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DEVELOPMENT OF FIXED WING VTOL UAV.

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Abstract: **Modern unmanned aerial vehicles have grown mature enough to be applied to countless applications. However, they have limitations based on flight ranges and manoeuvrability. Conventional fixed-wing UAVs can fly long distances, but they need runways or open spaces for takeoff. On the other hand, the most popular multi-rotor have extremely manoeuvrable characteristics, but their slower speeds and relative higher power consumption mean that they cannot be used for long-distance flights. VTOL UAVs have the manoeuvrability of Multi-Rotor UAVs while having the speed to cover greater distances. In this project, we propose a hybrid VTOL UAV with these advantages. There is a detailed discussion of the design methodologies and manufacturing process, followed by several flight tests to validate the concept. There is a challenge associated with fixed-wing UAVs, which often cannot operate effectively in confined airspace. As a result, UAVs are usually required to operate at low speeds and altitudes in an urban setting where runway usage is impossible. Fixed-wing VTOL is a promising trend that may help resolve this issue. During this project, we will present the design and calculations of a VTOL fixed-wing UAV using the Dual System or Extra Propulsion system for VTOL & In every aspect of VTOL UAV design, implementation, onboard equipment integration, and ground station support. Furthermore, with the appropriate controller, the VTOL UAV can achieve full autonomous in an outdoor environment.**

[1] *Keywords —Airfoil, Angle of attack, Aspect Ratio, Computational Fluid Dynamics, NACA, Fixed wing, UAV, VTOL*

I. INTRODUCTION

VTOL Fixed-Wing UAVs combine the benefits of multi-rotor platforms with fixed-wing drones and transition between the two modes during flight. The ability to vertically take off and land, without the need for a launcher or runway, means these drones can be operated in almost any location. Modern UAVs available on the market are mature enough to cover countless areas of application. UAVs have their limitations in terms of flight range and manoeuvrability. Conventional fixed-wing UAVs can fly long distances, but require runways or open spaces to take off. On the flip side, the most popular multi-rotor UAVs are extremely manoeuvrable, but cannot be used for long-haul flights due to their slower speeds and relatively higher power consumption. This project suggests the implementation of a hybrid VTOL UAV that has the manoeuvring advantage of a multi-rotor UAV, while they can travel fast to cover greater distances.

	Pros	Cons	Typical Uses
Multi-Rotor	Accessibility Ease of use VTOL & hover flight Good camera control Can operate in a confined area	Short flight time Small payload capacity	Aerial photography and Video Aerial Inspection
Fixed-Wing	Long Endurance Large area coverage Fast flight speed	Launch and recovery needs a lot of space No VTOL/ hover Harder to fly, more training needed Expensive	Aerial Mapping, Pipeline and Power line inspection

Table.1. Comparison between Multi rotor & fixed wing.

II. CONCEPTUAL DESIGN

Conceptual design is an early phase of the design process, in which the broad outlines of function and form of something are articulated.

During the conceptual design phase of a new aircraft, designers will evaluate a large number of different concepts, searching for the one that meets the requirements in the best way. This means that they need to iteratively cycle through sketching a concept, analyze it and evaluate and compare its performances.

Conceptual Design is a step-by-step process, we start with mission requirements as per requirement weight estimation is done for the mission. Weight estimation is an iterative process depending upon 'Geometric Constraints', 'Airfoil Selection and 'Performance parameter' once the configuration is selected, then the empirical estimation of stability and performance is done and based on that power plant selection is done.

A. Weight Estimation

Conceptual Design Calculations:

Sr no.	Item	Mass(g)	Quantity	Total Mass(g)
1	Payload	1000	1	1000
2	Battery	2500	1	2500
3	Motor	200	4	800
4	Motor	400	1	400
5	Frame Wt.	2800	1	2800
6	Avionics	500	1	500
			Total All up Weight	**8000**

Table.2. Weight Estimation.

Weight estimation is important because it is basic for mission requirements. Most of the item weights can be decided by doing a market survey, like for payload, battery, avionics and motor whereas for frame weight it is an assumption. After weight estimation, we can move to the next step which is airfoil selection now we know the weight so we need an airfoil which can produce enough weight as a wing.

B. Airfoil Selection

For the selection of airfoil first, we have to decide the cruise velocity after deciding velocity then we calculate the Reynolds number to get airfoil data so for this we decided on a range of velocity which is 15 m/s to 30 m/s after calculating these velocities we get a range of Reynolds number which is shown below.

The Reynolds number is calculated from:

$$Re = \frac{\rho v l}{\mu} = \frac{v l}{\vartheta}$$

Where:

v = velocity of the fluid
l = The characteristics length, the chord width of an airfoil
ρ = The density of the fluid
μ = The dynamic viscosity of the fluid
ϑ = The Kinematic viscosity of the fluid

Reynolds Number range at 120 m altitude for velocity 15m/s & 30 m/s is 300,000 to 600,000.
Now after getting the range of Reynolds number, we have to choose some good lift generating airfoils.
We had 4 options for the airfoil

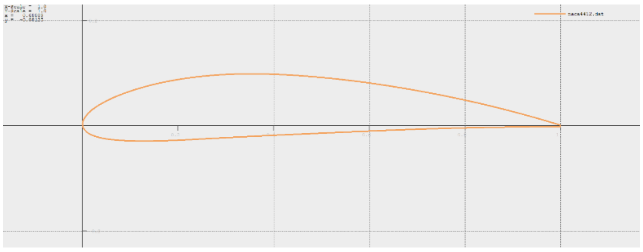


Fig.1. NACA 4415

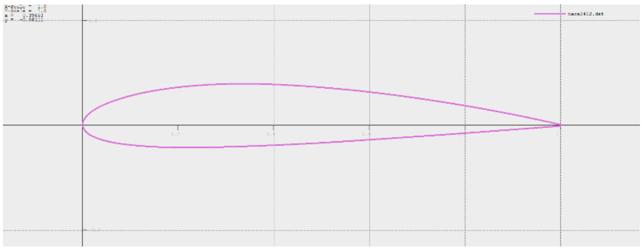


Fig.2. NACA 2412

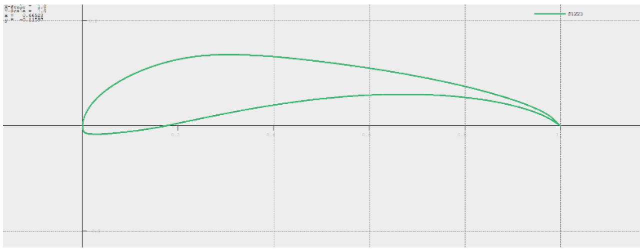


Fig.3. S1223

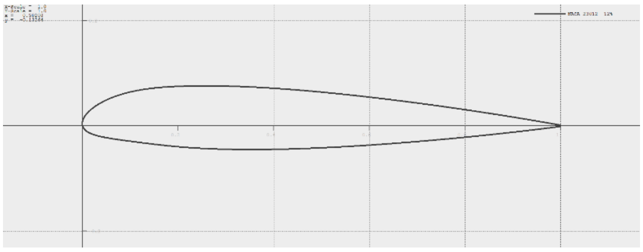


Fig.4. NACA 23012

All the above airfoils have good performance in the selected range of Reynolds number but comparing them together in XFLR-5.

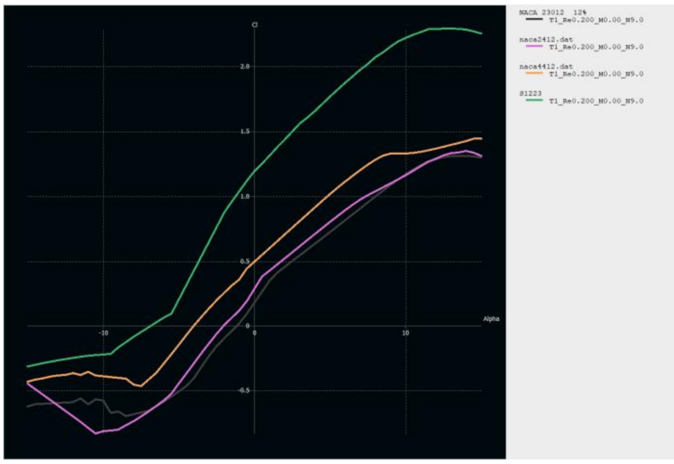


Fig.5.C_L vs alpha graph

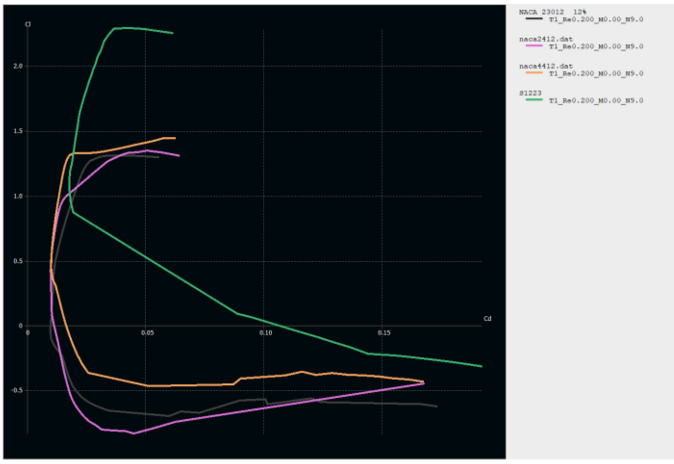


Fig.6.C_L vs C_D graph

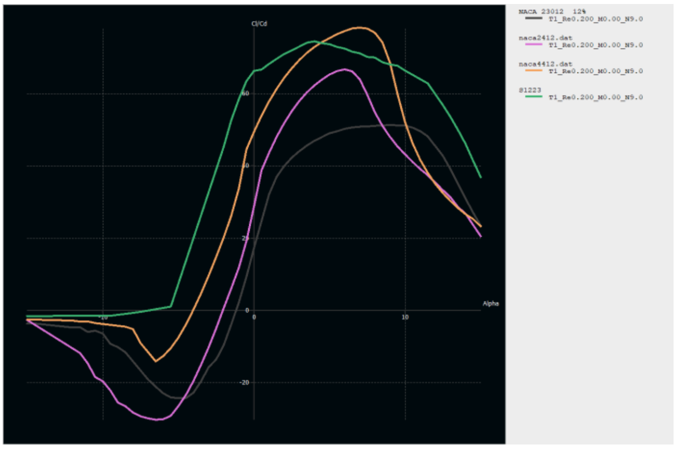


Fig.7.C_L/ C_D vs alpha graph

Hence, from the above graph, we can say that NACA 4412 fits the requirement.

So, we choose NACA 4415 to work on. The main reason for choosing this airfoil is the same lift as NACA 4412 but more thickness so it is beneficial for spar attachment due to more thickness our spar will be greater so it will give more reinforcement and support.

C. Calculations

MTOW = 8 Kg, V = 16.66 m/s, $\rho = 1.225\ kg/m^3$, $C_l = 0.8$

$$L = W = \frac{1}{2} * \rho * v^2 * C_l$$

$$8 * 9.81 = \frac{1}{2} * 1.225 * 16.66 * 16.66 * S * 0.8$$

S = 0.58m^2

Choosing AR = 9

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

$$9 = \frac{b^2}{0.58}$$

b = 2.28 m

$$S = b * c \Rightarrow 0.58 = 2.28 * c$$

c = 0.25 m

$$S = \frac{b}{2} * C_R * (1 + \lambda) \Longrightarrow 0.58 = \frac{2.28}{2} * C_R * (1 + 0.75)$$

$$C_R = 0.29\ m$$

$$C_T = \lambda * C_R = 0.75 * 0.29$$

$$C_T = 0.22\ m$$

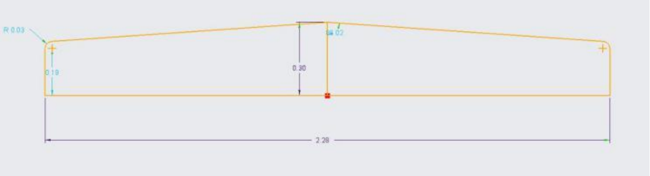


Fig.8. 2D Sketch of Wing

Tail Sizing by Volume Method

$V_{HT} = 0.50 \quad V_{VT} = 0.04$

$$V_{HT} = \frac{l_{HT} \times S_{HT}}{S_W \times C_W} \qquad V_{VT} = \frac{l_{VT} \times S_{VT}}{S_W \times b_W}$$

$Taking\ l_{VT}\ same\ as\ l_{HT}$

$$0.5 = \frac{1 \times S_{HT}}{0.58 \times 0.25} \qquad 0.04 = \frac{1 \times S_{VT}}{0.58 \times 2.28}$$

$$S_{HT} = 0.0725\ m^2 \qquad S_{VT} = 0.0528\ m^2$$

we are taking a V tail in this design so because of that we are adding both the vertical and horizontal tail areas to get desired surface area.

$$S_T = S_{HT} + S_{VT} = 0.0725 + 0.0528 = 0.1253\ m^2$$

$$\frac{S_T}{2} = \frac{0.1253}{2} = 0.0626\ m^2\ each\ side$$

Choosing AR for tail = 4

$$AR = \frac{b^2}{S} \Longrightarrow 4 = \frac{b^2}{0.0626}$$

b = 0.5 m

$$S = \frac{b}{2} * C_R * \left(\frac{(1+\lambda+\lambda^2)}{1+\lambda}\right) \Rightarrow 0.0626 = \frac{0.5}{2} * C_R * \left(\frac{(1+0.75+0.75^2)}{1+0.75}\right)$$

$$S = \frac{b}{2} * C_R * \left(\frac{(1+\lambda+\lambda^2)}{1+\lambda}\right) \Rightarrow 0.0626 = \frac{0.5}{2} * C_R * \left(\frac{(1+0.75+0.75^2)}{1+0.75}\right)$$

$$C_R = 0.19\ m \qquad C_T = \lambda * C_R = 0.15\ m$$

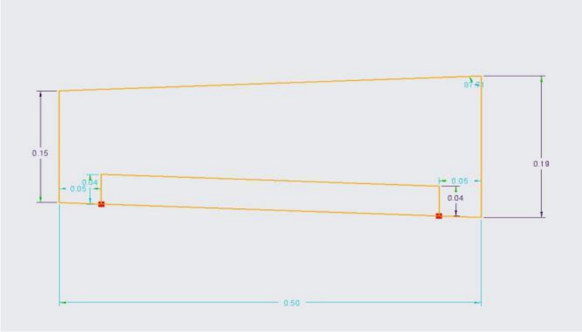


Fig.9. Tail semi span.

For V tail angle calculation

$$\frac{S_{VT}}{S_{HT}} = 0.73$$

$$\tan(x) = \sqrt{0.73}$$

$$X = 40.51^o$$

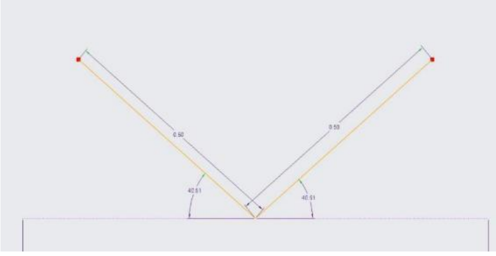


Fig.10.V-tail angle between 2 tail span.

III. PRELIMINARY DESIGN

Sr no	Parameters	Value
1	VTOL T/W Ratio	2.0
2	FF T/W Ratio	0.5
3	Wingspan	2.28 m
4	Mean Chord Length	0.25 m
5	Root Chord	0.29 m
6	Tip Chord	0.22 m
7	Taper Ratio	0.75
8	Cruise velocity	16.66 m/s
9	Wing Surface Area	$0.58\ m^2$
10	Maximum Takeoff weight	8 Kg
11	Horizontal tail area	$0.0725\ m^2$
12	Vertical tail area	0.0626
13	V- tail Angle	40.51^o
14	HT volume coefficient	0.50
15	VT volume coefficient	0.04

Table.3. Finalized Parameters for analysis

Designing the wing on XFLR-5 to get the coefficient of lift and coefficient of drag, to know whether the values will be efficient or not. The value of C_L we got from XFLR-5 is around 0.66 at 2.5 AOA.

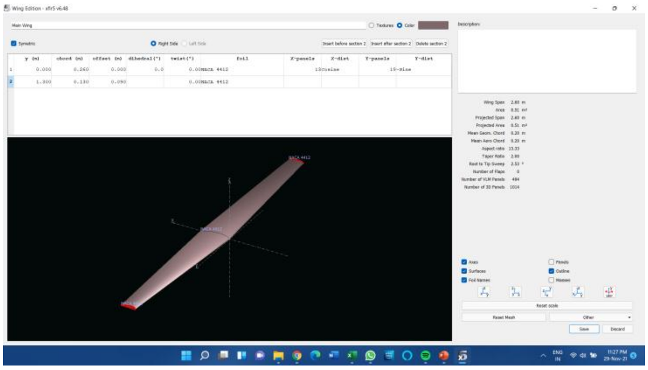


Fig.11.Wing Analysis in XFLR-5.

To validate this result, we also did a CFD analysis on Fluent. For CFD analysis in fluent, we start with designing the wing and then an enclosure around the wing, the dimension of the enclosure is 2.5b in front and 5b behind.

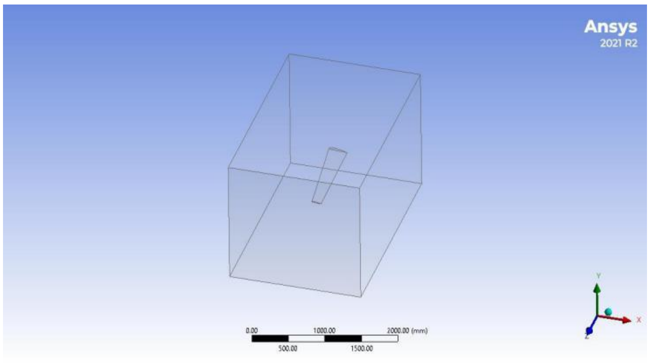


Fig.12.Wing Geometry in Design Modeller.

Moving towards meshing, element size of 50 mm. the orthogonal quality around minimum 1.39e-2 and maximum 0.9915. The total element count is around0.78 million.

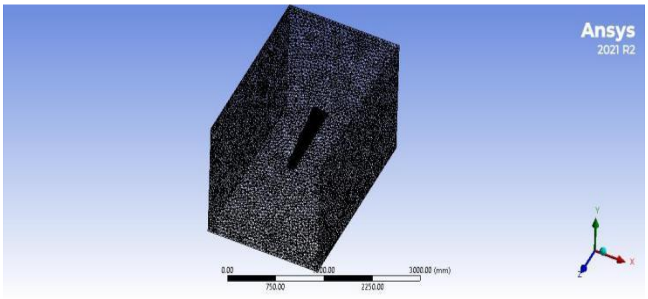
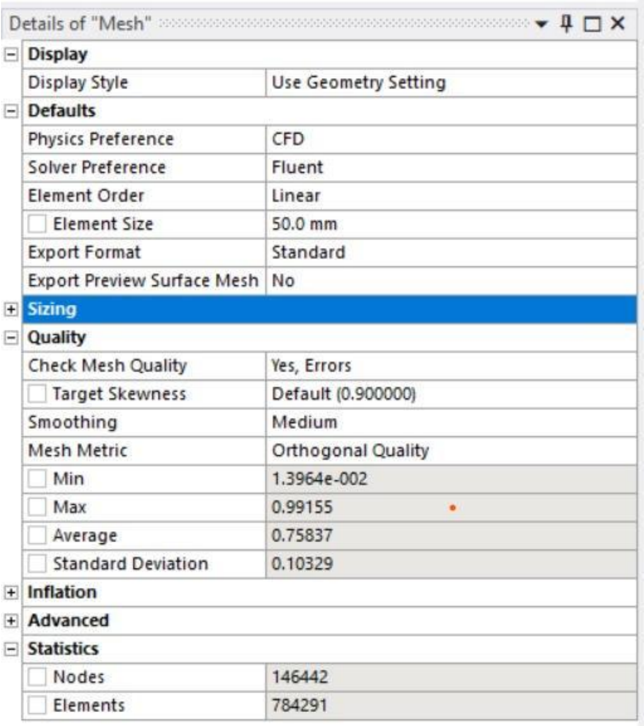


Fig.13.Meshing of Wing in Ansys.



Details of "Mesh"

⊟ **Display**	
Display Style	Use Geometry Setting
⊟ **Defaults**	
Physics Preference	CFD
Solver Preference	Fluent
Element Order	Linear
☐ Element Size	50.0 mm
Export Format	Standard
Export Preview Surface Mesh	No
⊞ **Sizing**	
⊟ **Quality**	
Check Mesh Quality	Yes, Errors
☐ Target Skewness	Default (0.900000)
Smoothing	Medium
Mesh Metric	Orthogonal Quality
☐ Min	1.3964e-002
☐ Max	0.99155
☐ Average	0.75837
☐ Standard Deviation	0.10329
⊞ **Inflation**	
⊞ **Advanced**	
⊟ **Statistics**	
☐ Nodes	146442
☐ Elements	784291

Table.4.Details of Mesh.

The Numerical setup for simulation was the K-epsilon turbulence model. The velocity was 16.667 m/s and the operating pressure of 101325 Pa. The P-V coupling was selected to be SIMPLE with the second order. The simulation was around for 800 iterations. For results, pressure contour was observed on the wing and velocity contour around the wing and coefficient of lift graph.

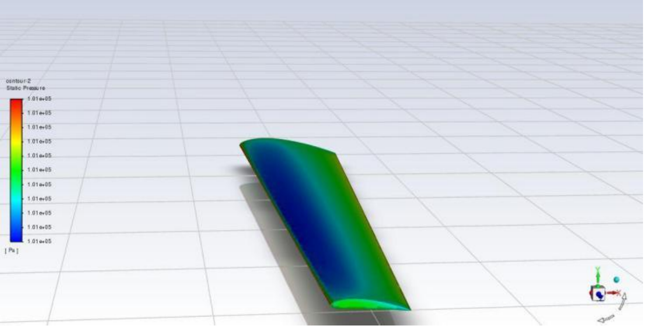


Fig.14 Pressure Contours.

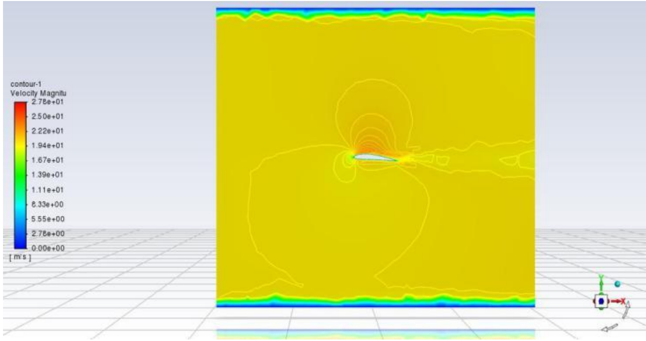


Fig.15. Velocity Contours

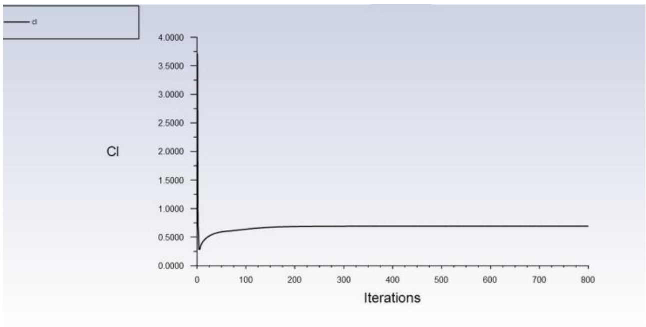


Fig.16. Coefficient of Lift Graph

The value of the coefficient of lift we got from CFD analysis was 0.60, which has around a 6% error with respect to the XFLR-5 result. Hence, we can say our result is validated.

Fig.17. Fuselage Side View.

After the results for the coefficient of lift are validated. We can move towards designing the model on Solidworks software.

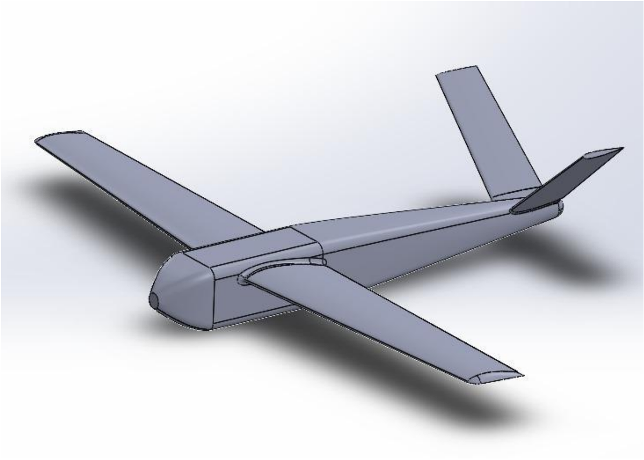


Fig.18. Final Fixed Wing CAD Model.

IV. DETAIL DESIGN

Here, making the model more streamlined and efficient is the goal and adding the booms for VTOL motors. After the CAD Modelling, we move towards CFD analysis.

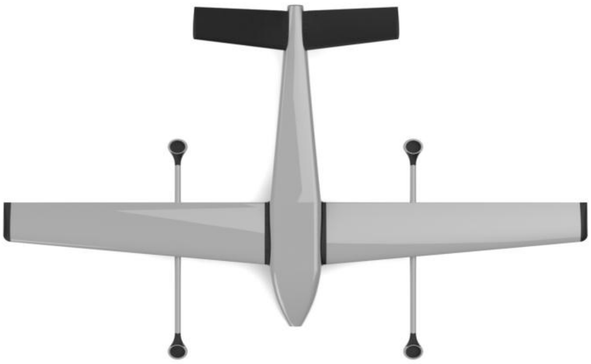


Fig.19. Fixed-wing VTOL Top View

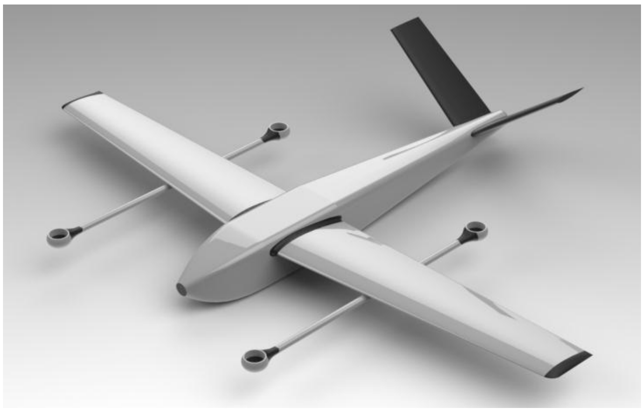


Fig.20. Fixed-Wing VTOL Isometric View.

The domain for the model was 5b in front 10b behind the model and 10b around. After the enclosure is ready, we start with the meshing of the whole model. We start with the surface mesh for the UAV and then the volume mesh of the enclosure domain. The mesh quality for mesh was Min 8.71e-3 Max 0.999. The skewness was contained under 0.95, and the growth rate was 1.2 to ensure smooth transition.

Solver setup on fluent

General	
Solver	Pressure-Based
Time	Steady
Energy Equations	Off
Model	Spalart-Allmaras
Curvature Correction	On

Table.5

Method Solution	
P-V Coupling	SIMPLE
Pseudo-Transient	Off
Warped Face Gradient Correction	Off
High Order Term Relaxation	Off

Table.6.

For results, pressure contour was observed on the UAV and velocity contour around the UAV and coefficient of lift graph.

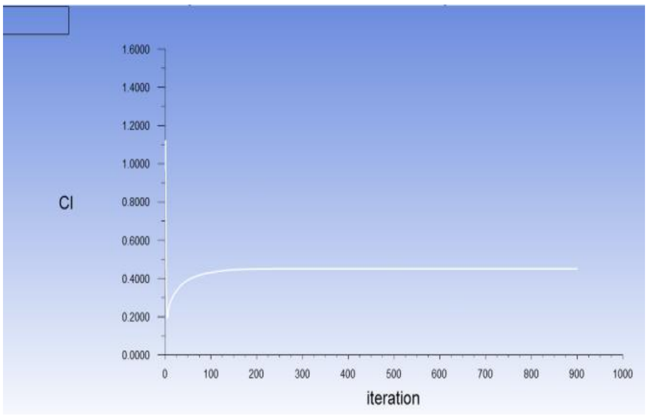


Fig.21. Coefficient of Lift Graph

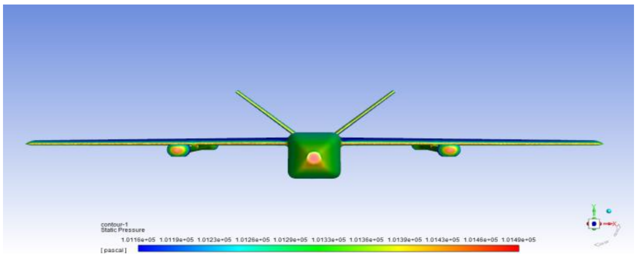


Fig.22. Pressure Contour

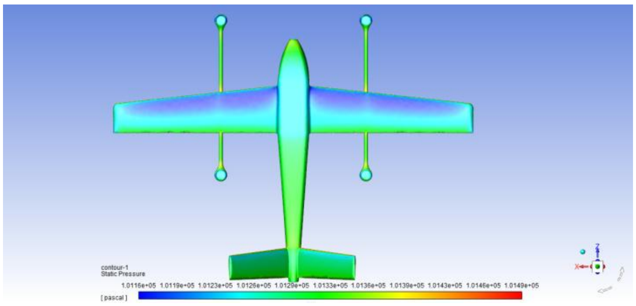


Fig.23. Pressure Contour top view

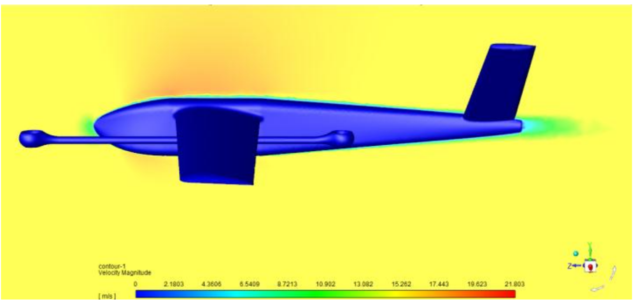


Fig.24. Pressure Contour Side view.

V. CONCLUSION

Here we can conclude that using this methodology, we designed fixed wing VTOL UAV and further analyzing we got appreciative values for coeffient of lift and pressure contour suggesting the methodology was correct and simple to use. By modifying the needs accordingly, we can move forward for its prototyping and after a successful flight test of the prototype we are good to go for the final product manufacturing process.

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