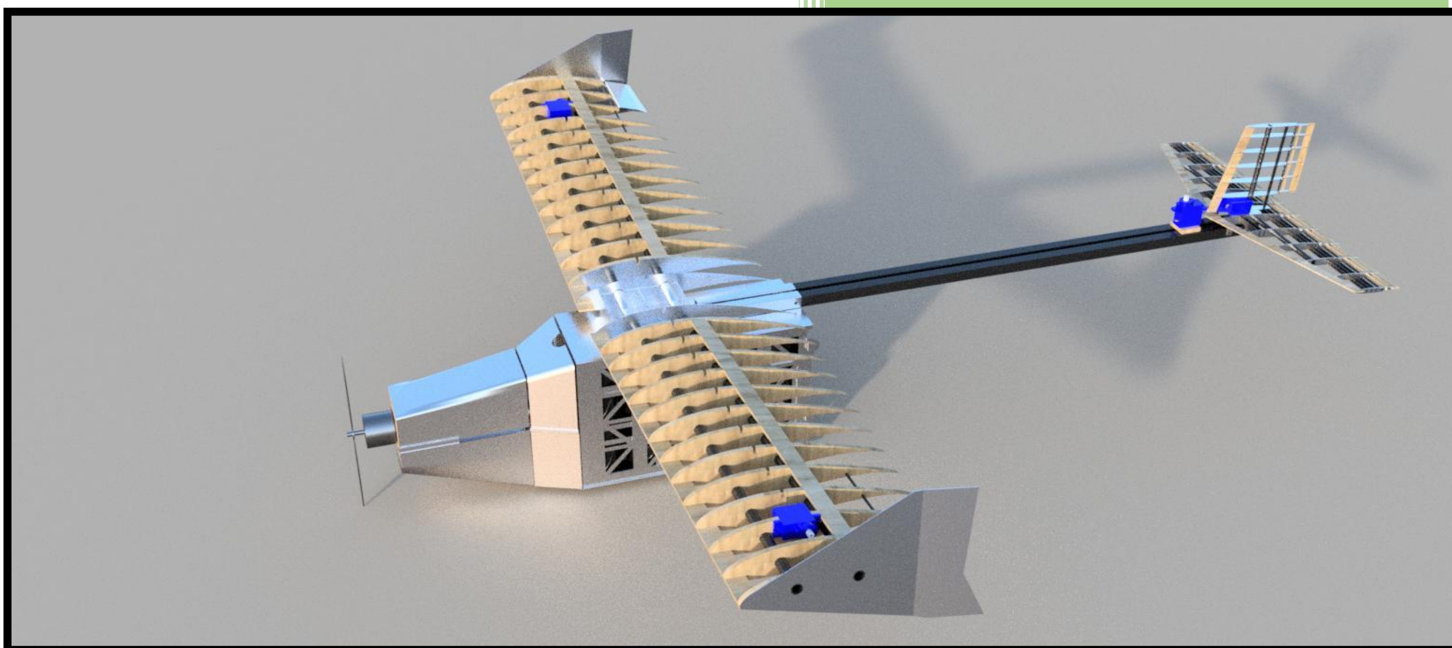
2020

Submission for event at GraVITas'20, VIT Vellore

Aerodominator Design Report



Team Name:

Team Horus

Team Number:

AD-019

School Name:

BITS Pilani, K.K. Birla Goa Campus

Team Members:

- Deven Paul (c)
- Rajat Garg
- Aaditya Mishra
- Advait Menon
- Ishan Neogi

VIT
Vellore Institute of Technology
(Deemed to be University under section 3 of UGC Act, 1956)

SAE-VIT
SAE INDIA |STUDENT CHAPTER

AERODOMINATOR 7.0

STATEMENT OF COMPLIANCE

Team Name: Team Horus

College Name: BITS Pilani K K Birla Goa Campus

Faculty Advisor: Dr. Ranjit S Patil

Faculty Advisor's Email: ranjitp@goa.bits-pilani.ac.in

Statement of Compliance-

"As a Faculty Advisor, I certify that the registered team members are enrolled in collegiate courses. This team has designed, and/or modified the radio controlled airplane that they will use for SAE-VIT AERODOMINATOR 7.0 Competition, without direct assistance from professional engineers, R/C model experts or pilots, or related professionals."

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(Signature of Faculty Advisor)

(Signature of Team Captain)

Table of Contents:

Introduction

During this period of worldwide pandemic where there is a huge setback faced by various organizations due to stagnation of transportation of goods, the next gen innovators are finding new ways to transport essential items without human exposure. UAVs have been the fastest mode of transport of goods since more than half a century, now as we move further in the advanced technology phase UAVs are no longer used for remote dropping of goods but door to door delivery of various essential items. Aero Dominator 7.0 is an Aero Design challenge meant to take innovation further in this regard.

Abstract and Mission Statement

Our team has designed a micro class plane with an objective to transport medical supplies, while keeping within the multitude of rules and constraints as set by the organizing team. The aircraft is to be adept at delivering medical supplies, hence stability and endurance were the biggest design considerations for the aircraft.

The report incorporates different models that were tried and after that coordinated to deliver a hypothetically airworthy plane that would support a payload of 1200g in flight. The design was incorporated while keeping in mind the payload to be carried as well as cost of materials used. The design was assimilated after finalizing the exact payload configuration and then extensive research was carried out to find appropriate airfoils to provide us with the desired output. Once these initial parameters were finalized, a detailed analysis of the same was carried out in Computer Aided Engineering software (XFLR-5) to determine exact dimensions of wing, stabilizer and ailerons. Along with the former task in hand, a substantial amount of research was done to finalize the motor-prop configuration taking into account the material and battery constraints. Finally, Computer Aided Design (Fusion 360) was extensively worked on by the team to give shape to the idea originally perceived.

Design Summary

General Plane Characteristics

Weight: 1000 grams (empty + allowances) + 1200 grams (Payload) = 2200 gram

Operating Angle of Attack:	Loaded: 1.6 degrees;	Unloaded: 1.95 degrees
Operating Speed:	Loaded: 17.3 m/s	Unloaded: 11.5 m/s
Stability Margin:	Loaded: 6%	Unloaded: 5.6%
Operational $C_L^{3/2}/C_D$:	Loaded: 11.7	Unloaded: 10.74
Operational Drag Range:	Loaded: 1.76 N (wing + tail) + 1 N (fuselage) = 2.76 N	
	Unloaded: 0.885 N (wing + tail) + 0.5 N (fuselage) = 1.385 N	

Wing Characteristics

Span: 780 mm	Area: 1287 cm^2	
Chord:	Root: 180 mm	Tip: 150 mm

Sweep Angle: -1.10°; trailing edge forward swept, leading edge no sweep

Angles:	Dihedral: 5 degrees	Incidence: 2.5 degrees
Ratios:	Aspect Ratio: 4.73	Taper Ratio: 1.20

Horizontal Tailplane Characteristics

Span: 320 mm	Area: 240 cm^2	
Chord:	Root: 100 mm	Tip: 50 mm

Sweep Angle: 13.19°; leading edge swept back, trailing edge no sweep

Incidence Angle: 5 degrees

Vertical Tailplane Characteristics

Span: 180 mm	Area: 81 cm^2	
Chord:	Root: 100 mm	Tip: 80 mm

Sweep Angle: 9.46°; leading edge swept back, trailing edge no sweep

Tail Lever Arm Length: 580 mm

Control Surface Characteristics

Elevator:	Size: 20% H.stab area	Max Deflection: 6°
Rudder:	Size: 25% V.stab area	Max Deflection: 15°
Ailerons:	Size: 20% tip chord * 60 mm	Max Deflection: 12°

Payload Bay Characteristics

Length: 20 cm	Width: 8 cm	Height: 12.7 cm

Payload Contents

No. of Spheres: 15 No. of Cylinders: 5

Accessibility and Securing mechanism

Slide in tray for payload; fit-in gate for payload securing

Velcro attachment for removable electronics; elastic fitting metal sheet for electronics accessibility

Electronics Used:

Battery: 2200 mAh 3-cell LiPo Battery (main) + 1000 mAh 3-cell LiPo Battery (secondary/Emergency)

Motor Prop combination: AT 2308 2600KV with APC 6x4 propeller

Electronic Speed Controller: 50 Amps Servo: TowerPro SG90

Design Process

Wing Planform Design and Analysis

$$P_{req} = T_{req}V = DV = \frac{WV}{\frac{C_L}{C_D}} = \sqrt{\frac{2W^3C_D^2}{S\rho C_L^3}}$$

$$\Rightarrow P_{req} \propto \frac{1}{\frac{C_L^{\frac{3}{2}}}{C_D}}$$

The Biggest driver for all design choices was the bid to maximize the endurance of the aircraft. For every design consideration, we tried to keep $C_L^{3/2}/C_D$ as high as possible, in a bid to ensure greatest endurance.

All analyses done henceforth are done on a model net weight of 2.5 kilograms. We aim to keep the actual loaded weight below this number. All results henceforth will include a healthy margin of error for a real aircraft. All analyses were done on the foil analysis software XFLR5.

Airfoil Choice

To choose an airfoil, a certain set of parameters were decided to weigh the pros and cons against. The parameters are as follows:

- Coefficient of Lift (C_L) must be above 1.5 for Reynolds numbers (Re) > 100,000.
- C_L vs Alpha curves for various Reynolds numbers must be smooth over Re>100,000 and must be very close to each other. This will ensure that the wing can sustain flight even with deviations from ideal Reynolds numbers over time.
- Ratio of coefficient of lift to coefficient of drag (C_L/C_D) has a maximum over 70 for Re>200,000 and is as high as possible.
- C_D vs Alpha curve must be relatively smooth with no sudden changes in slope at Re>100,000 and its minimum must be below 0.02

With the help of airfoiltools.com, we shortlisted several airfoils for comparing endurance. Running these airfoils through a batch analysis at various Reynolds number values in XFLR5 got us our final pick: **Wortmann FX 63-137.** This airfoil provides the best endurance of the bunch.

Wing Geometry and Analysis

Using the Airfoil and wing analysis tool XFLR5, the aircraft wing was modelled. The aim of the wing geometry was decided to be based on the following factors:

- The wing needed to carry a minimum weight, in this case an estimated 2.5 kg.
- The wing needed to produce enough lift to carry the entire weight without the tail.
- The value of $C_L^{3/2}/C_D$ for the wing also must be as high as possible.
- The operation speed and angle of attack ranges need be nominal and far from stall.
- The wing needed to be able to fly at high angle of attack at low speeds without stalling, to facilitate hand launching. The speed value chosen for this is 14 m/s.

- The drag needs to be minimized as much as possible, after all constraints are met.

After several iterations with different wing geometries, the one ideally meeting all these parameters and therefore finalized is of the dimensions:

Wing Span: 78 cm (Actual Span = 85 cm, further discussed in CAD Modelling of wing)

Root Chord: 18 cm; Tip Chord: 15 cm

Sweep details: Trailing edge swept forward; Sweep angle = -1.10 degrees

This wing is able to lift the entire This wing is stalling at under 14 m/s. This allows for hand launching, and the use of elevator would help the case further. Actual details of various parameters are omitted here to save space, and since these values don't represent the final values after inclusion of tail and control surfaces.

XFLR5 can model vortices to some degree of accuracy, and can produce values of viscous and induced drag separately. Net drag of wing (and eventually wing and tail) was calculated through

$$D = \frac{1}{2}\rho v^2 S_{planform}\left(C_{D_{parasitic}} + C_{D_{induced}}\right), where\ C_{D_{induced}} = \frac{{C_L}^2}{\pi * Aspect\ Ratio * e}$$

And added to Fuselage Drag value.

Fuselage Drag

Fuselage drag was estimated by creating a simply shaped 3D solid block for the aircraft, and was run for drag analysis in Ansys Fluent. Drag for the fuselage was estimated to be approximately 1 N for cruise.

Tail Design and Stability

The tail became a tool for achieving a stable flight in conditions that will maximize endurance, rather than a tool to increase endurance itself. We opted to design the tail with only stability in mind, and not to increase lifting capacity. Increased lifting capacity was a consequence of the design, and was rather used to lower operational speed.

Airfoil Choice

Similar criteria were used for the tail airfoil as was for the wing, notably the requirement of smoothness with Reynolds number variation and high C_L/C_D requirement. Also, the airfoil had to be symmetrical.

Airfoil Chosen after comparisons and XFLR5 foil analysis: **NACA 63010**

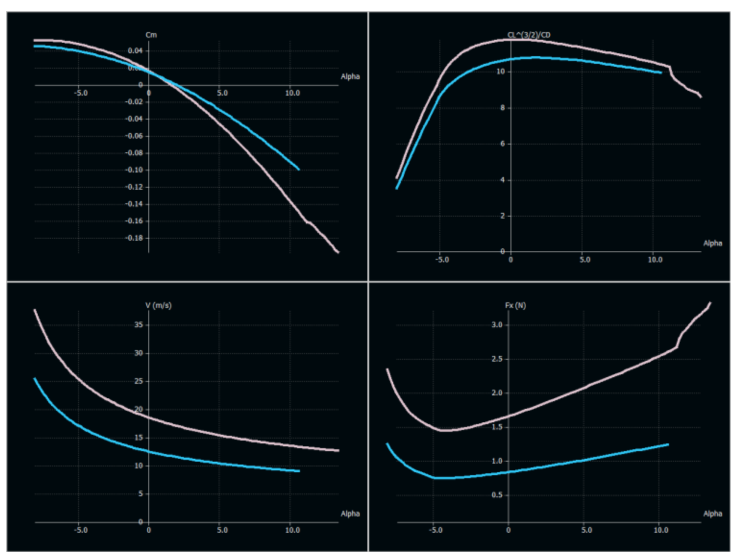
Longitudinal Stability

Longitudinal stability analysis requires a careful calibration of parameters like horizontal stabilizer geometry, the tail lever arm length and position of the center of gravity with respect to the wing and tail (i.e. the stability margin of the aircraft). The key requirements are these:

- The plane needs to achieve static stability in pitch stability, and hence, derivative of C_M w.r.t Alpha needs to be negative, and C_M at 0 alpha needs to be positive.
- In order to keep the cargo horizontal and to minimize form drag of wing and fuselage, the trim point needs to be as close to 0 as possible in cruise. This is possible through an angle of incidence.
- The operational speed needs to be in 15-20 m/s and endurance factor at that speed ($C_L^{3/2}/C_D$) high.
- Drag at operational angle of attack needs to be as low as possible.

After beginning with a general horizontal tailplane geometry, several runs of trial and error were done in order to achieve the best geometry and positioning for the horizontal tailplane.

Final parameters:



- **Horizontal Tailplane Span: 32 cm**
- **Root Chord: 10 cm, Tip Chord: 5 cm**
- **Sweep details: Leading edge swept backward; Sweep angle = -13.90 degrees**
- **Tail Lever Arm length: 58 cm, Tail Height over wing: 8 mm**
- **CG location (x position from Leading edge of wing): 8.5 cm**
- **Incidence of Tail w.r.t. Wing = 2.5 degrees**

Once again, the final values of performance indicators have been omitted here due to lack of space.

Once the CAD model was ready, all these analyses were run again using the same geometry, but with the actual loaded and unloaded weight. All characteristic performance parameters aforementioned in the design summary are results of this re-done analysis.

Lateral Stability

Vertical stabilizer geometry and sizing were decided based on these parameters:

$$0.04 \leq Vertical\ Tail\ Volume\ Ratio \leq 0.06$$

$$1.2 \leq Vertical\ Tail\ Aspect\ Ratio \leq 2$$

- **Vertical Tailplane Span: 9 cm**
- **Root Chord: 10 cm, Tip Chord: 8 cm; leading edge swept backwards**
- **Tail Lever Arm length: 58 cm, Tail Height over wing: 8 mm**

5 degrees of dihedral was also added on to the wing in order to encourage lateral stability further.

Finally, **an angle of incidence of 2.5 degrees** was added in both wing and tail, in order to bring the trim point close to 0 degrees angle of attack, bringing wing to a net incidence of 2.5 degrees and tail to 5 degrees.

Control Surface Sizing and Dynamic Stability

Aileron Sizing

The first iteration of analysis was done by taking the standard size of ailerons i.e. width as 1/5th of chord length and length 1/4th of the wingspan. The results showed that L (rolling moment) was 1.04 at 15°, which was outside the desirable range. Using this value, the time response of the airplane was also calculated.

$$P_{ss} = \sqrt{\frac{2 \cdot L_A}{\rho\,(S_w + S_{ht} + S_{vt}) C_{D_R} \cdot y_D^3}}$$

$$\phi_1 = \frac{I_{xx}}{\rho y_D^3\,(S_w + S_{ht} + S_{vt})\,C_{D_R}} \ln(P_{ss}^2)$$

Our goal is to find the steady state i.e. when damping becomes equal to the rolling moment. In this case, the plane will get uncontrollable.

We iterated over these given formulas until t_2 was about the same as t_{req} and by changing the aileron sizing accordingly at the end of each iteration. Thus, we concluded that ailerons length needs to be as small as 6 cm in order to maintain the control of the plane.

Roll Moment at max angle deflection (12°) = 0.3

Roll Moment at 5° = 0.15

Control Derivative at 0° = 0.07311

Control Derived at 12° = 0.06527

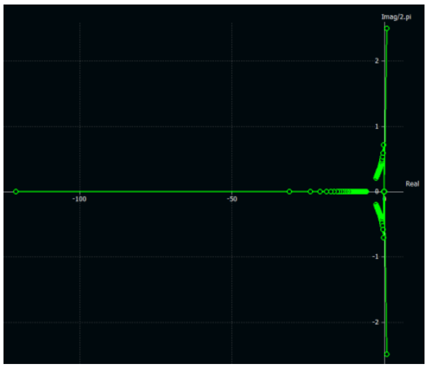
$$\dot{P} = \frac{P_{ss}^2}{2\phi} \qquad t_2 = \sqrt{\frac{2\phi_{des}}{\dot{P}}}$$

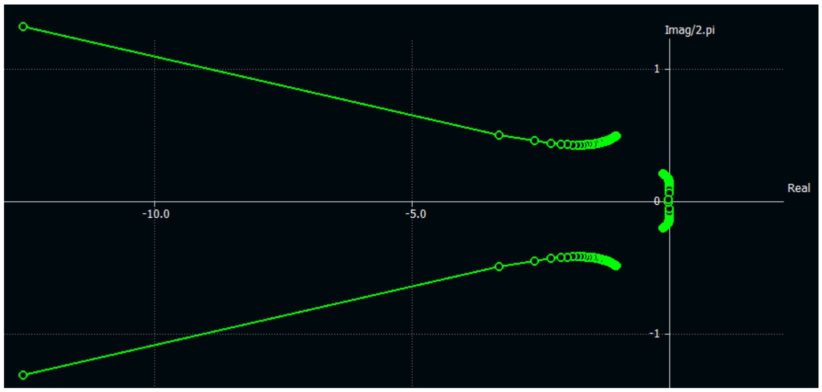
Elevator Sizing

The first iteration of the analysis was done by taking a standard size i.e. 30% of chord length as elevator.

Results showed that the range of the deflection angles is quite small.

The graph of Img/2.pi vs Real given below shows the range of deflection angle on which plane remains stable.





The process was repeated and thus we concluded that taking 25% of chord length as elevator, the range attained is sufficient and at up to 6 deg we can trim the plane.

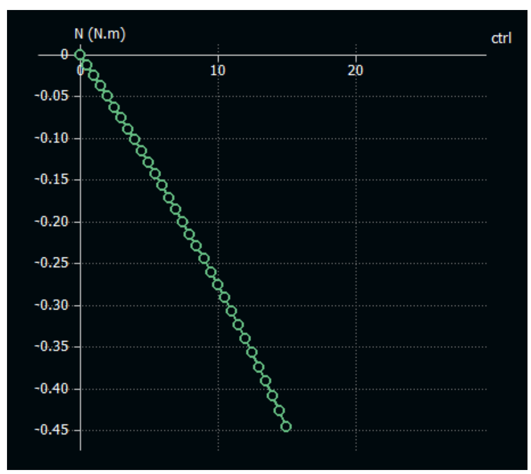
max deflection = -20° to 6°

Control derivative at 0° = -1.68172

velocity range = 11 m/s to 30 m/s

Rudder Sizing

The standard size of the rudder, i.e. 25% of the chord length as rudder, was taken for the analysis. Results were acceptable and a stable configuration was achieved.



Max deflection angle = 15°

Control Derivative at 0° = -0.06105

Control Derivative at 15° = -0.06636

Yaw moment at 15° = -0.45

Electronic Choices

Motor and Propeller Selection

Variables like; diameter and pitch of the propellor, and the current drawn were used to determine a suitable configuration

Motor and Propeller selection was done based on two factors.

1. A motor propellor setup should be capable of providing dynamic thrust that counters the drag (of 3N in this case) at the determined cruising speed of 17.3m/s, the relation for which is given by: -

$$F = 4.392399x10^{-8} \cdot RPM \frac{d^{3.5}}{\sqrt{pitch}} (4.23333x10^{-4} \cdot RPM \cdot pitch - V_0)$$

   - For our needs we required a high KV motor with a fair tolerance for an increased motor RPM than depending on the increased propellor dimensions which would require higher operational power.
   - After this several motor propellor configurations that fulfilled the requirements were shortlisted.

2. Endurance of the aircraft based on the amount of current the configuration draws

The endurance of an aircraft or the flight time of an aircraft is dependent on the battery discharge rate and the battery capacity

The discharge time for the given battery configuration was approximated using Peukert's law. As the rate of discharge increases, the battery's available capacity decreases and the relationship between the battery capacity and discharge time is given by:

$$t = H\left(\frac{C}{IH}\right)^k$$

- Hence, in order to increase endurance, the amount of current should be kept minimal to increase the discharge time; for this reason, two motor propeller configurations were further shortlisted. This includes the AT2317 1400KV motor with an 8*6 propellor and AT2308 2600KV motor with a 6*4 propellor.

- Out of the two **AT2308 2600KV motor with an APC 6*4 E propellor** was chosen for the following reason:

Due to a higher KV rating this motor can provide increased thrust at higher throttle providing more allowance during ascents at a much lower current as compared to the AT2317 1400KV motor with an 8*6 propeller at a much cheaper price.

Battery Selection

As our motor propellor configuration draws a maximum current of 28A, A 3-cell LiPo configuration of 15C rating was used which can provide a maximum continuous current of 2.2×15=33A.

ESC Selection

As the maximum current drawn by the setup is 28 A, a 40 A rated ESC was used to avoid overheating.

Servo Selection

The moment required for getting the required aileron deflection was calculated using an XFLR5 analysis. The moment for ailerons was found out to be 0.1 Nm and 0.09 Nm in the case of elevators. So, a 9g micro servo was used to fulfil the moment requirements for roll, pitch, and yaw.

Performance Prediction

Endurance:

The endurance can be calculated using the peukert's relation, assuming the peukert's constant to be 1.05 for a LiPo battery with a constant current of 16.4A being drawn by the setup

$$\boldsymbol{t \text{ (in hrs)} = \frac{C}{I^n}} \quad \textbf{i.e.} \qquad \boldsymbol{t = 2.\frac{2}{16.4^{1.05}}}$$

by following the above calculations, the endurance of the aircraft comes out to be **0.117 hrs** or **7 mins**

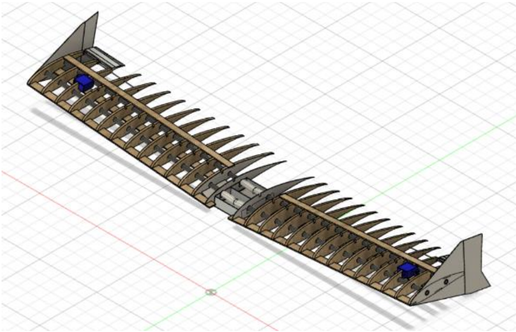
Range:

Range of the aircraft can be calculated by multiplying the cruising speed by the endurance of the aircraft,

So, the range in our case comes out to be **(17.3m/s) ×(7×60sec) = 7266 metres**

CAD Designing and Manufacturing

Wing



The wing geometry is as per defined in Design summary. The important thing to point out here is the analysis was done using 78 cm span wing, while this wing spans just under 85 cm. This was done to eliminate the loss of lift due to the wide fuselage, and better estimate the lift capabilities of the exposed wing. Wing consists of a total of 26 airfoil sections made of Balsa wood with 4 additional thin aluminum airfoil sections (2 for support and 2 to mesh the wing into the fuselage). The airfoil sections are joined and aligned using 2 Carbon Fiber spars, the positioning of which were closely analyzed to provide maximum support and stability to the design.3 additional Balsa wood spar were introduced (on each side) to the design for stability purpose. Ailerons(aluminum) were attached to the trailing end of the wings using Carbon Fiber spar, to generate necessary rolling motion, whose positioning and length were first finalized using XFLR-5. Finally, 2 Servos (Towerpro Micro Servo 9g) were placed in wings to control steering and adjust wing surfaces. Winglets were added to reduce induced drag.

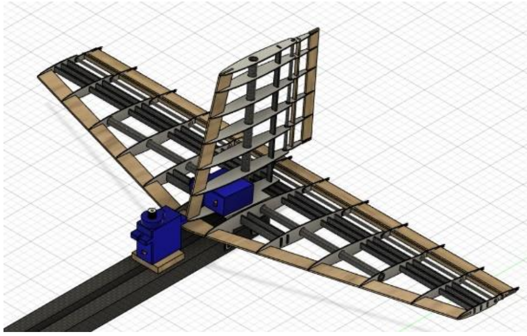
Tail

Horizontal Stabilizer

Geometry is as per design summary. Tail consists of 12 aluminum airfoil sections in the main frame and 12 aluminum airfoil sections in the elevator section. The elevator sections are joined together using Balsa spar while they are hinged with the leading airfoil sections using a Carbon Fiber spar. All of the leading airfoil sections are joined together using 3 rectangular Carbon Fiber spars, while a wider circular spar is used for additional support. 2 more rectangular Carbon Fiber spars were attached in the leading edge to provide additional support on mounting the vertical stabilizer. The overall shape was delineated by leading and elevator Balsa wood spars.

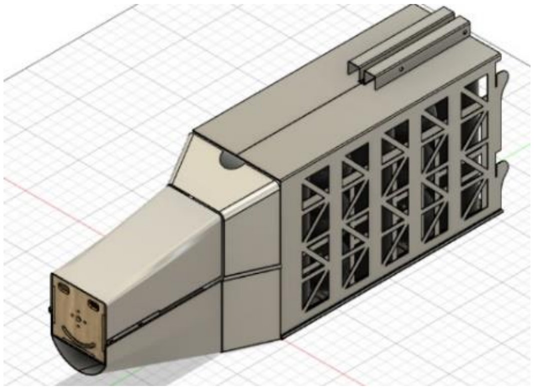
Vertical Stabilizer

The vertical stabilizer consists of 6 aluminum airfoil sections in the main frame and 6 aluminum airfoil sections in the rudder section. The rudder section is joined together using a rectangular Balsa spar and is hinged with the mainframe using a Carbon Fiber spar. The main frame is joined using a rectangular Carbon fiber spar and a Wide circular Carbon Fiber spar is used to join the overall structure to the Horizontal Stabilizer. The shape is given by the leading and trailing Balsa Wood spars. Finally, the overall design is placed on an aluminum structure for mounting on Horizontal Stabilizer.



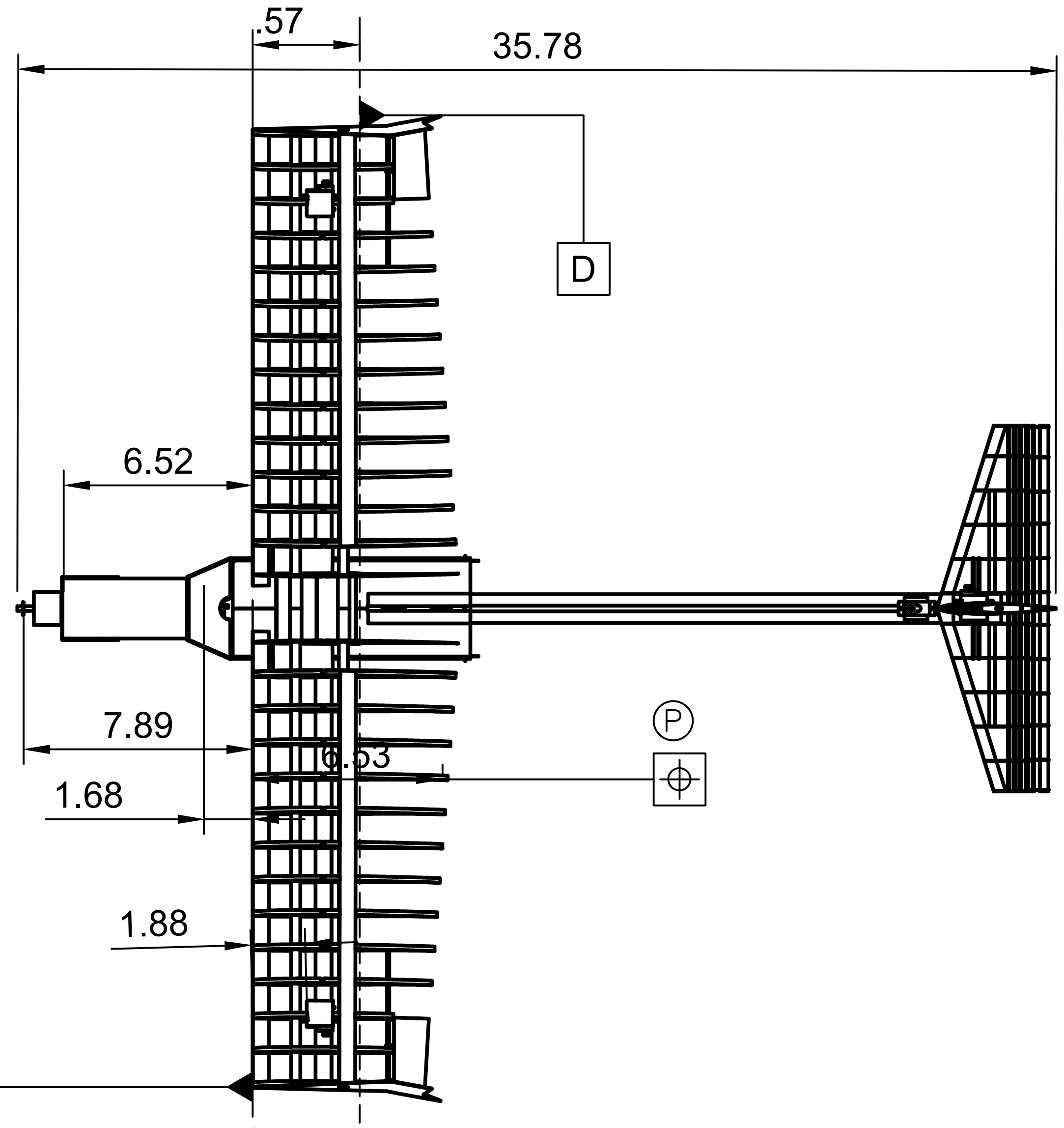
Tail Assembly

The Vertical Stabilizer is mounted on the Horizontal Stabilizer and joined using one previous mentioned Carbon Fiber spar. Both the horizontal and vertical stabilizer are bolted onto two square carbon fiber spars, along with servos as appropriate gaps left in the structure to facilitate easy access and maximum torque transfer.

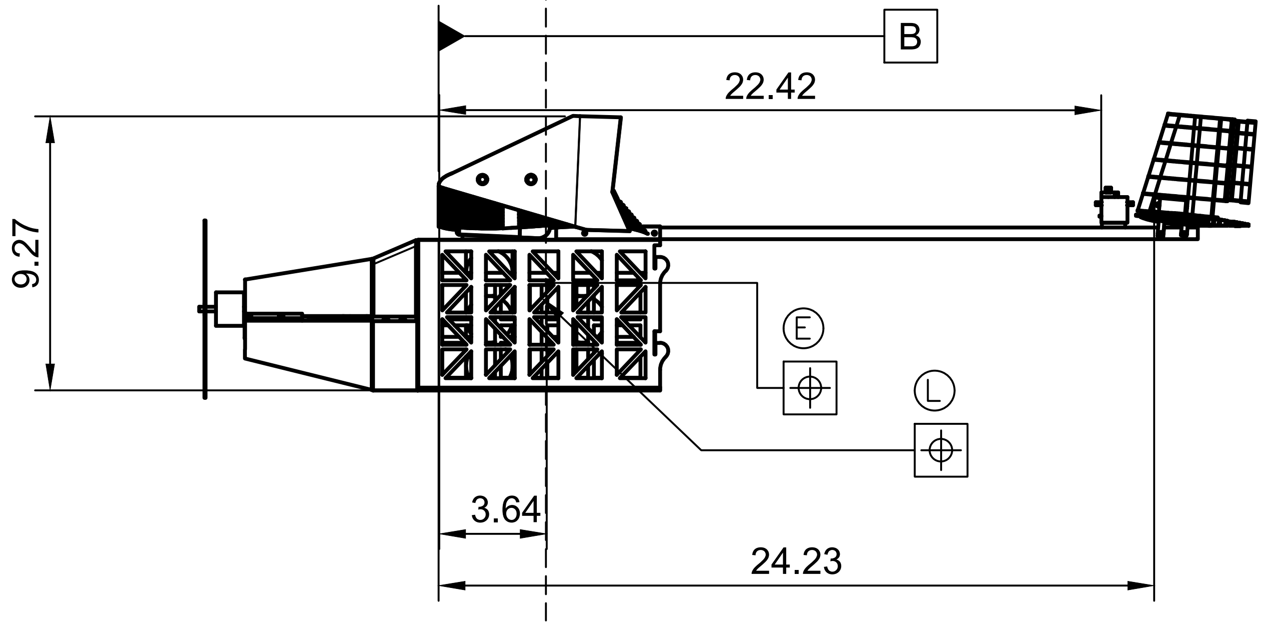


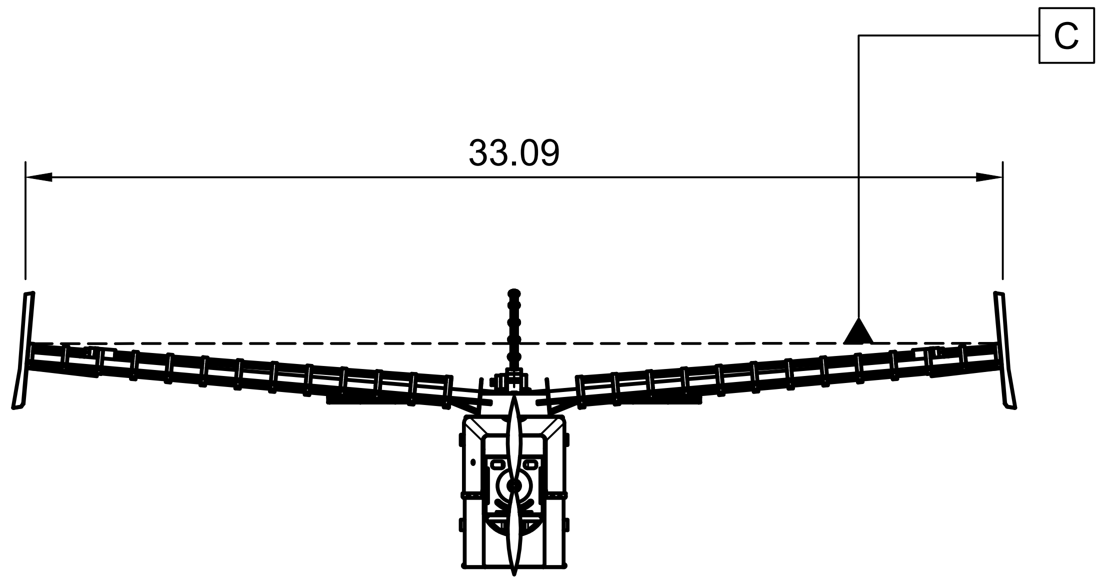
Fuselage and Payload Bay

The overall Payload bay is covered with sheet metal aluminum structure with an opening at the hind side for the extraction of the payload tray. A fit-in gate (aluminum) mechanism is used for the insertion and extraction of the payload bay. The sheet metal continues to form an electronics bay in front of the payload, and extends on to become a base for the motor mount. The spars from the tail are bolted and the wing base is welded, both onto the roof of the structure. The complete fuselage gains a lot of strength by virtue of being a single sheet of folded aluminum, and is structurally sound to handle the weight. The implementation of TIG welding at certain locations will allow for stronger parts and connections like the base of the wing to the fuselage roof. The electronics are also accessible through a thin metal sheet that elastically fits in the fuselage. **Most components have been designed as per Structural analysis results from Ansys.**



Item	Qty	Part Number	Description	Material
1	-	Wingspan	83.4cm overall 79cm without fuselage part.	Balsa Wood, Carbon Fiber Spar
2	-	Empty Weight	Without Payload	Balsa Wood, Aluminium, Carbon Fiber Spar,Aeroply Wood
3	1	Battery	2200 mAh 3-cell LiPo Battery (main)	Custom Weighted Metal
4	1	Motor	AT2308 2600KV	Custom Weighted Metal
5	1	Propeller	APC 6x4 propeller	Custom
6	1	ESC	50 Amps	Custom
7	4	Servos	TowerPro 1600g/cm 4.8V	3 pole ferrite, all nylon gear





Weight and Balance Information

Left View: Height of Aircraft -> 9.27 in
Distance of Servo from Datum -> 22.42 in , 24.23 in
Distance of Payload from Datum -> 3.64 in
L point -> Loaded CG
E point -> Empty CG
A -> Datum

Top View : Length of Aircraft -> 35.78 in
Distance of Motor from Datum-> 6.52 in
Distance of Servo from Datum -> 1.88 in
P point -> Mean Aerodynamic Cord (6.53 in)
B -> Datum
Distance of Prop from Datum -> 7.89 in
Distance of Battery from Datum -> 1.68 in

Front View : Wingspan -> 33.09 in
C -> Datum

D -> Neutral Point

Neutral Point Distance from Datum -> 0.57 in (in Front View)
Loaded Stability Margin -> 6%
Unloaded Stability Margin -> 5.5%

Team Number	Team Name	School Name
AD-019	Team Horus	BITS Pilani K K Birla Goa Campus

Micro Class Tech-Data Sheet: Weight Build-up

Team Name: Team Heron

School Name: BITS Pilani, K.K. Birla Goa Campus

Team Number: AD-019

Sl. No.	Component	Weight (g)
1	Battery (Main)	174.94
2	Aluminium Ballast/Dead Weight	85
3	Motor	47
4	Propeller	28
5	Electronic Speed Controller	6.5
6	Receiver Module	4
7	Servo motors (x4)	108.1
8	Main Fuselage 0.5 mm Aluminium Sheet	139
9	Motor support L-bracket 2 mm Aluminium Sheet	2.8
10	0.5 mm Aluminium wing base construct	13.2
11	0.5 mm Aluminium Wing rib construct (x2)	18.5
12	0.5 mm Aluminium Winglet (x2)	25.8
13	0.5 mm Aluminium sheet Nose cone cover	19.38
14	0.25 mm Aluminium sheet removable cover (x2)	14.44
15	0.5 mm Aluminium sheet Payload tray construct	38.57
16	Welded Aluminium V-tube wing support (x2)	8.6
17	Aluminium Aileron Constructs (x2)	10
18	0.5 mm Aluminium tail ribs & support structures (x19)	10.36
19	0.5 mm Aluminium Elevator and Rudder flanges (x18)	1.01
20	0.5 mm Aluminium Gate construct	11.313
21	Carbon Fibre Main tail square spars (x2)	86.16
22	Carbon Fibre Tail round spars (various lengths and diameters) (x4)	7.95
23	Carbon Fibre Tail Rectangle spars (Various Lengths and dimensions) (x6)	5.69
24	Carbon Fibre Wing round spars (various lengths and diameters) (x6)	68.85
25	Aero Ply Motor Mount construct	6.39
26	4 mm Balsa Wing ribs (x26)	28.55
27	2 mm Balsa Wing spars (x6)	8.65
28	1 mm Balsa Tail spars (x6)	1.1
29	4 mm balsa servo support	0.22
30	Payload	1200
31	Misc. components (Nuts, Bolts, Glue, Weld material)	50