SAE INDIA SOUTHERN SECTION

AERO DESIGN CHALLENGE 2020

MICRO CLASS DESIGN REPORT

By

TEAM ID: ADC2020179

TEAM NAME: IARE - LAKSHYA

INSTITUTE OF AERONAUTICAL ENGINEERING

AUTONOMOUS

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2020 SAE ISS AERO DESIGN CHALLENGE

STATEMENT OF COMPLIANCE

Certification of Qualification

Team Name : **IARE - LAKSHYA** Team Number- **ADC2020179**

School : **Institute of Aeronautical Engineering,Hyderabad**

Faculty Advisor : **Ms. Yelluri Shwetha**

Faculty Advisor'sEmail: **Shwetha.yss@gmail.com**

Statement of Compliance

As Faculty Advisor, I certify that the registered team members are enrolled in collegiate courses. This team has designed, constructed and/or modified the radio-controlled airplane they will use for the SAE Aero Design 2020 competition, without direct assistance from professional engineers, R/C model experts or pilots, or related professionals.

____

Signature of Faculty Advisor

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1 INTRODUCTION

Ever since the man has touched the skies, the flight ability of the birds has never failed to fascinate him. It always has been an Inspiration and Unquenched Thirst. So is our Inspiration, every bird soaring in the sky is a gesture of freedom and self-pride. SAE has provided such a unique platform for many such aspirants to prove themselves and gain Industrial level experience through SAE Aero Design Challenge. Inspiring from long soaring bird flight we have decided to study and design the Biomimetic wing. We have committed ourselves to adopt the Wing Structure of Long Soaring Birds and are adept to make it a success.

1.1. BACKGROUND

Bird wing configuration was a very popular and most sought configuration in the early age. Over the time researchers and innovators concentrated their views on what we now call as conventional wing configuration. Most of the experiments conducted on bird wing configurations were flapping wing type.

1.2. DESIGN OBJECTIVE

The objective of the design is to obtain the highest payload fraction and the lowest empty weight possible. The design objective is accomplished by designing a model having high C_L/C_D in order to obtain the maximum lift enhancing design innovation carrying highest payload.

2 PROBLEM STATEMENT

The team must design a Micro Class UAV by following all the rules and regulations stated by SAEISS. The challenge is to incorporate a design that possesses contrasting criteria of carrying the maximum amount of payload and simultaneously exhibiting the lowest empty weight possible while still being capable of undertaking basic maneuvers safely and efficiently. The UAV must possess ease of access using a portable carrying container stated by the SAEISS.

2.1. DESIGN CONSTRAINTS

Table 1: DESIGN REQUIREMENTS

S. No	Design Feature	Constraints
1.	Aircraft Type	Fixed Wing
2.	Powerplant Type	Electrical Motor
3.	Empty Weight	≤1.501 Kg
4.	Aircraft Weight	≤4.499 Kg
5.	Aircraft container Volume	≤0.0849 m^3
6.	Maximum Battery Package	3S Lithium Polymer
7.	Payload Bay	0.127m x 0.0381m x 0.0381m (+/-0.0025m)

2.2. MISSION REQUIREMENT

Table 2: MISSION REQUIREMENTS

S.No	Mission Feature	Constraint
1.	Hand Launch	3.048 Radius Zone
2.	Take-off Distance	60.96 m
3.	Initial Turn Distance	121.92m from start
4.	Landing Distance Limit	60.96 m (in take-off direction
5.	TX Frequency allowance	2.4 GHz

2.3. MISSION PROFILE

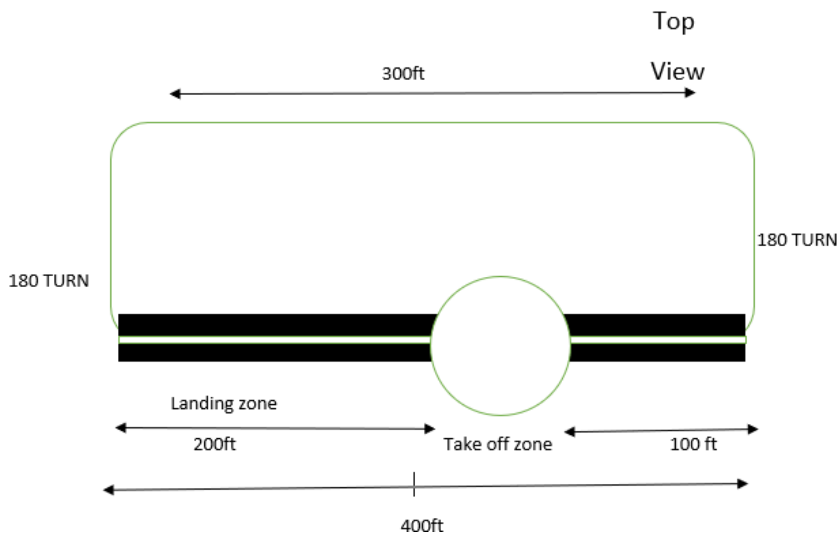

Figure 1: MISSION PROFILE

3 INNOVATION

- ❖ Biomimetic Wing configuration inspired from Long Soaring bird, Albatross (Diomedeidae) which possess high aerodynamic efficiency and perfectly meet the contradictory requirements of gliding and Soaring flight due to its high L/D ratio.
- ❖ The Twin Boom attached to Double finned Empennage proposes high pitching and rolling stability.
- ❖ An under-research concept of introducing serrations to trailing edge of main wing (Inspired from Birds) proved to be improving Cl/Cd ratio significantly.

4 LITERARATURE REVIEW

- ➢ Lin YF, Lam K, Zou L, et al. Numerical study of flows past airfoils with wavy surfaces. J Fluids Struct 2013;36: 136-148. (L. K. Lin YF 2013)
- ➢ M.J. Brennan and A.C. Stevenson, simplified two-dimensional airfoil theory and helped predict airfoil characteristics. (Raymer n.d.)

- H. Glovert, proposed element of aerofoil and airscrew theory in his book theory of Wing Sections. (H.Glovert n.d.)
- G.I. Taylor stated that a symmetrical airfoil with thickness ratio 1/20 has a maximum efficiency of 8.8 neglecting skin friction in his work Journal of Fluid Dynamics: 173, December 1986. (G.I.Taylor December 1986)
- L.M. Milne Thomson provided vector or two-dimensional methods to solve aerodynamic complexities in his book Theoretical Aerodynamics. (Thomson n.d.)
- Usama Hussain, Saif Ul Malook and Ozaif Ali presented computational and experimental study of NACA0012 with serrated trailing edges. (Usama Hussain n.d.)

5 TRADE-OFF STUDIES

Various configurations have been vigorously investigated under trial and error method and best out of them has been chosen for maximum efficiency of the aircraft.

5.1. WING CONFIGURATION

Table 3: WING CONFIGURATION

Type	Figure of Merit	L/D	Stability	Structural Weight	Ease of Manufacture	Total Score
	Score Factor	**0.4**	**0.2**	**0.3**	**0.1**	
Bird Type (Wing Structure)	Falconidae (Falcons)	0	1	1	0	0.5
	Diomedeidae (Albatross)	1	1	1	0	0.9
	Gannets (Morus)	1	1	0	0	0.6
	Gulls (Larus)	0	1	1	0	0.5
Wing Planform	Swept	1	1	0	0	0.6
	Tapered	1	1	1	0	0.9
	Rectangle	0	1	0	1	0.3
Wing Location	High	1	1	0	1	0.7
	Middle	1	0	1	0	0.7
	Low	0	1	0	1	0.3

5.2. CONFIGURATION SELECTION

Table 4: CONFIGURATION SELECTION

	Figure of Merit	Score factor	Conventional	V-tail	Dual Fin
Tail configuration	Stability	0.3	0	0	1
	Drag	0.2	1	0	1
	Structural Weight	0.4	1	0	0
	Manufacturability	0.1	1	0	1
	Total Score		0.7	0.2	0.6
Fuselage configuration			Twin Boom	Conventional	Single Boom
	Weight Distribution	0.4	1	1	0
	Stability	0.2	1	0	0
	Structural Weight	0.3	0	0	1
	Manufacturability	0.1	1	1	1
	Total Score		0.7	0.5	0.4
Motor configuration			Pusher	Push- Pull Motor	Tractor
	Weight	0.2	1	0	0
	Power	0.3	0	1	1
	Efficiency	0.3	1	0	1
	Thrust Factor	0.2	1	0	1
	Total Score		0.7	0.3	0.8

5.3. OVERALL CONFIGURATION

Table 5: OVERALL CONFIGURATION

Wing	Swept back, Variable -Tapered and 10^0 Dihedral
Fuselage	Twin Boom
Tail	Dual Fin
Motor	Twin and Tractor type

5.4. AIRFOIL ANALYSIS

Lifting Airfoil with minimum drag by increasing thickness of Eppler E423 from 12% to 15%.

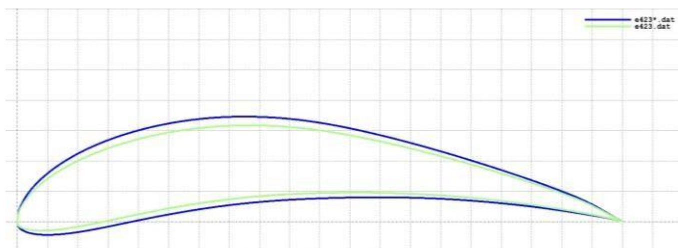

Figure 2: HYBRID FORMULATION

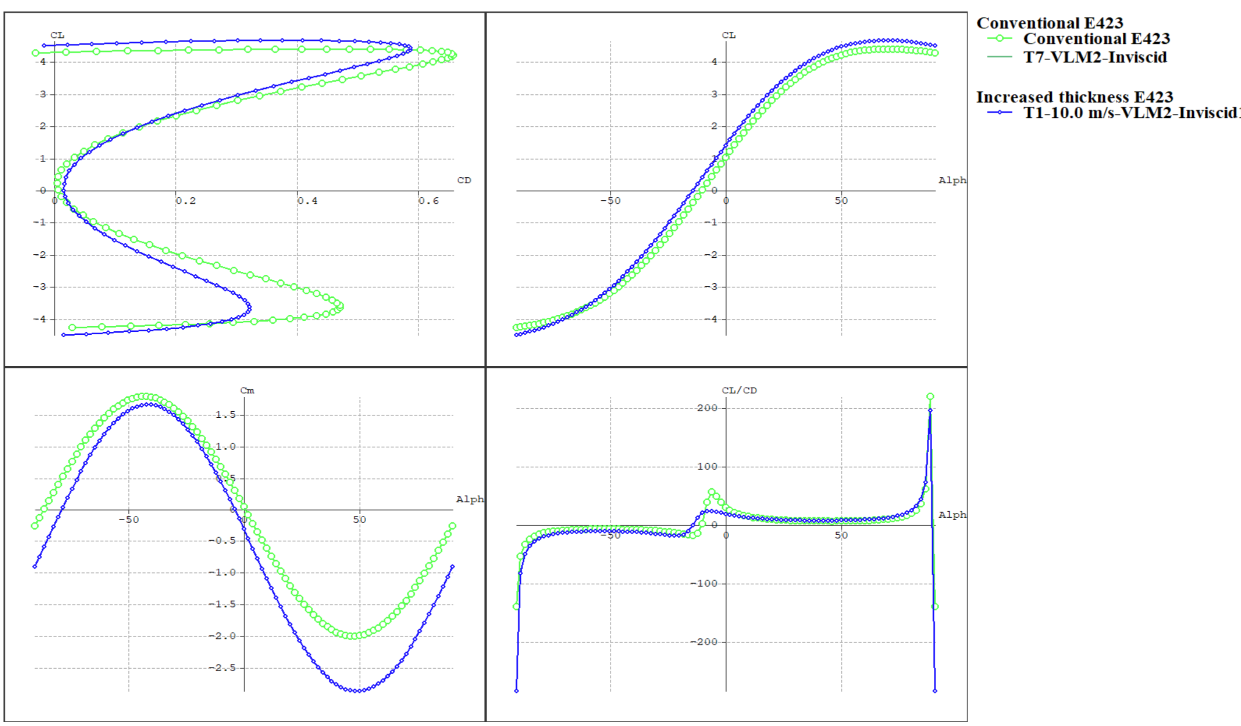

Figure 3: MAIN WING CONFIGURATION

The purpose of horizontal tail plane in an aircraft is to provide a pitching effect. Balsa wood plate of area 0.0255 m^2. For vertical stabilizers(fins) of area 0.0180 m^2. Both Horizontal and Vertical tail planes are slotted into the fins made up of balsa again in the shape of symmetrical airfoil with appropriate pockets made into it to account for weight reduction with strength intact.

5.5. MATERIAL SELECTION

Highly durable materials with no compromise on strength as well as an added advantage of light weight have been used.

Table 6: MATERIAL SELECTION

S. No	Material	Properties	Advantages	Locations of Usage
1.	**Balsa Wood**	High strength and shock absorbing	Lightweight, Rough surface	Ribs, Empennage, Skin
2.	**Monokote**	High Coefficient of Expansion	Easy to mend into shapes and reduces flow separation	Skin
3.	**ABS Plastic (3D Printed)**	Anti-corrosive and has high yield strength. Thermoset material.	Versatile shapes can be molded.	Motor Mounts, Spars
4.	**Aircraft Grade Aluminium**	Alloy of Titanium and Aluminium	Provides overall structural strength to framework	Fuselage Booms, Spars of Wing
5.	**Depron foam**	Low density and light weight	Easily shaped and smooth Surface	Cargo hold (Fuselage)
6.	**Plywood**	Shear resistance and shock resistance	Absorb vibrations	Ribs, Spars

5.6. POWERPLANT SELECTION

Table 7: POWERPLANT SELECTION

Motor	 **EMAX RS2306**			 **EMAX MT 3110**			 **BH SS 2207.5**		
KV	2400			700			3400		
Weight ($kg \times 10^{-3}$)	34			78			29.3		
Rated Voltage (LiPo)	3-4S			3-4S			3-4S		
Peak Current (10V)	30A			50A			70A		
Idle Current (10V)	2A			2A			2A		
Cost	2324			1989			1382		
Recommended Propeller = 6 x 4 (Dual-blade Prop)									
Motor	**EMAX RS2306**			**EMAX MT 3110**			**BH SS 2207.5**		
Throttle (%) Parameter	50	75	100	50	75	100	50	75	100
Thrust (kg)	0.718	1.110	1.557	0.778	1.090	1.565	0.800	1.203	1.606
Voltage (V)	15.5	15.71	15.1	15.9	14.9	15.7	12.3	12.0	11.4
Current (A)	13.8	27.33	51.4	11.2	25.78	43.1	22.2	36.6	62.1
Power (W)	229	441	761	171	485	622	227	472	713
Efficiency (T/P)	2.99	2.48	2.11	4.15	3.12	2.73	3.11	2.57	2.3
Preference	Moderate			Low			High		

Selected Motor- Brother Hobby SS 2207.5. The thrust to power ratio of the selected motor is adequate when compared to the other motors in the similar design specifications. Two motors of the same will be used simultaneously so as to provide equivalent thrust of around 3 kgs. This payload value has been derived from a targeted payload fraction of 0.702.

5.7. AVIONICS SELECTION

Table 8: ESC SELECTION

ESC	EMAX BL Heli Series 30A	Tekko32 F3
Continuous Current (A)	30	65
Peak Current (A)	40	80
Weight (Kg x 10^{-3})	28	5.9
LiPo	2-4S	3-6S
Size (mm)	52 x 26 x 7	18 x 27 x 3
Cost (₹)	1039	2240
BEC Output	5V/2A	5.5V/3A

Table 9: BATTERY SELECTION

Battery	Max Amps 1600	Orange 1000
Capacity (mAh)	1600	1000
Voltage(V)	11.1(3S)	11.1(3S)
Discharge (C)	150	80
Weight (g)	126	85
Size (mm)	67x35x21	72x34x17
Cost (₹)	3042	1099

6 WEIGHT ESTIMATION

6.1. PAYLOAD FRACTION ANALYSIS

Take-off weight = Empty weight + Payload

Based on Payload Fraction analysis, maximum payload fraction was chosen to be 0.702.

The Empty weight is concluded to be 0.7 kg. Hence, maximum payload weight is required to be 1.65 kg.

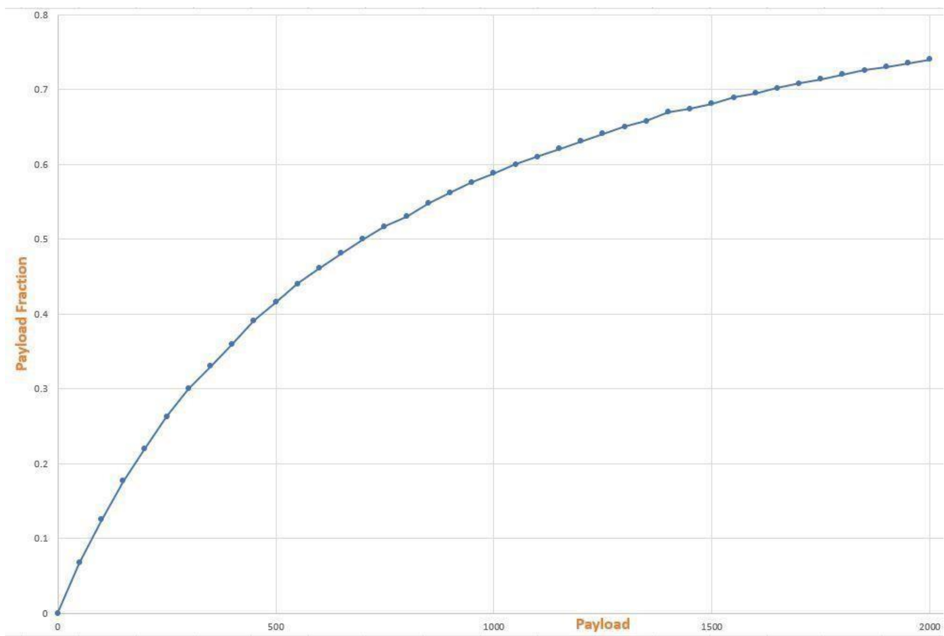

Figure 4: PAYLOAD FRACTION ANALYSIS

6.2. WEIGHT BUILDUP

Table 10: MASS BREAKDOWN AVIONICS

S. No	Components	Weight (kg)
1.	Battery	0.130
2.	Motors and motor mounts	0.090
3.	ESC(s)	0.030
4.	Propeller(s)	0.015
5.	All servos	0.030
6.	Total	0.295

Table 11: STRUCTURAL WEIGHT ESTIMATION

S. No	Components	Weight (kg)
1.	**Main wing**	0.210
2.	**Horizontal tail**	0.030
3.	**Vertical tail(s)**	0.030
4.	**Fuselage (Cargo hold + Booms)**	0.130
5.	**Total**	0.400

Empty weight = $W_{Structure}$ +

$W_{Avionics}$ Empty Weight = 0.400 +

0.295 = 0.695 kg.

Hence, Take-off weight = 0.695 + 1.650 = 2.345 kg.

7 INITIAL SIZING

7.1. WING SIZING

After studying the Glide and Soaring flight of Albatross bird, the Aspect Ratio and Wingspan was fixed for the Multi – Taper Main wing. Design and Assembly restrictions limits the maximum span of 0.88m. Therefore, Aspect Ratio obtained = 8.576. Appropriate dihedral was given by identifying weak points in Structure of wing. Much of the swept back was inspired by High Soaring birds during their glide flight. Density, velocity being constant, surface area required was found to be 0.0903 m^2.

Max C_L/C_D (with 7^0 twist angle) is obtained in XFLR5 V6 is 18.571.

Table 12: WING DATA

Parameter	Main Wing
Wing Span	0.88m
Wing Surface Area	$0.0903m^2$
Aspect Ratio	8.576
Root Chord	0.15m
Taper Ratio	2.5
Sweep Angle	12.49^0
MAC	0.10853

7.2. FUSELAGE SIZING

With all the constraints of main wing, the total distance of nose to tail is limited to 0.62m. Hence, Total Length of the fuselage (Cargo hold and Booms) is 0.62m. The horizontal distance between main wing and tail wing is 0.27m(excluding chord). To provide additional strength without owing much to structural weight twin booms of dimension 0.001m x 0.001m x 0.50m is used and Cargo hold of 0.08m x 0.08m x 0.30m (with aerodynamic shape nose) is used for carrying payload and avionics.

7.3. EMPENNAGE SIZING

Balsa plates in the shape of symmetrical wing have been used for Vertical and Horizontal tail. The surface was modified with maintaining a minimum roughness for gradual separation of flow and the Horizontal tail is insert between two Vertical tails at a height of 0.13m from Y-plane for firmer joint and counteract the adverse pitching moments and upwash and downwash effects. Some parts from both the tails is pocket out for weight reduction.

Table 13: VERTICAL TAIL DATA

Specifications	Dimensions
Span	0.15m each
Surface area	0.0225 m^2
Aspect ratio	4
Taper ratio	2
Root chord	0.10m
Mean chord	7.78m
Sweep angle	14.04^0

Table 14: HORIZONTAL TAIL DATA

Specifications	Dimensions
Span	0.34m
Surface area	0.0255 m^2
Aspect ratio	4.53
Taper ratio	2
Root chord	0.10m
Mean chord	7.78m
Sweep angle	12.44^0

7.4. CONTROL SURFACE SIZING

Primary control surfaces are mounted on aircraft for stabilize the pitching and rolling moments of an aircraft. According to the thumb rule, the area of ailerons is 15-25% of the wing chord and width of the aileron is 0.3 times the chord length. Hence, Aileron chord is 0.05m and area is 0.02m^2. The area of an elevator should at least be 50% of the area of the horizontal stabilizer and its chord is generally 25-50% of its tail chord. Hence, chord is 0.05m and area of elevator is 0.015m^2. There is no rudder used in this model, Ailerons are used for turning maneuvers.

7.5. SERVO SIZING

Sizing motors and servos is very difficult as it is an application-controlled process. Dimensions of the control surface play a major role in calculating the torque. The servos selected should be quite capable of handling the peak loads experienced by the control surfaces. Hence, it is important to calculate the peak torque that a servo an provide. The empirical relation between the torque required and the dimensions of the control surface is,

$$T = 8.5 \times 10^{-6} \times \frac{c^2 v^2\, l \times sin(S_1) \times \tan(S_1)}{\tan(S_2)}$$

Torque Require = 0.32 kgf.cm.

c = chord of the control surface in cm

S1 = maximum control surface deflection in degrees

l = length of the control surface in cm

S2 = maximum servo deflection in degrees

v = speed in mph

8 DESIGN ANALYSIS

8.1. AERODYNAMIC ANALYSIS

Aerodynamic analysis has been analyzed using XFLR5 V6 software in non-viscous flow model.

Results and graphs have been computed with appropriate mission requirement

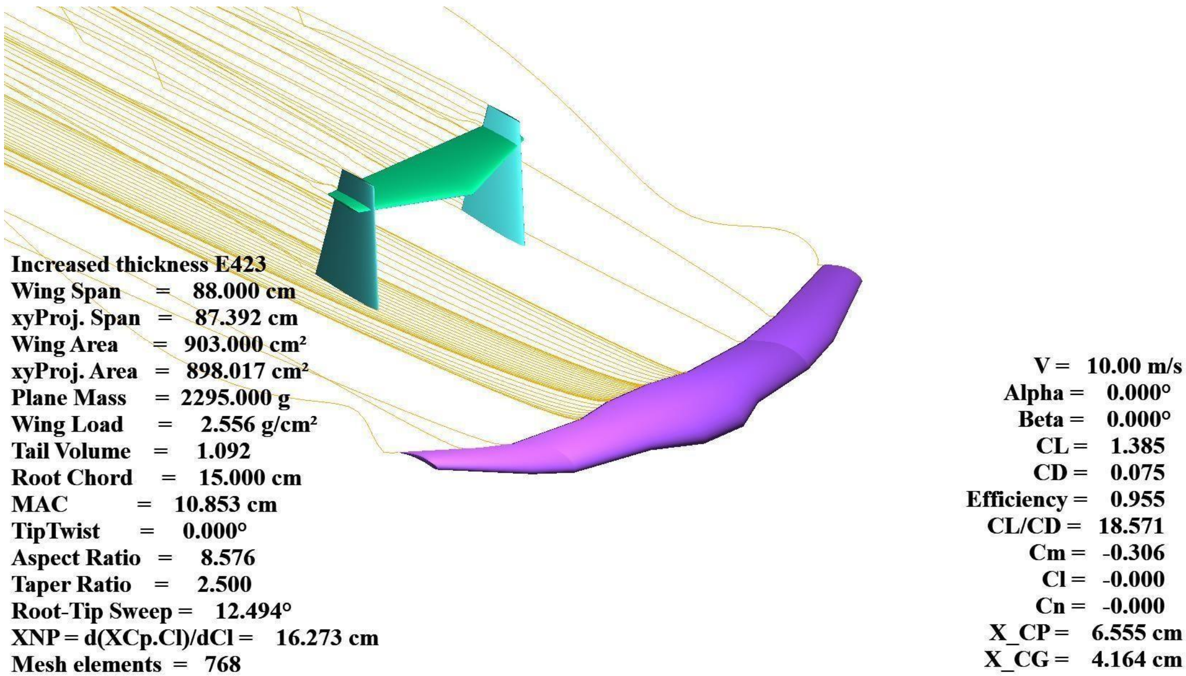

Figure 5: XFLR5 DESIGN & PERFORMANCE OVERVIEW

At Zero AOA and 10m/s velocity, the following aerodynamic data has been computed:

Table 15: LIFT DRAG COEFFICIENTS

C_L	1.385
C_D	0.075
C_L / C_D	18.571
C_m	-0.306
C_{Lmax}	4.670

8.2. STABILITY ANALYSIS

8.2.1. STATIC STABILITY ANALYSIS

Static stability is defined as the initial tendency of an airplane, following a perturbation from a steady-state flight condition, to develop aerodynamic forces or moments that are in a direction to return the aircraft to the steady-state flight condition. Static stability criteria for the three rotational modes of the aircraft must be considered individually and they are:

Pitch: An aircraft is said to be stable in pitch when the slope of the C_m v/s alpha curve is negative and the intercept of the curve on y-axis is positive. The stability graph obtained for the design clearly satisfies the criteria for pitch stability i.e., $C_{m\alpha}$ is negative and C_{m0} is positive.

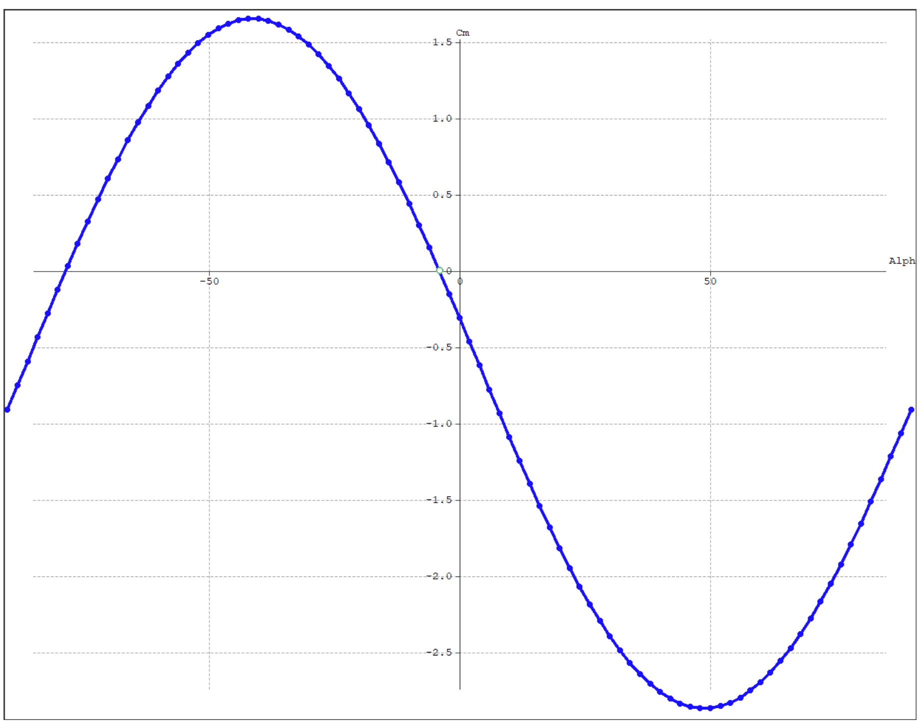

Figure 6: C_M v/s alpha

Roll: An aircraft must possess a negative slope for Cl v/s Beta in order to have a roll stability.

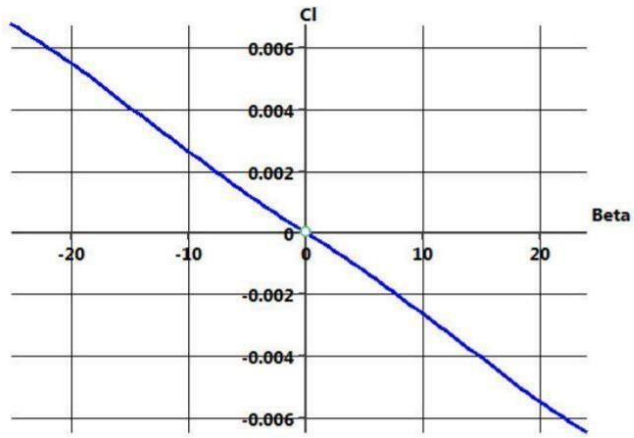

Figure 7: C_L V/S beta

Yaw: The directional static stability derivative is denoted by Cnβ. It is always positive for an aircraft possessing yaw stability. The positive slope ensures that the aerodynamic moments developed cancel out the sideslip.

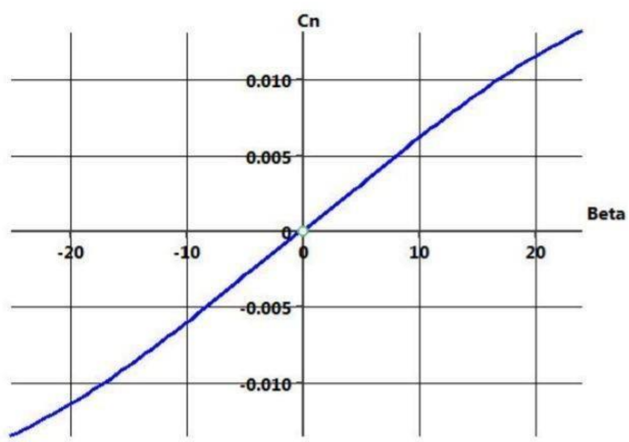

Figure 8: C_N v/s beta

A negative Cm vs Alpha slope suggests that the aircraft possesses longitudinal static stability. Maximum CL/CD is achieved at Zero Angle of Attack, and the flight trim condition is at 2° AOA, meaning maximum aerodynamic efficiency is achieved at an AOA very close to that of the flight's trim condition which is essential for good aerodynamic performance.

8.2.2. DYNAMIC STABILITY ANALYSIS

Aircraft dynamic stability focuses on the time history of the aircraft motion after the aircraft is disturbed from an equilibrium or trim condition.

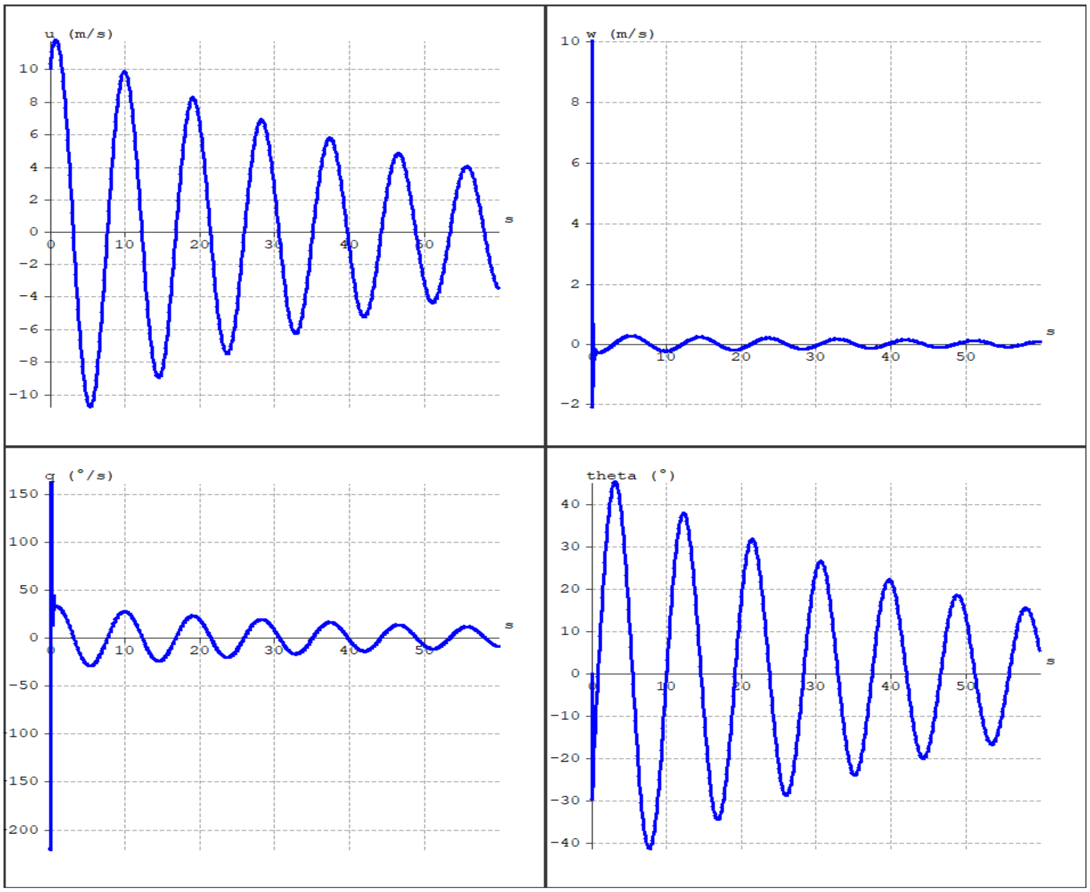

Figure 9: LONGITUDINAL DYNAMIC STABILITY

Where u, w depicts the x and z direction velocities respectively, q stands for x direction angular velocity and theta stands for side slip angle. All of which displaying reducing magnitude with time, i.e., damping or stabilizing nature of the aircraft.

Similarly, the same can be said about the lateral stability graphs. A gust having velocity v acting in the y direction of the aircraft destabilizes the aircraft initially, but with time the magnitude dampens bring the aircraft attitude to its original position. The curves obtained below in the lateral stability graphs suggests that the aircraft possess dynamic lateral stability.

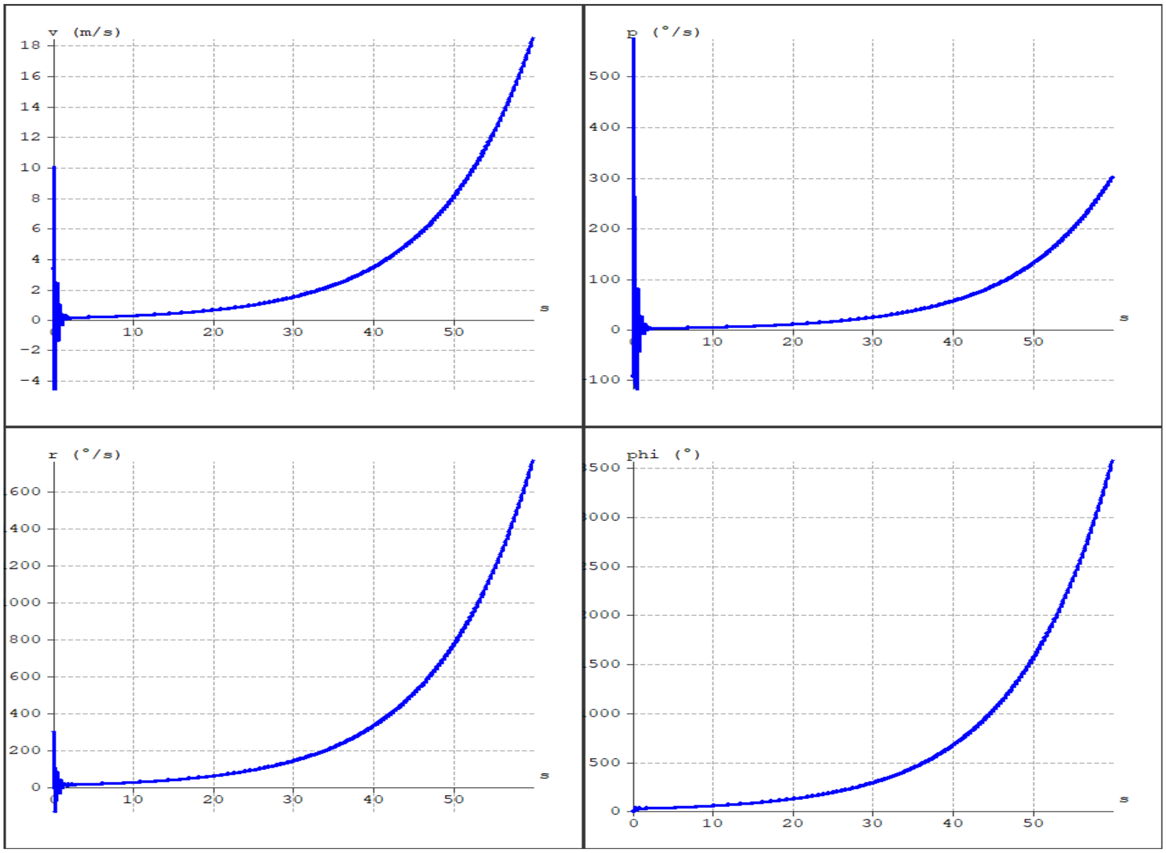

Figure 10: LATERAL STABILITY

8.3. FLOW AND STRUCTURAL ANALYSIS

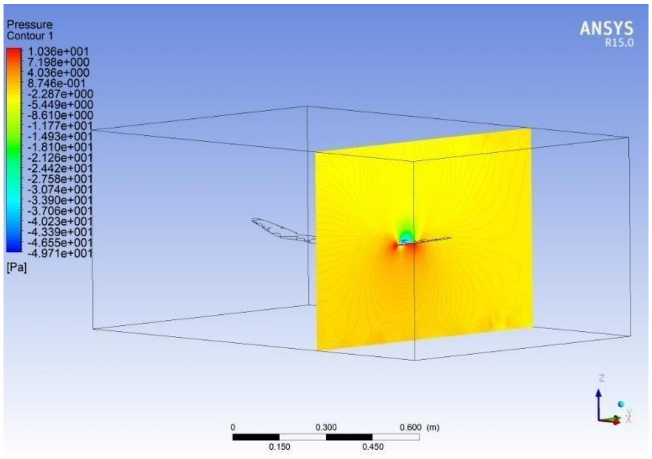

Figure 11: CFD ANALYSIS ON ISO WING

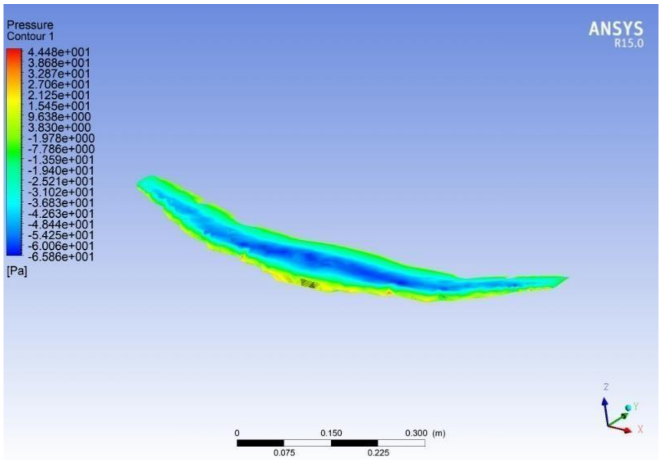

Figure 11: CFD ANALYSIS ON SOLID WING

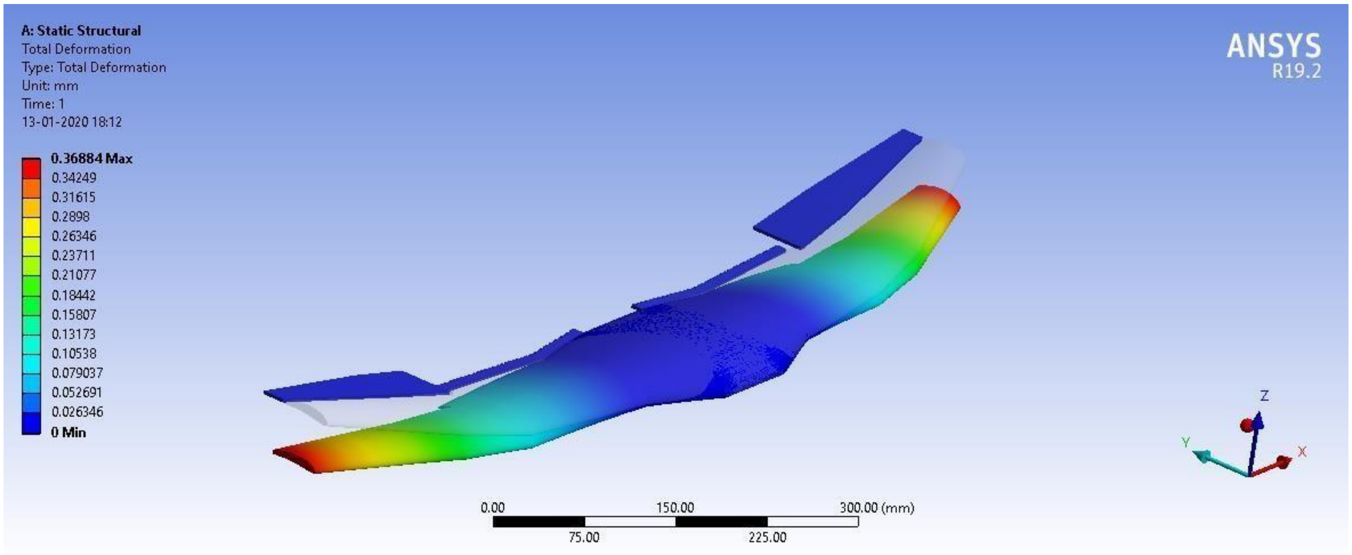

Figure 12: TOTAL DEFORMATION

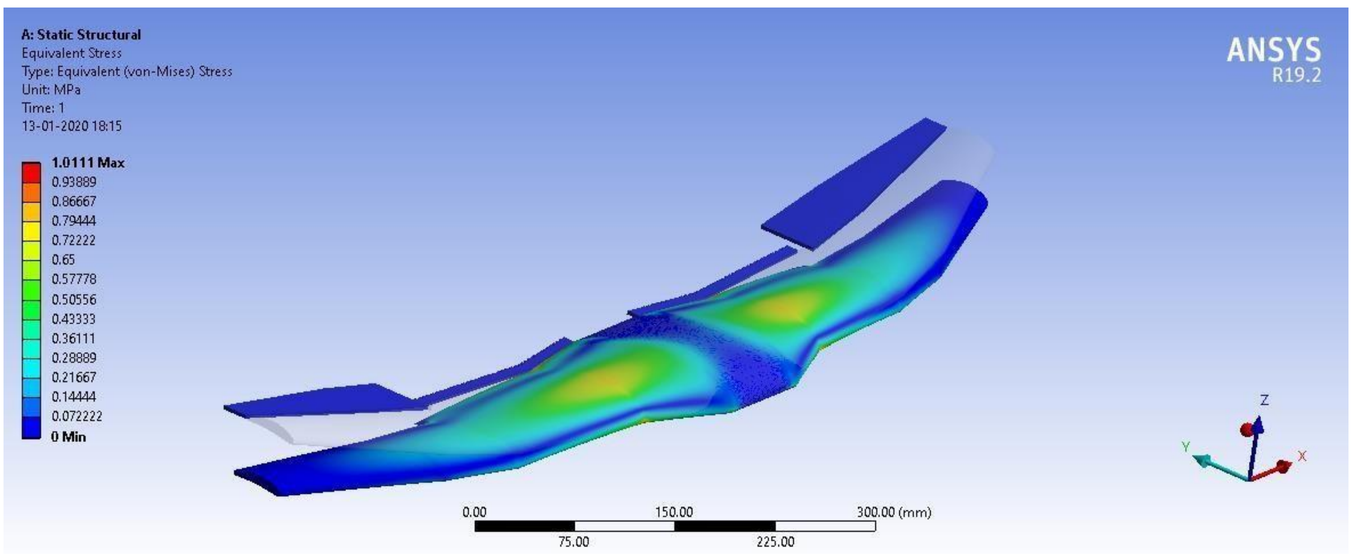

Figure 13: EQUIVALENT STRESS DISTRIBUTION

8.4. POWERPLANT ANALYSIS

Dynamic Thrust can be calculated using the empirical formula stated below.

$$T_{dynamic} = (-8.77 * 0.001 * V + 1) * T_{static}$$

Table 16: STATIC AND DYNAMIC THRUST ANALYSIS

	Throttle (%)	Static thrust(kg)	Voltage (V)	Dynamic Thrust (kg)
Brother Hobby Speed Shield 2207.5	50	0.800	12.3	0.791
	75	1.203	12.0	1.076
	100	1.606	11.4	1.445

9 FABRICATION TECHNIQUES

Figure 15: FABRICATION TECHNIQUES

Method	Application
Laser Cutting	Ribs, Motor Mount
3D printing	Motor Mounts, spars
Aluminium Brazing	Spars
Hot Wire Precision Cutting	Avionics Housing, Nose design

10 PERFORMANCE PREDICTION

Table 17: TAKEOFF, CRUISE & STALL VELOCITIES

Take-off Velocity	$V_{TO} = \frac{1.2}{0.7}\sqrt{\frac{2 \times W_{TO}}{\rho \times S \times C_{Lmax}}}$ **= 6.331 m/s**
Cruise	$W_{TO} = \frac{1}{2} \times \rho \times v^2 \times s \times C_L$ **V = 5.509 m/s**
Stall Velocity	$V_{stall} = \sqrt{\frac{2 \times \frac{W}{S}}{\rho \times C_{Lmax}}}$ **= 3.7 m/s**

V_{TO} – Take off Speed
W_{TO} – Take off weight
ρ – Density
S – Surface Area
C_{Lmax} – Max coefficient of lift
C_L – Coefficient of lift
V_{stall} – Stall Velocity
W/S – Wing Loading
v – Cruise Speed

11 FLIGHT TEST

Table 18: FLIGHT TEST DATA

#Flight	Objectives	Observations	Date
1	To test design feasibility and functionality	Design is working perfectly with appropriate stability and CG placement	02-01-2020
2	To sort out thrust requirement with twin boom setup	Over all thrust up to 3 kgs within design limits is achieved	05-01-2020
3	Estimating the payload fraction.	Achieved payload fraction of 0.65 and 0.67 with successful flying of a model.	07-01-2020
4	Design modification and optimization with selected materials and avionics.	Overall structural weight reduced and hence, model retains its structural integrity with increase in Payload Factor.	11-01-2020

12 DETAILED CAD DESIGN

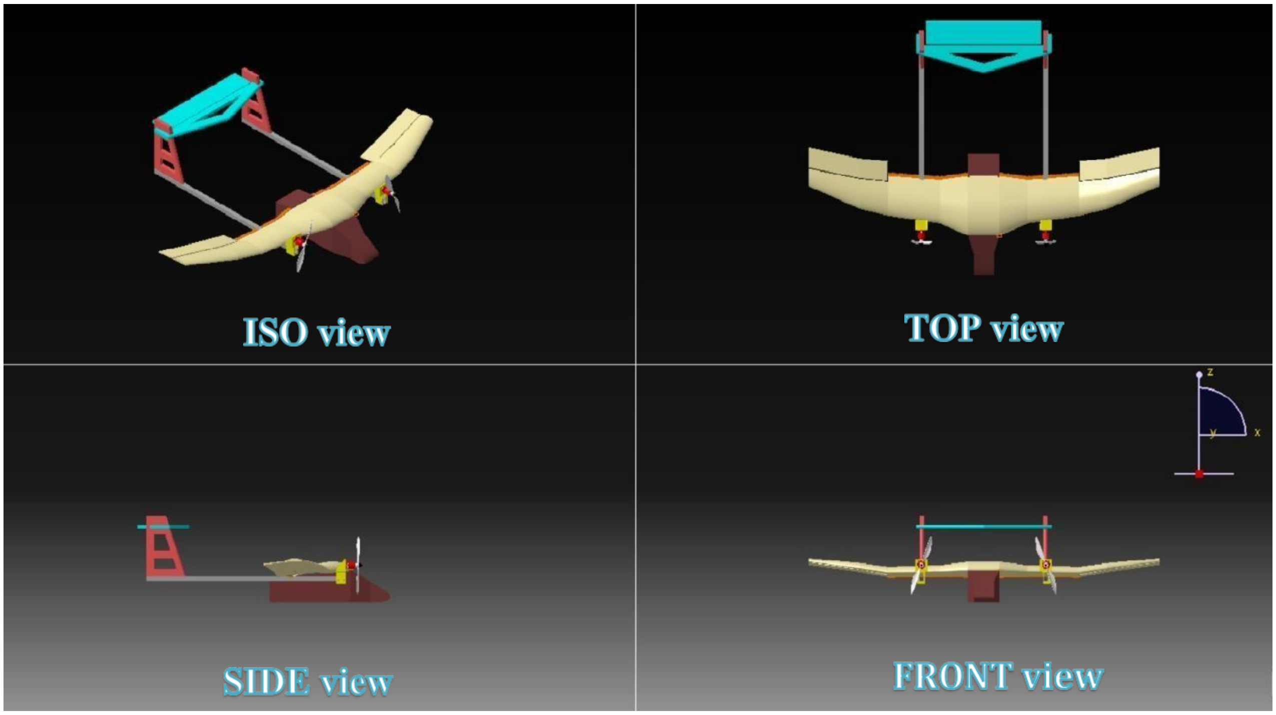

Figure 16: MULTI VIEW OF DETAILED DESIGN

13 UAV IN CONTAINER

The challenge is to fit the aircraft into the smallest form factor possible without damaging the components themselves. The aircraft model will be dismantled into an assembly box of dimensions 0.18m x 0.36m x 0.90m with the help of hinge mechanisms.

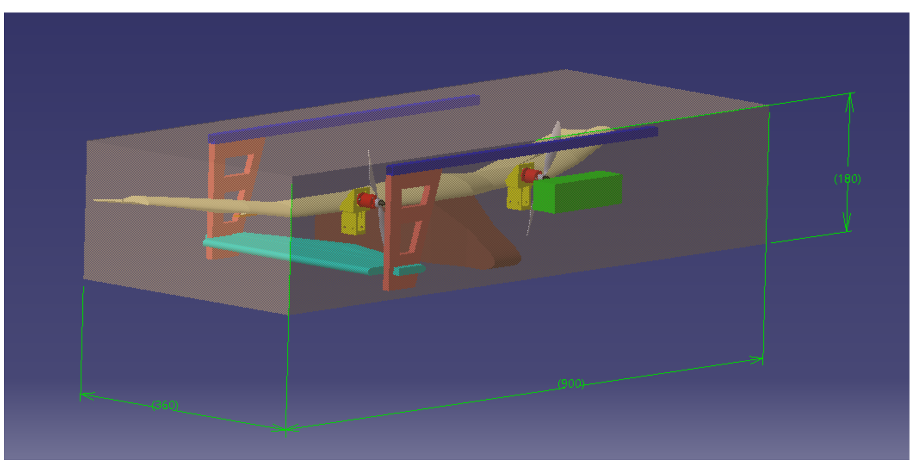

Figure 17: ISOMETRIC VIEW OF CONTAINER

14 REFERENCES

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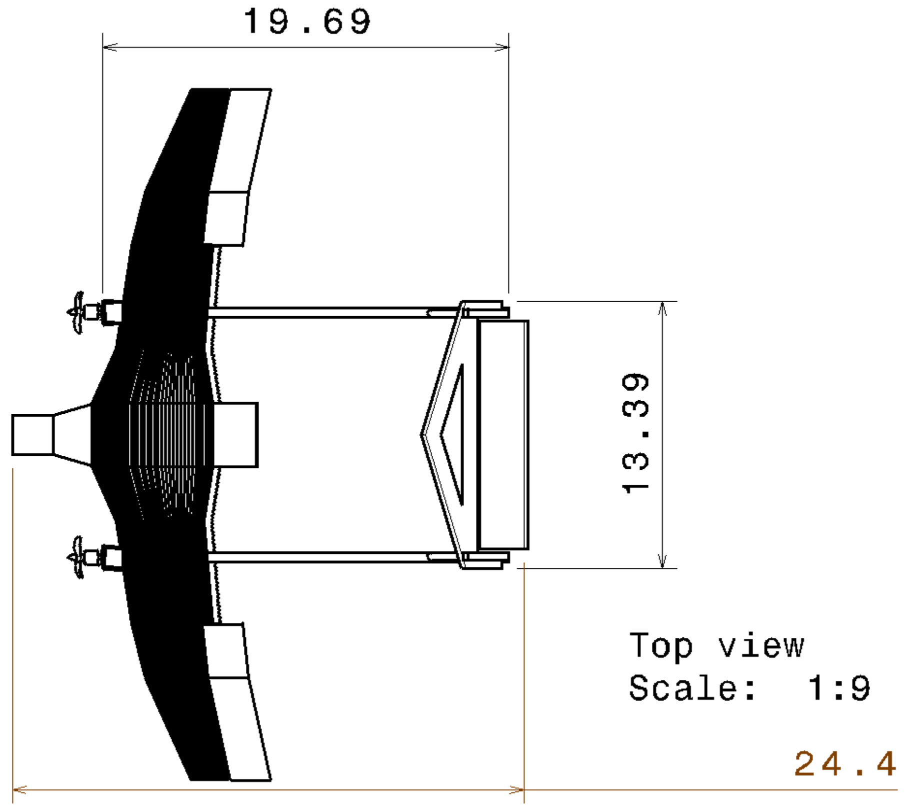
J Fluids Struct ;36: 136-148.

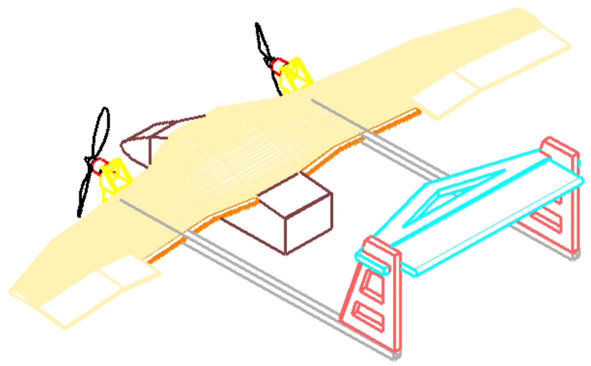
APPENDIX A : WEIGHT BUILDUP SHEET

S.No	Component	Weight (kg)
1.	**Motor Mount port**	0.014
2.	**Motor Mount Starboard**	0.014
3.	**Motor Port**	0.029
4.	**Motor Starboard**	0.029
5.	**Propeller - Port**	0.0068
6.	**Propeller - Starboard**	0.0068
7.	**Electronic Speed Controller**	0.018
8.	**Battery**	0.126
9.	**Payload**	1.650
10.	**Main Wing**	0.210
11.	**Aileron servo – Port**	0.009
12.	**Aileron servo – Starboard**	0.009
13.	**Horizontal Stabilizer**	0.0304
14.	**Elevator Servo**	0.009
15.	**Fin – Port**	0.015
16.	**Fin – Starboard**	0.015
17.	**Boom – Port**	0.050
18.	**Boom – Starboard**	0.050
19.	**Fuselage**	0.030
20.	**Red arming plug**	0.015
21.	**Avionics Housing**	0.014
22.	**Total**	2.35

APPENDIX B : 2D DRAWING SHEET



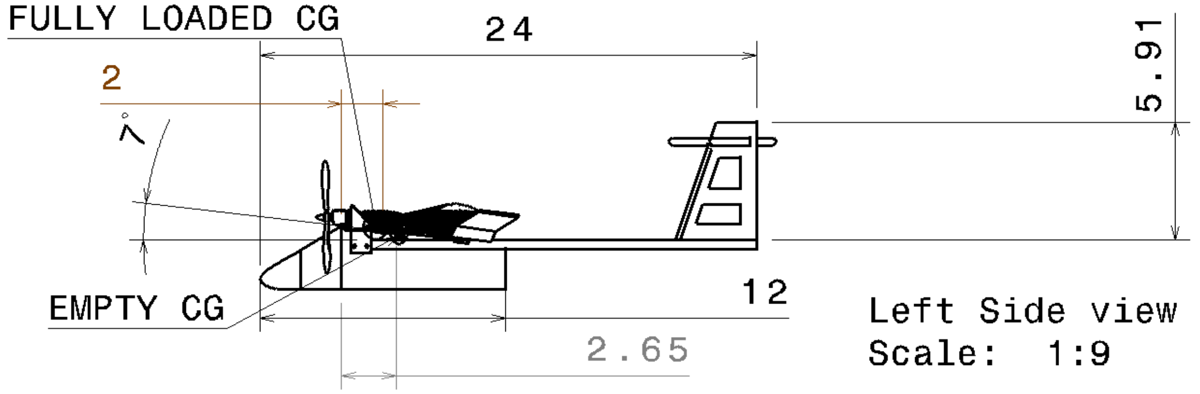
Top view
Scale: 1:9



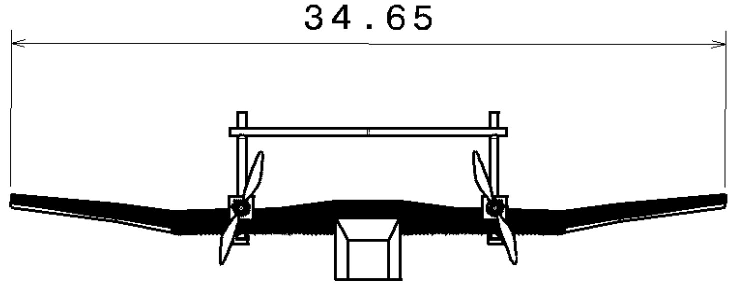
Isometric view
Scale: 1:9

WINGSPAN	CHORD	EMPTY WEIGHT	FULLY LOADED WEIGHT
34.65 inches	4.27 inches	0.700 kg	2.350 kg

LENGTH	WIDTH	HEIGHT
24.40 inches	34.65 inches	8.66 inches



Left Side view
Scale: 1:9



Front view
Scale: 1:9

ELEMENT	SPECIFICATION	WEIGHT(kg)	DISTANCE FROM DATUM(inches)	MOMENT (kg.inch)
MOTOR(s)	BH SS 2207.5(3400kV)	0.0586	0	0
BATTERY	MAXAMPS 1600mAh (3S)	0.126	-1.97	-0.24822
ESC(s)	TEKK032 F3 (65A)	0.0118	0	0
SERVO MOTOR(s)	TOWER PRO SG90	0.018	3.54	0.06372
PROPELLER(s)	6045(6*45)	0.008	-1.18	-0.00944
PAYLOAD	COPPER TITANIUM ALLOY	1.650	0	0

DATE: 14-01-2020
DIMENSIONS: Inches

IARE - LAKSHYA
ADC2020179

SIZE A3
SCALE 1:9
WEIGHT (kg) 2.350
DRAWING NUMBER MICRO CLASS
SHEET 1/1

I	_
H	_
G	_
F	_
E	_
D	_
C	_
B	_
A	_