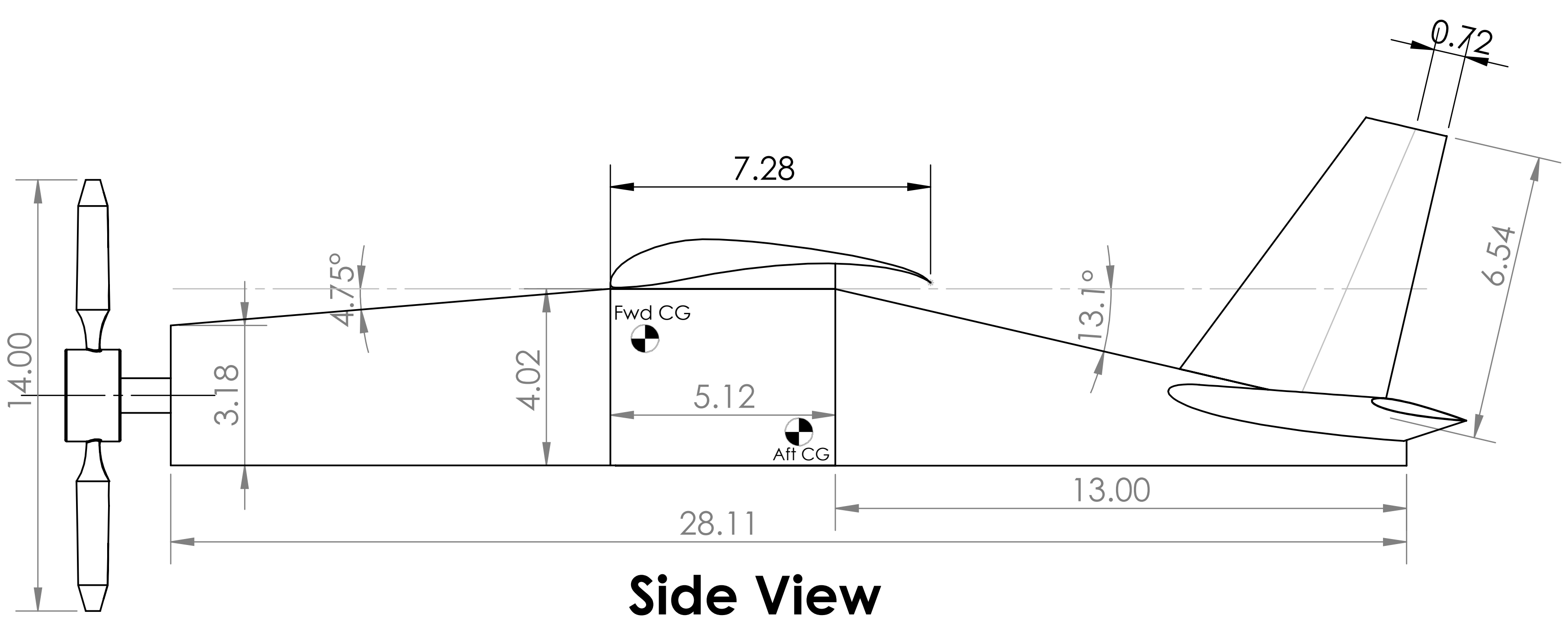
All the units in inches

VT - MAV
Team Nautilus
Team ID : ADC20220181
Hindustan University, Chennai

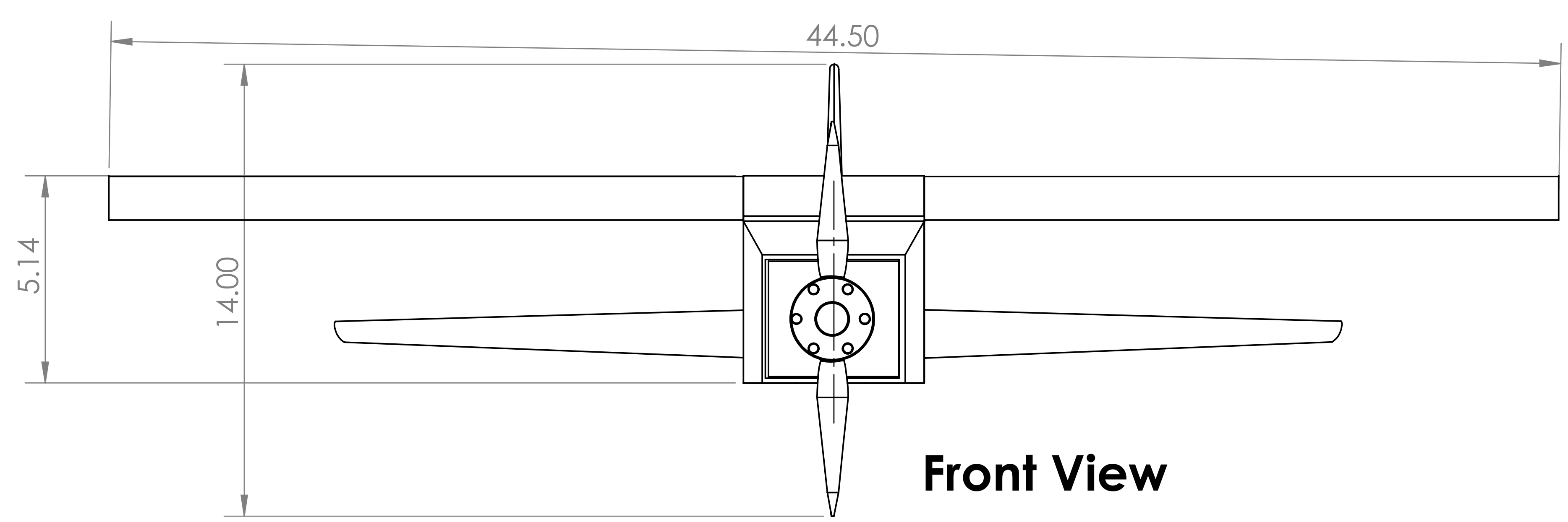


Top View

Length	28.11 inches
Height	7.49 inches
Wingspan	40 inches
Motor (Manufacturer & Specs)	750 kV, High Torque Brushless Motor Model : 5010 Shaft Diameter : 4mm Weight : 112g
Propeller (Manufacturer & Specs)	Carbon Nylon Black Propellers Length : 14” Pitch : 4.7” Weight : 57g
Servo Motors (Manufacturer & Specs)	Tower Pro SG90 Servo Weight : 9g
Empty Weight	1170g



Side View



Front View