DRONE DEVELOPMENT CHALLENGE 2023

DESIGN REPORT

DDC20230185 –

FEZA TEAM

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DATE (18 March 2023)

STATEMENT OF COMPLIANCE _

SAEISS DRONE DEVELOPMENT CHALLENGE 2023

Certification of Qualification

Team Name	FEZA
Team ID	DDC20230185
College/University	Mahindra University
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Statement of Compliance

As Faculty Advisor:

I certify that the registered team members are enrolled in collegiate courses.

I certify that this team has designed, constructed and/or modified the radio-controlled airplane with the intention to use this aircraft in the **SAEISS Drone Development Challenge 2023** competition, without direct assistance from professional engineers, R/C model experts or pilots, or related professionals.

I certify that this year's Design Report has original content written by members of this year's team.

I certify that all reused contents have been properly referenced and is in compliance with the University's plagiarism and reuse policies.

Prasad Pokku

Signature of Faculty Advisor

Date **(18 March 2023)**

Signature of Team Captain

Date**(18 March 2023)**

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APPENDIX

- v = Velocity of the aircraft.
- g = Acceleration due to gravity.
- W_s = Wing loading in kg/m2
- ρ = Density.
- b = Wing span.
- c = Mean aerodynamic chord length.
- S = Wing area.
- α = Angle of attack.
- C_m = Coefficient of moment.
- C_L = Coefficient of lift.
- $C_{M\alpha}$ = Coefficient of moment per degree of angle of attack.
- $C_{L\alpha}$ = Coefficient of lift per degree of angle of attack.
- V_H = Tail volume ratio (Horizontal).
- V_{vt} = Tail volume ratio (Vertical).
- $X_{n.p.}$ = Distance for neutral point.
- $X_{c.g.}$ = Distance for center of gravity.
- η = Efficiency of the tail.
- ε = Downwash angle.
- I_w = Wing setting angle.
- I_t = Tail setting angle.

1. INTRODUCTION

The report details the unmanned aerial vehicle (UAV) created by Team Feza for the 2023 Drone Design Challenge organized by the Southern Section of the Society of Automotive Engineers India (SAEISS). The competition's objective is to provide engineering students with practical challenges that they may encounter during their academic tenure by tasking them with researching, developing, designing, constructing, and producing a prototype of a fixed-wing UAV that meets the practical and mission requirements specified by SAEISS. The process also enables students to acquire vital technical and interpersonal skills.

2. OBJECTIVE

Team Feza's objective was to construct a UAV that adhered to the requirements outlined in the rulebook. The UAV would be launched manually from a circular location, which necessitated a focus on controllability during the design process. The team also prioritized weight optimization for the payload and ensured structural strength, while simultaneously striving for innovation.

3. MISSION REQUIREMENTS

SAEISS aimed to motivate undergraduate students to create a UAV capable of lifting the maximum payload according to the specified regulations. The UAV's weight limit, not including the payload, was set at 1.5 Kgs, and it had to fit inside a box with sides less than 3ft. The UAV had to be launched manually from a designated launch circle and complete a full 360 circuit using only a 3s battery for power.

4. RESEARCH

Our team has been participating in the micro class for three generations now and in the past, we prioritized the assembly of parts and structure. For our last project, we opted for a high wing rectangular configuration and utilized a complete monocoque fuselage. However, this time around, we aimed to simplify the design by utilizing a side paneled fuselage and adhering to the SAEISS rule book and Micro class constraints. Our inspiration came from the manufacturing processes of last year's Regular and Micro planes. Previously, we faced challenges in achieving a balanced center of gravity and installing the battery. To simplify the assembly process, we have designated specific positions for electronics and created separate holding spaces for them.

5. AIRFOIl SELECTION

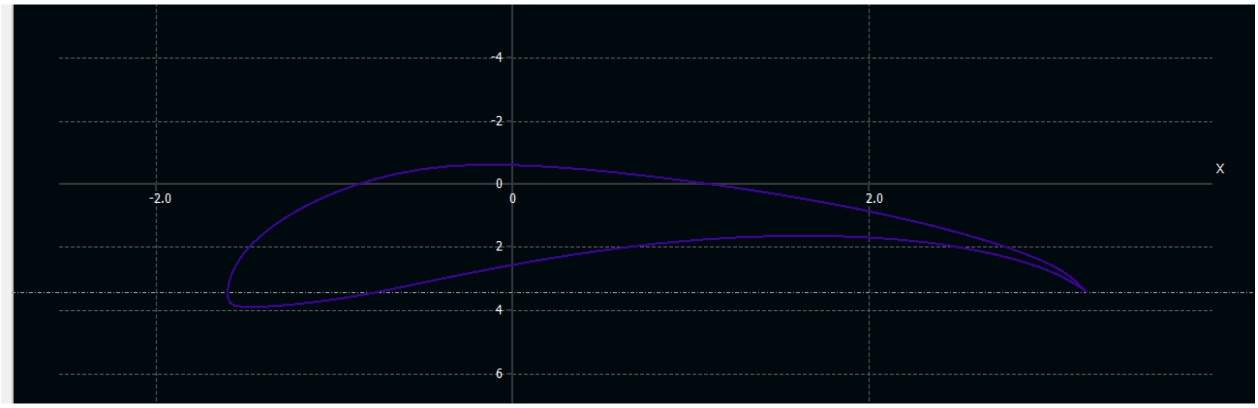
a. analysis

To narrow down the list of previously chosen airfoils, a number of flight determining factors are taken into account. These factors include the Coefficient of lift at ‘0’ angle of attack, Stall angle, Maximum coefficient of lift, Manufacturing limitations, and the Average drag coefficient across a range of Reynolds numbers. The analysis is conducted using Reynolds numbers ranging from 10,000 to 500,000 and an angle of attack between -10 to 30 degrees.

b. Wing airfoil

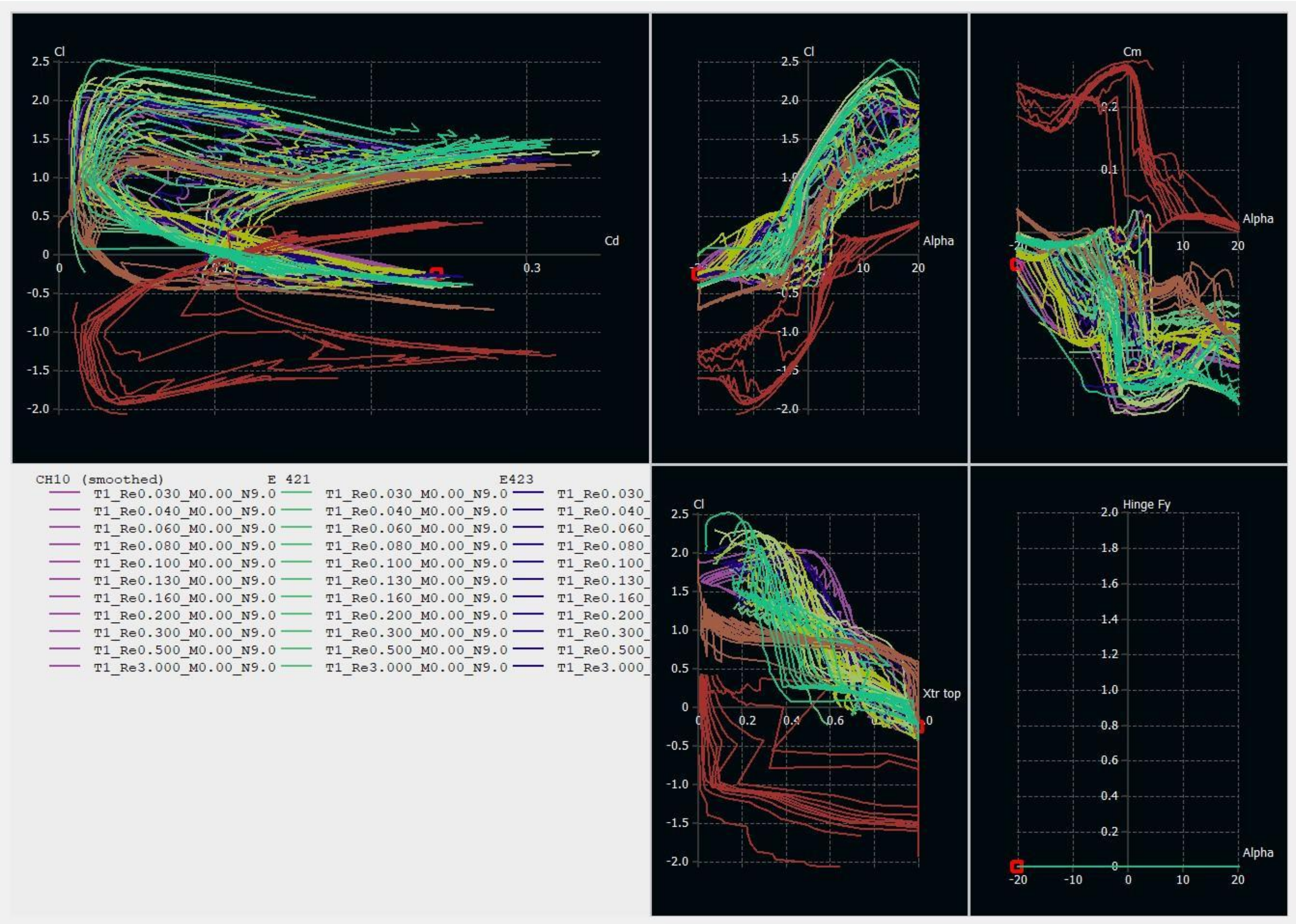
To pack as much lifting capabilities in to the plane, Airfoils with high cl values at low Reynolds-number are researched. For preliminary analysis of wing and horizontal stabilizer options, several cambered airfoils were considered. These included EPPLER's E423, E421, and E420, SELIG's S1223, S1223rtl, and S2027, WORTMANN's FX74-CL5-140 and FX63_137, AG35, CH10, NLF 0115, NACA 6409, Kenmar-il, Kc135 winglet, and LNV 109 A. After evaluation, EPPLER's E423, E421, and E420, SELIG's S1223 and S1223rtl, and CH10 were found to have the highest capabilities for cl and cl/cd at low Reynolds numbers. Of these, S1223 had the highest cl, as well as a high Cm. Despite the high Cm, the team chose to go with a high Cl airfoil in order to build the plane as compactly as possible.

S1223 –



Thickness	Max. Thick.pos.	Max. Camber	Max. Camber pos.
12.14%	19.82%	8.67%	49.05%

Table:1 tabular data of the shape of the Airfoil S1223



The graphs above primarily show the relationships between cl and cd, cl and alpha, and cm and alpha for types of foils: S1223 and NACA0012. EPPLER's E423, E421, E4203 and S1223rtl, and CH10

6. WING PLANFORM

After conducting a detailed analysis and comparing different planforms, a rectangular wing configuration was selected. The comparison revealed that the drag reduction offered by a tapered wing over a rectangular wing was minimal. Additionally, while elliptical wings have the advantage of stalling uniformly across the entire wing instead of at the tips first, manufacturing them is more complex than a rectangular wing. A delta wing was not chosen due to the stringent design, size, and manufacturing requirements it demands.

7. WING CONFIGURATION

The High wing configuration has been selected among the three options of Low, Mid, and High wing. This is because of its inherent keel effect or pendulum effect, resulting from the center of gravity being lower than that of the center of lift. Additionally, the Low wing configuration is avoided to prevent the UAV from landing on its wings. Furthermore, manufacturing the Low and Mid wing configurations to be longitudinally stable can be challenging. Based on our past experience with a Mid wing configuration, the UAV began to wobble and flutter its wings, whereas the High wing configuration offers a slight advantage for easy reinforcement. Another design advantage of the High wing configuration is that the wing can be slid on top of the plane and secured to complete the aircraft.

8. WING LOADING AND AREA SELECTION

Wing loading is the ratio of Aircrafts weight to its area. It helps determining the stall speed of the aircraft

$$W_s = \frac{1}{2}\frac{\rho C_l V^2}{g}$$

the above equation gives us the wing loading

Assume Cl =0.762 . $\rho = 1.29$, (values of Cl and ρ are chosen so that they cover most of the range of the flight.)

Table 5.1: Velocity vs Wing loading of the aircraft

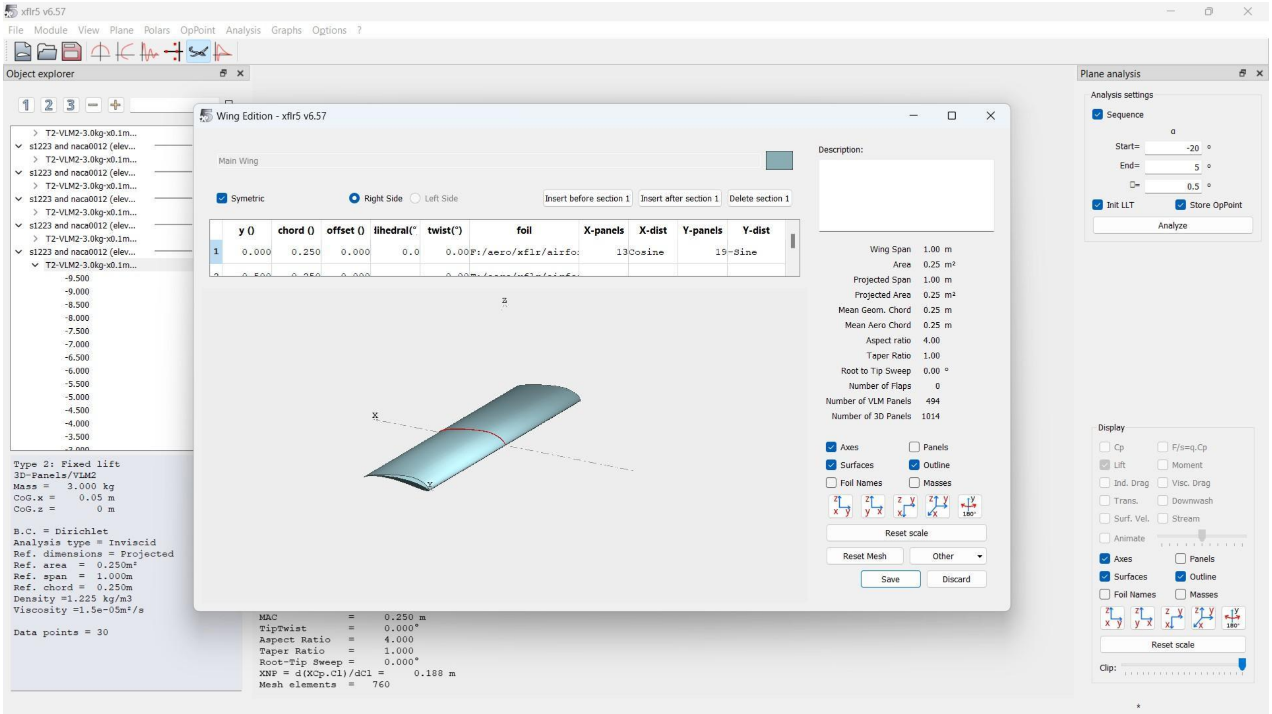
Velocity (m/s)	5	7.5	10	12.5	15	17.5	20	22.5
Wing loading (kg/m^2)	1.25	2.82	5.01	7.83	11.28	15.35	20.06	25.38

A step size of 0.25Kg is considered to calculate the wing area at different velocities that can be acquired from hand launch, with plane weight up to 3 Kgs

Table 5.2: Area of the wing in m^2 based on weight and velocity of the aircraft.

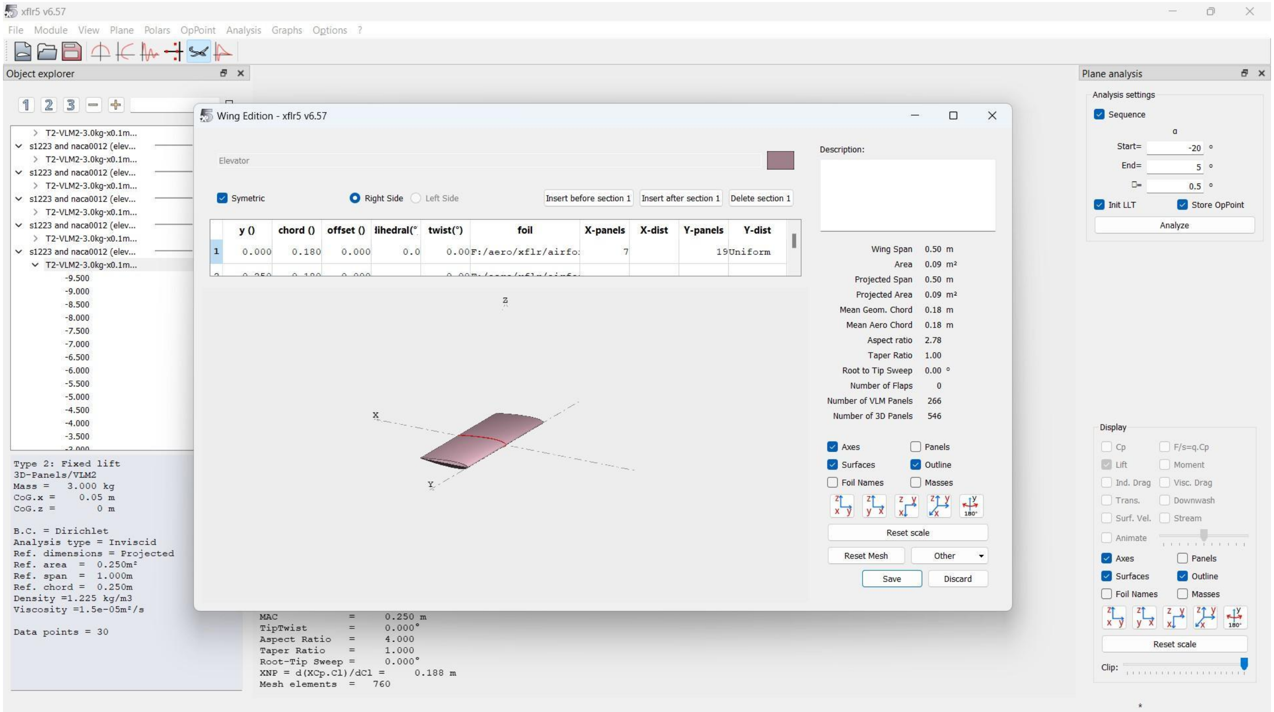
Velocity (m/s)	5	7.5	10	12.5	15	17.5	20	22.5
Mass = 1.5 kgs	1.2	0.53	0.29	0.19	0.132	0.09	0.074	0.059
Mass =2 kgs	1.6	0.70	0.39	0.255	0.177	0.13	0.099	0.078
Mass = 2.5 kgs	2	0.88	0.49	0.319	0.221	0.16	0.124	0.098
Mass = 3 kgs	2.4	1.06	0.59	0.383	0.265	0.195	0.149	0.118

We fixed our wingspan to be 120 cm to accommodate the wing loading capacity and still be able to fit in the box with all sides less than 3ft, through extensive analysis by XFLR5 we arrived at a wing span of $0.25m^2$ that is a chord length of 25 cm.

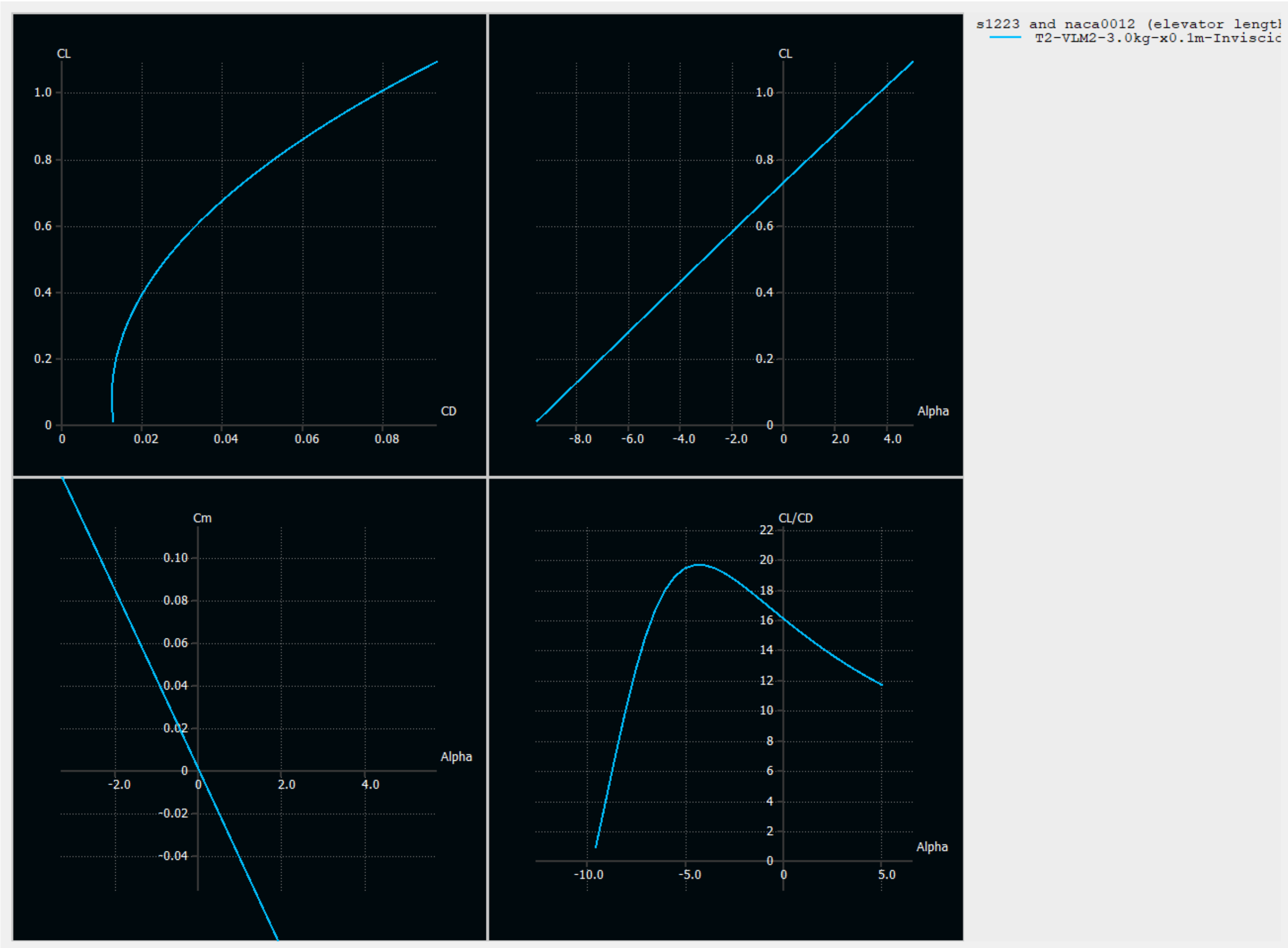


10. Tail

We chose to use the standard Tail configuration for our plane, which consists of two components - the horizontal stabilizer and the vertical stabilizer. These parts play a critical role in guiding and maneuvering the plane during flight. The Tail is an essential part of the plane that helps to maintain its orientation and keep it on the desired flight path in a passive manner. This is achieved by generating a moment around the Cg (center of gravity) through the deflection in orientation caused by any disturbances.



We decided to use the NACA0012 airfoil for the elevator of our plane due to its effective production of pitching moment and minimal drag. Our objective was to minimize the size of the horizontal stabilizer while still balancing the wing moment, and as a result, we were able to achieve satisfactory longitudinal stability.



the above picture gives you the flight characteristics of our plane

FINAL STABILITY CONFIGURATION

After the detailed and calculate evaluations of all the possible configurations of tail and the area of wing being 0.25 m2,the following configuration of the plane was achieved:

Table: Aircraft properties for stability configuration.

Name	Class	Numerical Value
Wing Properties	Chord Length	0.25m
	Wing area	0.25 m2
	Wing span	1.2m
	Wing setting angle	0
Horizontal tail properties	Chord Length	0.180m
	Tail span	0.5m
	Tail setting angle	0
Vertical tail Properties	Chord Length	0.180m
	Tail Span	0.25m

1. Electronics

a. Motor and ESC selection:

After considering the mission objectives and regulations, we opted for a DC brushless outrunner motor with a low kV rating. We selected a low Kv motor because it is more suitable for airplanes that fly at slower speeds, as it provides higher output torque. This enables us to use a larger propeller with a small pitch, which is typically used in short takeoff and landing aircraft. In our decision-making process, we also took into account the weight of the aircraft, including any cargo, the necessary thrust (keeping battery limitations in mind), and the required power output.

Type of airplane	Thrust-to-weight ratio
Glider/Trainer	0.35 to 0.55
Scale Flight	0.60 to 0.70
Sport and Slow acrobatic	0.70 to 0.80
Acrobatic	0.80 to 1.00
Jets and 3D	1.00 to 2.5

Our study found that the correlation between power (measured in watts, W) and thrust (measured in grams, g) is directly linked to the Kv rating of the motor. Nonetheless, the scatter of data points in the graph may differ depending on the propeller pitch. Fundamentally, when the Kv rating increases, a greater amount of power is needed to produce the same thrust. This is because using a higher Kv motor necessitates a reduction in propeller diameter.

Once you know the weight of your aircraft, the process consists of several steps:

· Determine the desired thrust-to-weight ratio.

· Calculate the amount of thrust required for your plane.

· Decide on the desired speed of your aircraft (fast or slow).

· Choose a Kv value that aligns with your objectives.

· Use the Kv value to identify the Power/thrust ratio.

· Determine the power (in watts) required to generate the necessary thrust.

· Based on the selected values for Kv, thrust, and power, select a motor from a reputable manufacturer.

·Either follow the recommended propeller specifications for the chosen motor or use an appropriate method to select a suitable propeller.

Calculating thrust:

Thrust= Weight*thrust/weight ratio (The thrust/weight ratio of an acrobatic plane is 1)

Thrust= 1900*1 = 1900g of thrust

As mentioned in the beginning of this section, we prefer a low kv value motor because it better suits the plane that fly at slower speeds. So, we chose a motor the 1000kv specification.

To go further in selecting a motor, we need the power of our motor.

Calculating power:

Power = thrust* power/thrust ratio

Power/thrust ratio=

0.17*(kv/1000)+0.09

=0.17*(1000/1000)+0.09

=0.26w/g

Now, going back to calculating power:

Thrust is found to be 1900g. => 1900*0.26= 494 watts

So, in conclusion, referring to the calculations made, we are looking for a motor with the following specifications:

1. 1000kv
2. **2.** 1900g of thrust
3. **3.** Wattage of 494w.

The motor we finalized is**Scorpion SII-3026-890KV (V2)**

[SII-3026-890KV]

MAS	10x7x3	11.1	39.60	439.5	9,553	63.3	1986.7	70.08	4.52
MAS	11x7x3	11.1	48.59	539.3	9,324	61.8	2392.7	84.40	4.44
MAS	12x6x3	11.1	54.47	604.6	9,104	51.7	2714.6	95.75	4.49
MAS	12x8x3	11.1	73.21	812.6	8,372	63.4	3243.3	114.40	3.99
Prop Manf.	Prop Size	Input Voltage	Motor Amps	Watts Input	Prop RPM	Pitch Speed	Thrust Grams	Thrust Ounces	Thrust Eff. Grams/W

The essential factor to consider while choosing an ESC was that the motor would not draw more current than the ESC's maximum rating. The motor consumes 70A of current at maximum power. We picked a **Readytosky 80A ESC 2-6S Brushless ESC Speed Controller**

which can support 80A rating based on this

b. Servo sizing:

The selection of servos for our aircraft is dependent on various factors such as the weight of the flight, the dimensions of the wing, and the required thrust. Additionally, we take into consideration the sizing of control surfaces and the type of battery used. The decision to choose a specific servo is also influenced by its rated speed, supply voltage, and the amount of output torque required.

$$T = 8.5 \times 10^{-6} \left(\frac{C^2 V^2 L \sin(s1) \tan(s1)}{\tan(s2)} \right)$$

c. Battery selection

The battery was selected based on the restrictions according to the rulebook supplied and the requirements of the motor and servos selected such that it be sufficient for a 5-minute flight keeping a 20% error margin. With maximum current required as 36A, 3S (due to rule book restrictions) 11.1V and the motor selected we researched batteries and decided to use the Orange 2200mAh 3S 30C/60C Lithium polymer battery Pack (LiPo) as it best fit our requirements and the manufacturer was well known for its quality.

d. Red arming plug

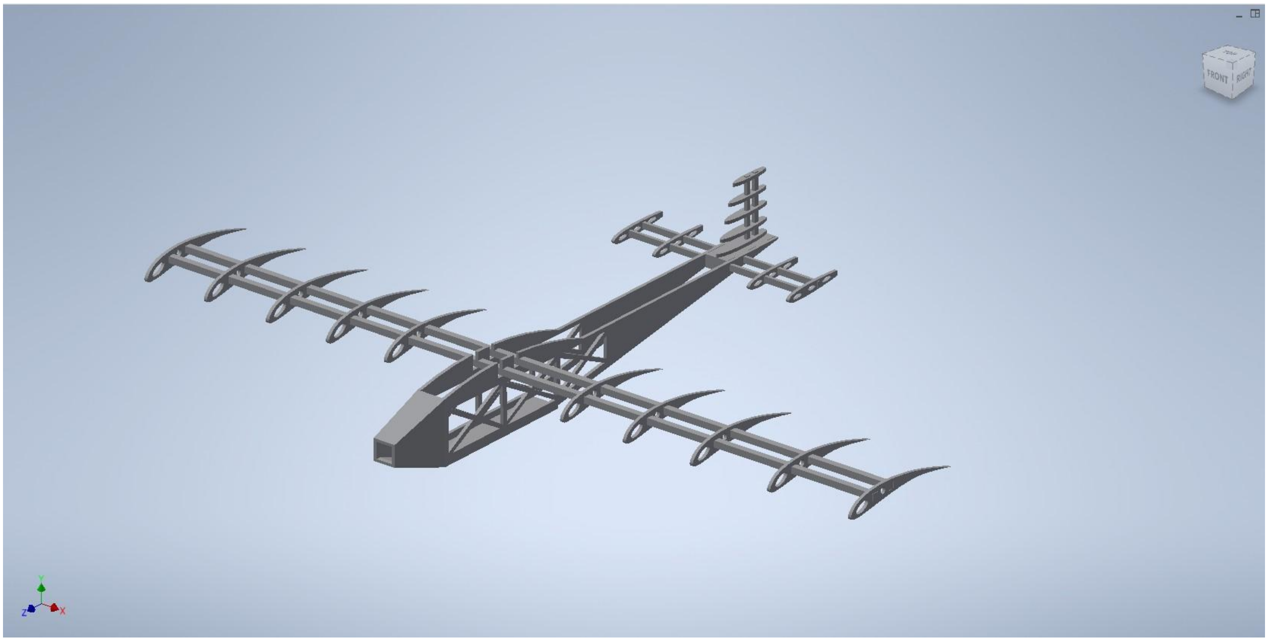
An arming plug, essential for safety, is a small plug, fit in the flight hardware to enable functions that, for instrument or personnel safety. Arming switches are used for isolating the battery from outside of the aircraft. The arming plugs are fabricated by the team to facilitate enough wiring length and to accommodate xt60 male plug from battery and bullet connectors from ESC and The necessary holes have been made for installation during flight so that it can be easily activated before flight.

13. Design

During our previous participation in the competition, we utilized a monocoque structure to construct a lightweight aircraft. However, we faced challenges in installing the necessary electronics such as the battery and ESCs. To overcome these difficulties, we opted to build a sidepaneled fuselage that resembles a rectangular
box-like structure for this year's competition. Our previous fuselage design consisted of two major elements, which were the ribs and longerons, and we avoided using stingers to reduce the complexity of the chassis. For this year's competition, we simplified the manufacturing process by eliminating all the ribs and spars, and instead, we constructed a high wing configuration plane.

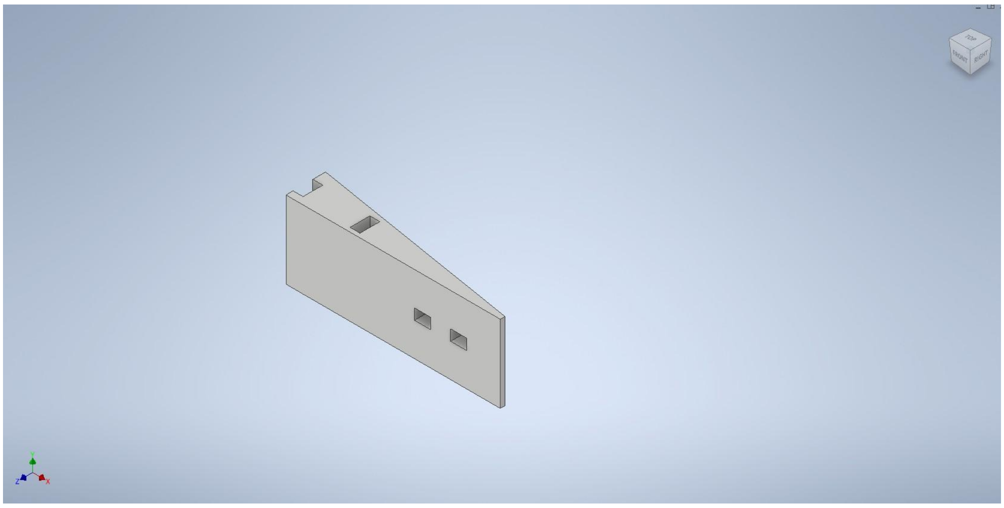
a. Fuselage

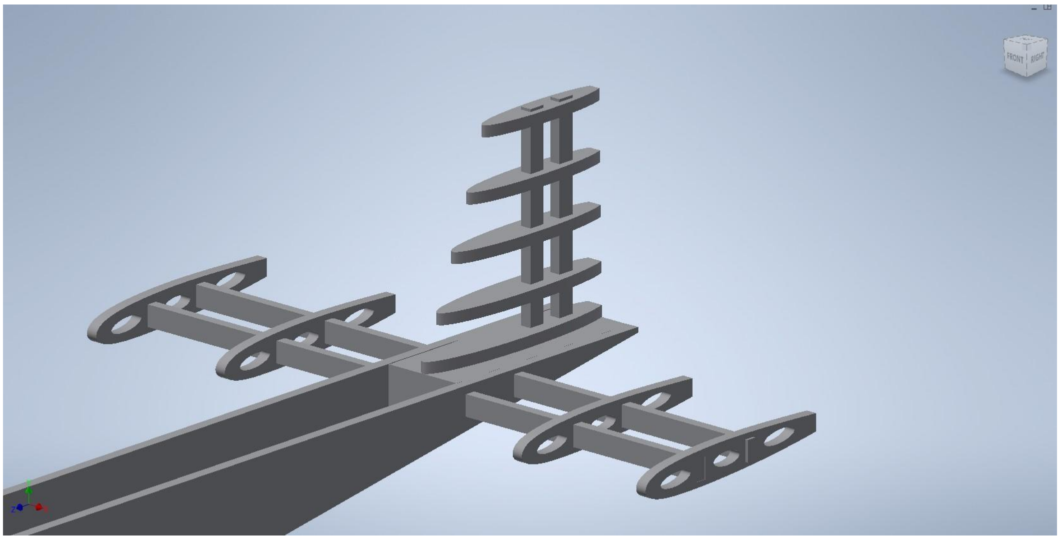
Our goal for the fuselage was to achieve both durability and lightness. After careful deliberation, we determined that implementing a truss system would be the most effective solution. This approach would enable us to reduce the amount of material required while still maintaining the necessary structural integrity. Our team conducted extensive research to acquire a comprehensive understanding of truss systems and to develop a suitable design for the fuselage. One of the innovative ideas we implemented this year was applying the truss theory to reinforce the structural strength of the fuselage.



b.Tail

This year, we created a high-quality CAD design for the tail of our aircraft, which utilizes an innovative approach where the fuselage walls are connected by a V-shaped ramp structure that can support both the horizontal and vertical stabilizers through intrusions. With this design, we expect to have decreased the amount of stress and shear on the tail compared to previous designs, and also made it easier to attach the rudder and elevator with less effort and time required during the plane manufacturing process.

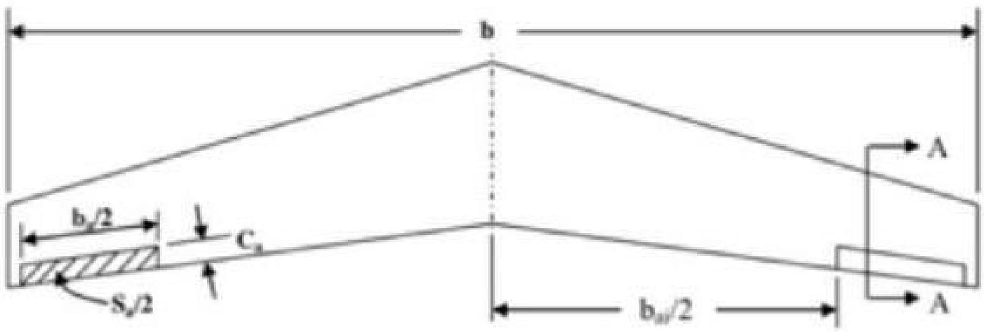




14. CONTROL SURFACE SIZING

AILERONS:

The 4 main parameters to be considered while designing the ailerons are the aileron planform area (S_a), the aileron chord/aileron span (C_a/b_a), the maximum up and down deflection (+(or)- D_{max}), and the location of inner edge of aileron along the wing span (b_{ai}).



a. Top-view of the wing and aileron

To set the proper dimensions of the ailerons a general guideline was followed. The typical values for these parameters are as follows:

Parameters	Approximate Values	Chosen values
1. S_a/S	0.05-0.1	0.1
2. b_a/b	0.2-0.3	0.3
3. C_a/C	0.15-0.25	0.3
4. b_{ai}/b	0.6-0.8	0.5

The value of S_a/S (area of ailerons by area of wing) was taken as 0.1. This was to maximise area of the aileron to minimise time to achieve a certain bank angle, resulting in a higher manoeuvrability.
The

issue with having a larger aileron is the load the actuators have to take will be higher. Thus, servo sizing was crucial.
The ratio of b_a/b (aileron length to wing span) was taken as 0.3 based on other aircraft data. The ratio of C_a/C (aileron chord length by wing chord length) was taken as 0.3. The area of the aileron was to be around 0.1 of the wing area. Thus, b_a and C_a were varied to ensure an optimal case for a desired area. The ratio of b_{ai}/b was taken as 0.5 to ensure the aileron doesn't end at the wing tip. This was to decrease excess wing tip vortex, which is caused due to the aileron ending at the wingtip. The aerodynamically accepted range of maximum deflection of the ailerons is 300. Increasing the angle beyond this would cause flow to separate, causing the surface to stall.
Thus, after running multiple iterations, it was decided the aileron would have the following values
C_a = 75 mm b_a = 600 mm b_{ai} = 180 mm

Thus, ailerons dimensions were 180 mm x 75 mm. Positioned at distance of 120 mm from either wing tip.

a. Elevator:

The rule of thumb is that the elevator should be 10%-25% of the area of the horizontal stabilizer. We chose the lower bound to keep the area of the elevator as less as possible so as to ensure less sensitivity to flying environments. Essentially, the span of the elevator=span of horizontal stabilizer. Only the chord of the elevator will be different. Length of chord=20% of length of chord of horizontal stabilizer. As the horizontal stabilizer was designed to have a span of 300 mm and a chord of 75 mm, the elevator was sized at the

following□ span = 0.5m

chord = 0.180m

a. Rudder:

The rule of thumb is that the rudder should be 10%-25% of the area of the vertical stabilizer. We chose the lower bound to keep the area of the rudder as less as possible so as to ensure less sensitivity to flying environments. So, the span of the rudder=span of vertical stabilizer. Only the chord of the rudder will be different. Length of chord=20% of length of chord of vertical stabilizer. As the vertical stabilizer was designed to have a span of 150 mm and a chord of 75 mm, the rudder

was sized at the following

Span = 0.25m

Chord= 0.180m

16. Manufacturing

a. Material selection

As stated in the beginning of the report, the weight of the plane designed for ADC 2022 was barely within the stipulated limits. So, the team did an analysis of areas to reduce weight. Hence, research was done from scratch on the design which resulted in the selection of Balsa wood. Balsa wood is an orthotropic material often used for hobby level UAVs due to its light-weight and decent strength. The mechanical properties of Balsa are as follows:

Table 6: Mechanical Properties of Balsa Wood	
Density	0.16 g/cm^3
Ultimate Tensile Strength	1.00 MPa (perpendicular to grains) 73.00 MPa (Axial)
Compressive Strength	1.00 MPa (Perpendicular to grain) 6.90-9.00 MPa (axial)

Flexural Modulus	2.55-3.17 GPa (Static Bending)

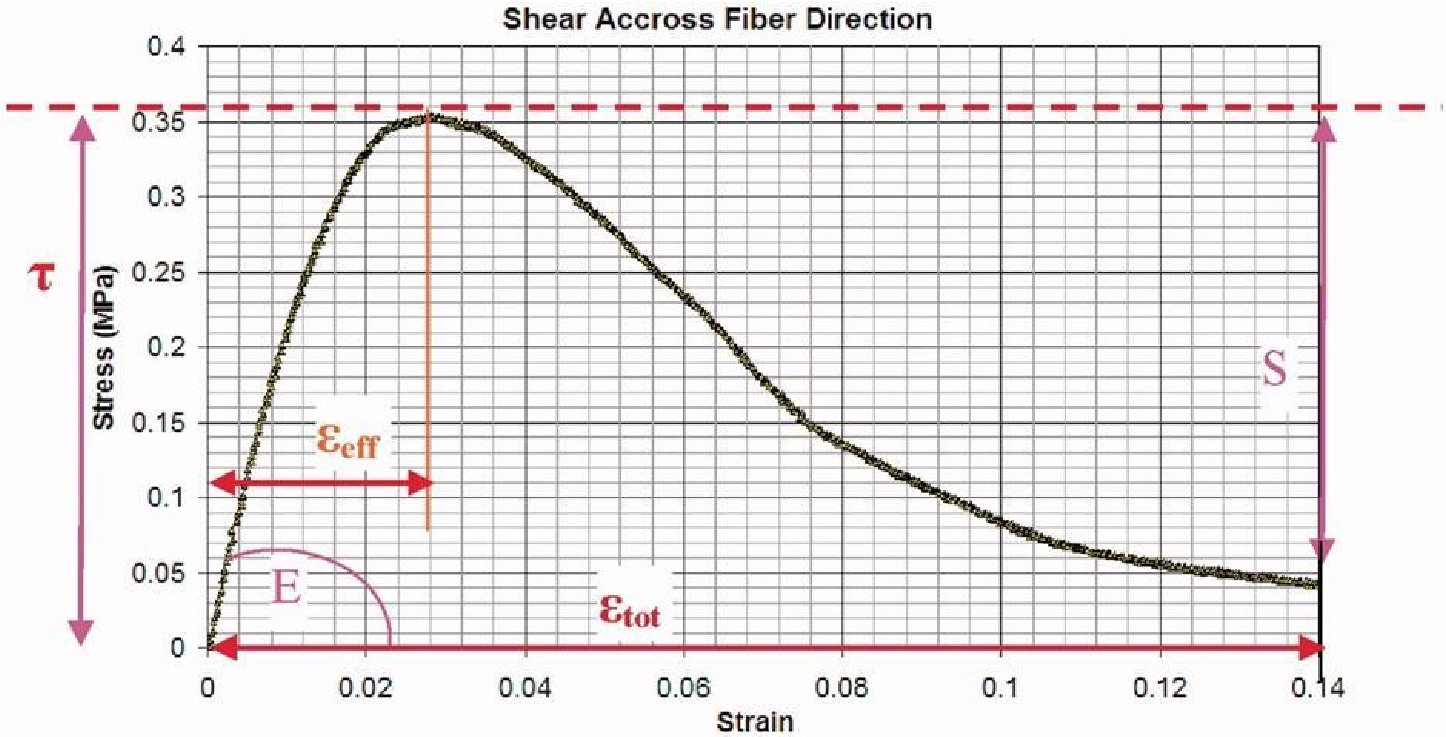


Fig: Characterization of balsa wood mechanical properties required for continuum damage mechanics analysis

In order to ensure that the air foils of the wings, elevator, and rudder remain firmly attached to the spar, it is imperative that the foundation is sufficiently strong. In our previous design, we utilized aero-ply as longerons and found that they were durable enough to withstand crashes. After conducting several prototype tests, we concluded that Aero-Ply would also make an excellent material for the spar that holds the airfoils together in wing manufacturing.

Aeroply is made up of multiple layers of plies of birch veneer. The number of layers or plies depends on the thickness of the Birch plywood panel. The two outermost layers of Birch plywood are the face and back veneers, while the inner plies are the core stock.

Foam may be utilized in our model solely for the purpose of decreasing its weight. During the prototype production process, foam could be incorporated to minimize the weight of the model. The fundamental mechanical characteristics of foam materials include plateau stress (σP), elastic modulus (E), yield point, and densification strain, with material parameters represented by coefficients C and m. The mechanical properties of foam can be summarized as follows: "

Properties	Value
Density (kg/m^3)	75
Compressive strength (MPa)	1.7
Tensile strength (MPa)	2.2
Shear strength (MPa)	1.3
Elastic modulus (MPa)	105
Shear modulus (MPa)	42
Strain at break (%)	3
Poisson's ratio	0.3

SAEINDIA SOUTHERN SECTION

b. Packing box

We determined that a 3x3x1 ft container would be the ideal size for packing the airplane according to the regulations. By placing the wing diagonally in the box, we can secure it properly. We can also secure the fuselage and tail in one of the triangular halves, leaving the other half empty for securing other items such as electronics, peripherals, and even spar parts and toolkits.

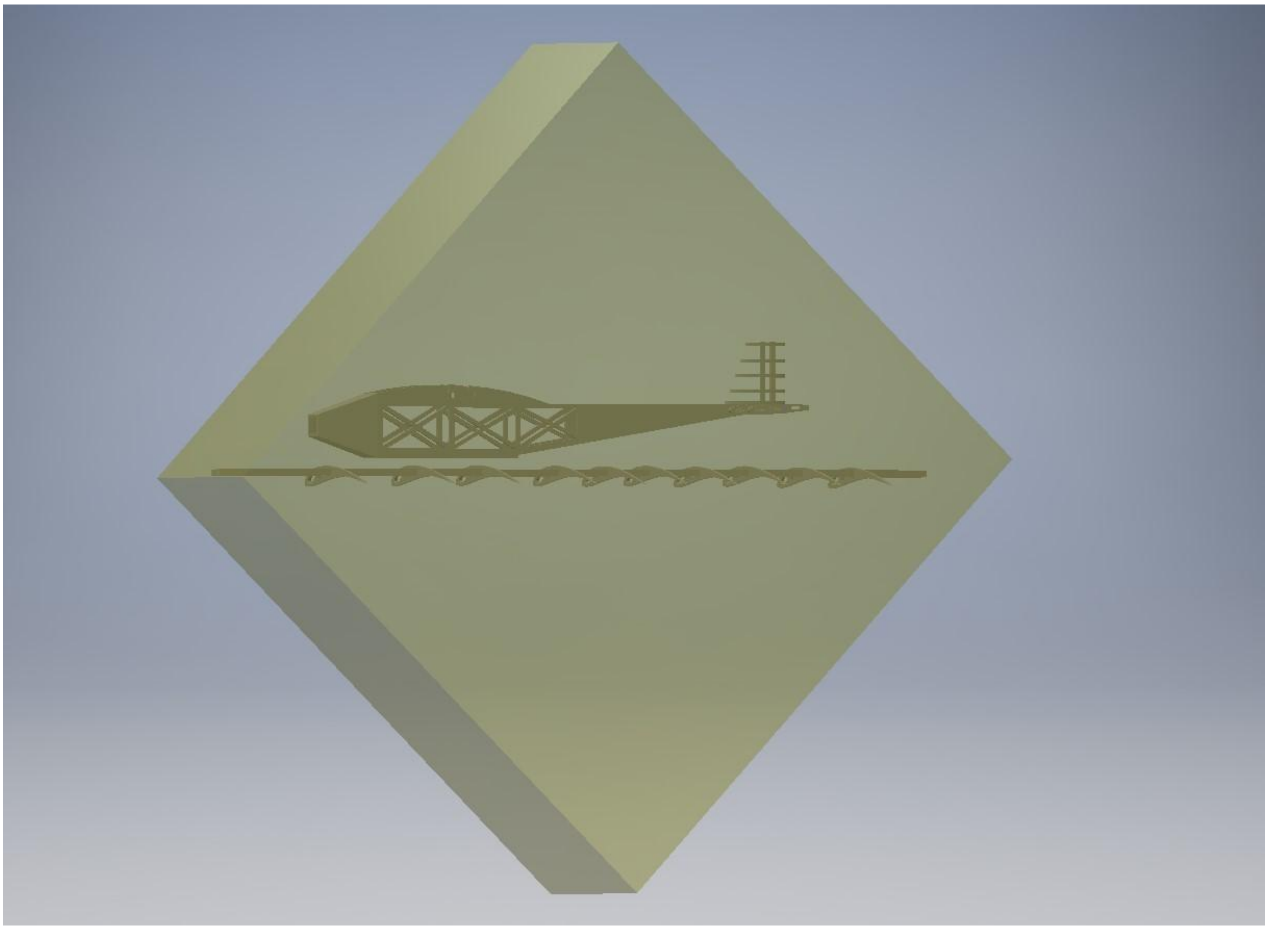


Figure 8 visual depiction of plane storage in box from isometric view

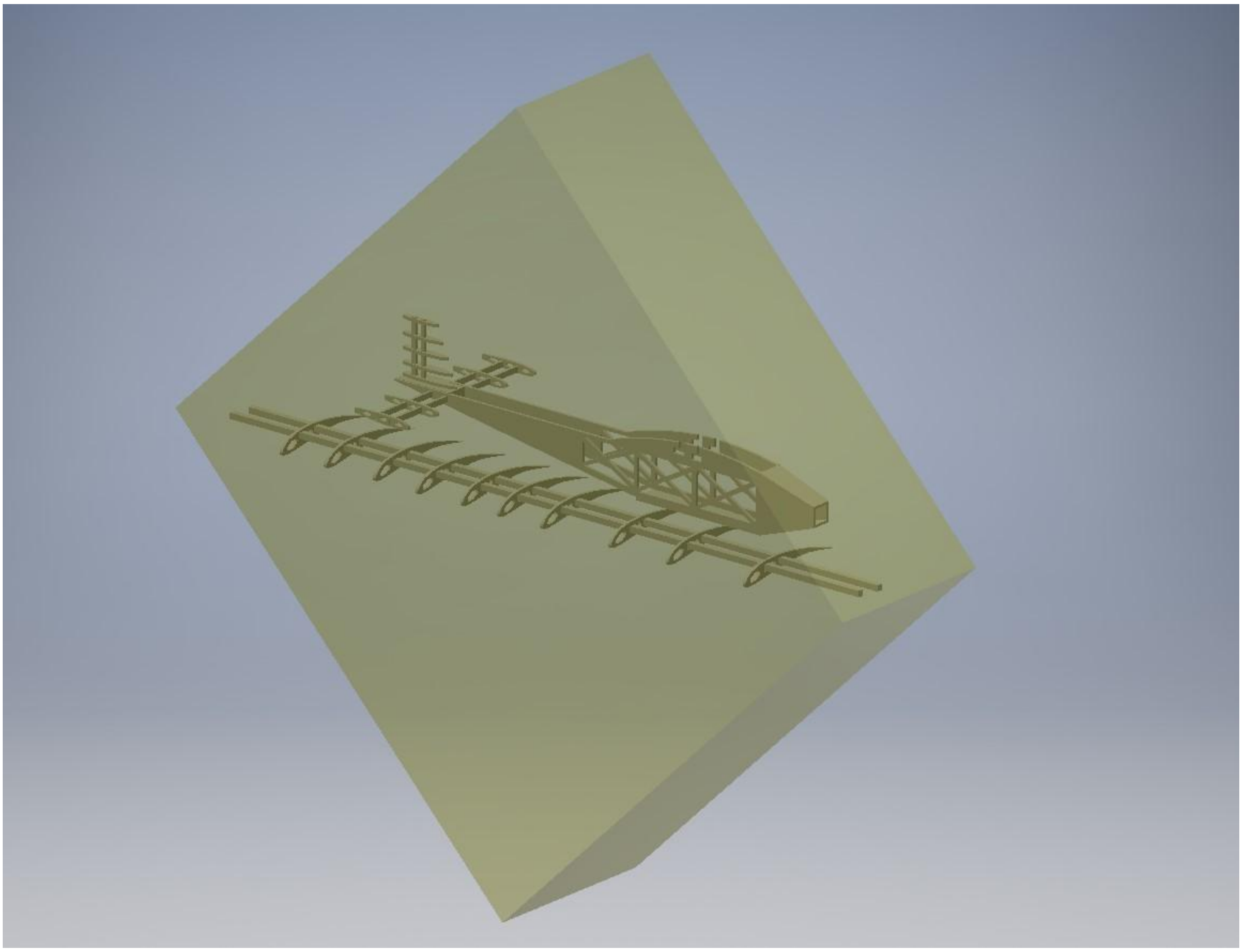


Figure 9 visual depiction of plane storage in the box

from top view

SAEINDIA SOUTHERN SECTION

1. Weight Built up and balance

PART	QUANTITY	MASS (Kg)
MOTOR	1	0.15
ESC	1	0.08
SERVOS	4	0.015
FUSELAGE + TAIL	1	0.55
WINGS	1	0.25
BATTERY	1	0.2
TOTAL		1.245