DESIGN AND FABRICATION OF ELECTRIC VERTICAL TAKEOFF AND LANDING

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Abstract - In response to the request for proposal we present the prototype Electrical Vertical Take-off and Landing aircraft (E-VTOLA). This report is the work of four students who are in final year under graduate in aeronautical engineering at Dayananda Sagar College of Engineering Bangalore. The report starts with an analysis of the E-VTOL aircraft market and a presentation of the design methodology. Then, the possible configurations are discussed. The core of the report presents the design cargo space of the aircraft. The performance is also studied into details. The design methodology and fabrication method are discussed extensively which will be followed by a number of flight tests to prove the concept. The proposed EVTOL will be equipped with electric motors and a horizontal thrust motor for vertical and horizontal flight modes respectively.

Key Words**:** aerodynamics, analysis, vertical take-off, speed controller, fluent flow

1. INTRODUCTION

There is an increasing demand for inter-city air travel, to avoid delay due to congestion on the surface mode of operation mode of transportation. To ensure environment friendly operations with lower carbon footprint, electrical propulsion system is recommended for such aircraft. It is desired that these air taxi aircraft should be able to operate with least possible ground support infrastructure. Hence, there is a need for an air taxi aircraft which can operate safely, while maintaining separation from airborne and ground-based obstacles.

1.1 VTOL

VTOL is not a new concept in aviation. There already exist several aircraft relying on different kinds of methods of achieving VTOL. The most well-known aircraft to make use of VTOL is the helicopter, which uses its main rotor on its roof to push a downwards facing airstream, resulting in vertical lift-giving thrust. This makes it a lot more versatile than a conventional airplane due to not needing a runway to take off from.

1.2 EVTOL

E-VTOL (electric vertical takeoff and landing) is a type of aircraft that uses electric power to hover, takeoff, and land vertically.

2. METHODOLOGY

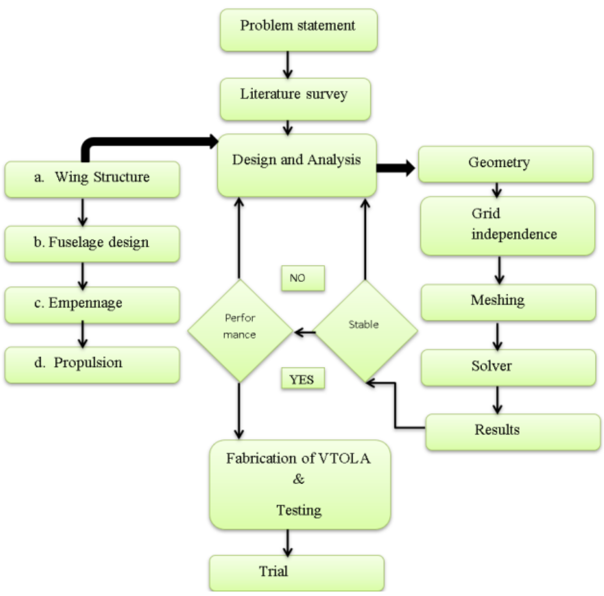

Fig -1: Methodology flowchart

3. DESIGN AND ANALYSIS

3.1 AIRFOIL SELECTION

The selection of the airfoil is done by the XFLR5 software and as well as in the airfoil tool also. Before the selection we studied the journal papers and we selected some the airfoils which they are used in their project and we chose the best among them. The three airfoil is selected to the comparison and they are: NACA 64(3)-418, NACA 6412, NACA 2412The different aerodynamic parameters which are studied at zero lift angle of attack (α^0), the maximum lift coefficient (Cl_{max}) as well as the corresponding angle of attack (α^0 max), the minimum drags coefficient (Cd_{min}), the corresponding lift coefficient (C_{ldmin}) and finally the maximum lift-to-drag ratio. The analysis results to the selection of the NACA 6412 airfoil. During the comparison of the airfoil with the variation of the Reynold's number between the min. of 50,000 to max. Of 1,00,000. The below figure shows the lift coefficients at different angle of attack and in this we see here the max lift coefficient is producing by the NACA 6412 in the yellow in the color as shown in fig 2.

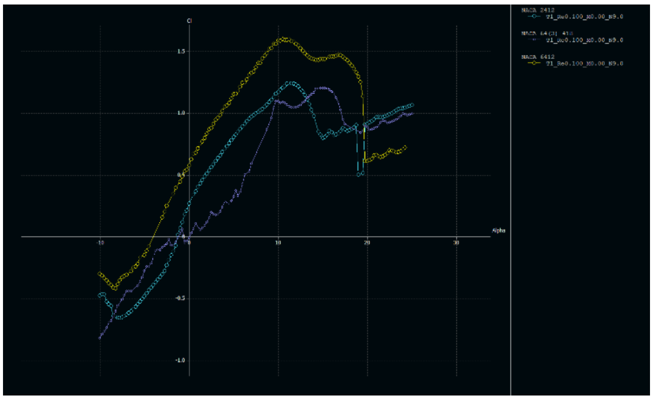

Fig.-2: Cl vs α

The below plot will represent the coefficient of drag at different angle of attack in XFLR5 and airfoil tool also. Here we can see the minimum drag produced by the airfoils.

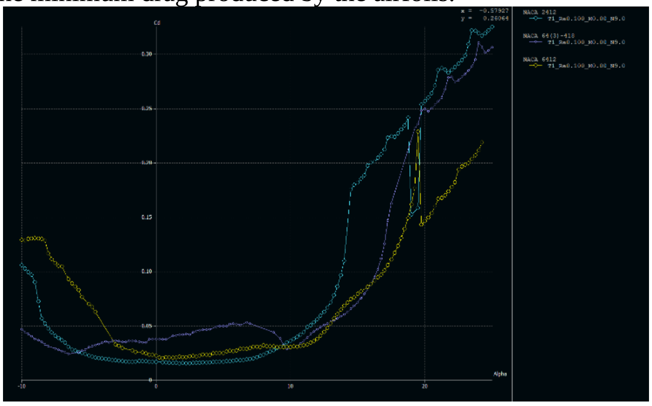

Fig -3: Cd vs α

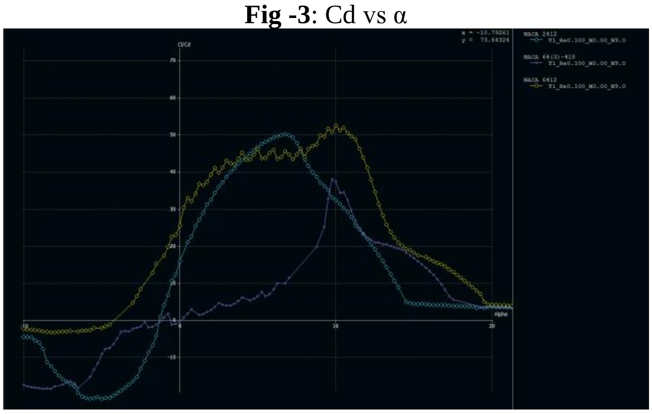

Fig -4: Cl Cd vs α

3.2 ANALYSIS OF AIRFOIL

To clarify the results, obtain by the XFLR5 to the airfoil naca6412, we once again analyzed the airfoil using the ANSYS Workbench 18.1 version. The Reynold's number range is between the 50,000-1,00,000. From there we obtain the lift and drag coefficient at different velocities and at the different angle of attack.

In ANSYS part the given geometry is meshed with structured one and flow analysis the results are carried out. The parameters for the analysis of the airfoil are,

Angle of Attack (AOA): -50,00,50,100,150

Reynold's number range:1,00,000

The Reynolds number was taken minimum and based on the following parameters:

The expression for Reynold's Number is given by:

$$Re = \frac{\rho * V * d}{\mu} = \frac{Vd}{\upsilon}$$

Where,

υ = kinematic viscosity

V=Velocity

d = chord width of airfoil

μ = Dynamic Viscosity

i. For minimum,

Chord width=0.1 m

Velocity = 35 m/s

Kinematic Viscosity = 1.5111 × 10 -5 m2 /s

35×0.1÷1.5111×10 -5 = 231619.3501

ii. For Middle Range,

Chord width = 0.1 m

Velocity = 55 m/s

Kinematic Viscosity = 1.5111 × 10-5 m2 /s

55×0.1÷1.5111×10 -5 = 363973.2645

iii. For maximum,

Chord width = 0.1 m

Velocity = 75 m/s

Kinematic Viscosity = 1.5111× 10 -5 m2 /s

75×0.1÷1.5111×10 -5 = 496327.1789

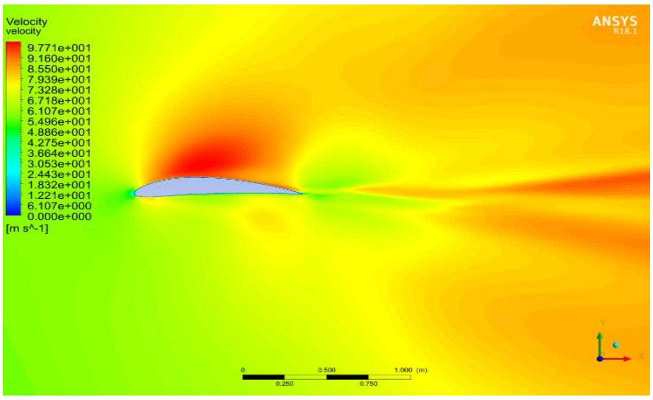

Fig -5: Velocity contour at 35m/s

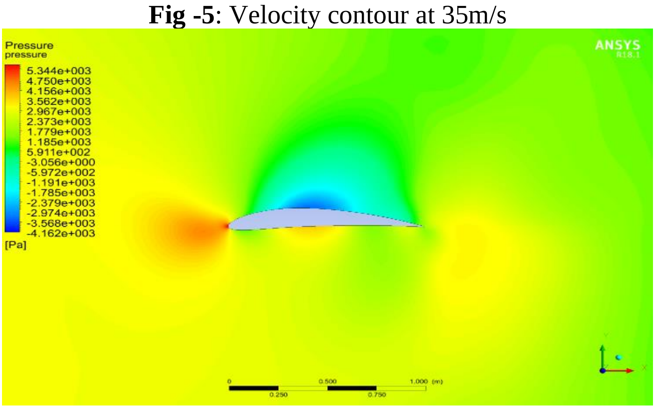

Fig -6: Pressure contour at 35m/s

The results from the analysis are plotted using excel sheet.

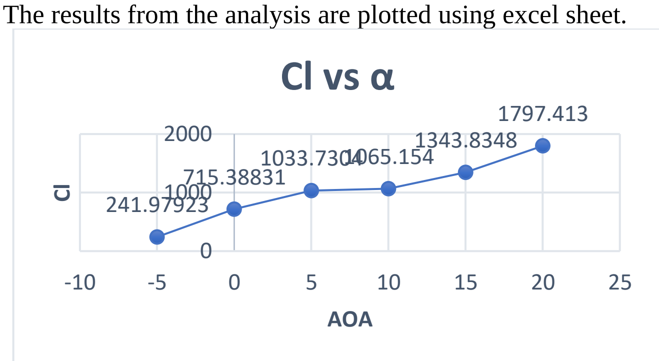

Fig-7: C_l vs α at 35m/s

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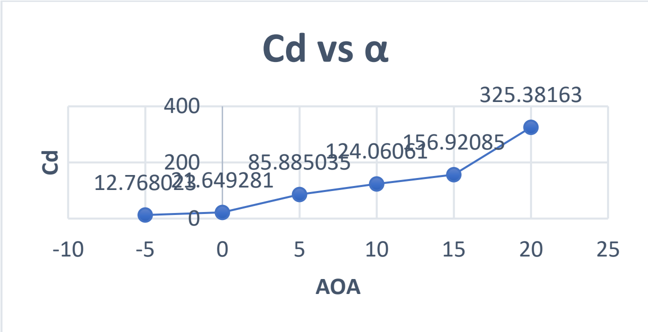

Fig-8: C_d vs α at 35m/s

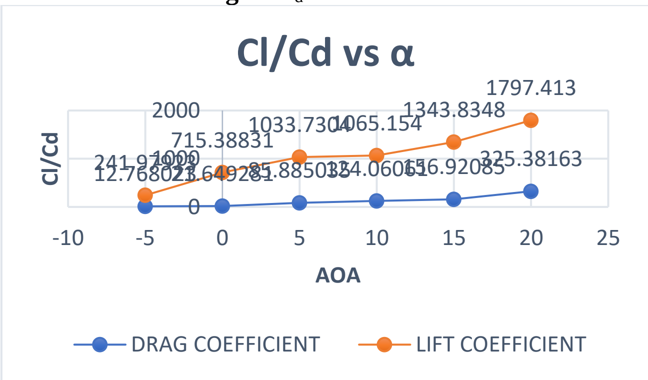

Fig-9: C_l/C_d vs α at 35m/s

Table-1: Various aerodynamic characteristics at different angle of attack for NACA 6412 at velocity 35m/s

AOA	VELOCITY	DRAG COEFFICIENT	DRAG FORCE	LIFT COEFFICIENT	LIFT FORCE
-5	35	12.76802	7.82041	241.9792	148.212
0	35	21.64928	13.2601	715.3883	438.175
5	35	85.88504	52.6045	1033.73	633.159
10	35	124.0606	75.9871	1065.154	652.406
15	35	156.9209	96.1140	1343.835	823.098
20	35	325.3816	199.296	1797.413	1100.91

From these the velocity parameter we see the variation of the lift and drag coefficients and the forces acting on it. The airfoil NACA 6412 having the max thickness of 12% at 30.1% of chord and max camber 6% at the 39.6% of the chord.

3.3 MODEL DESIGN

The high wing configuration method is used to build the VTOL aircraft due to the minimum separation between the ground and the propeller. Each part of an aircraft was evaluated and analyzed using the computational tools which available in ANSYS software. The rectangular wing plan form, a boom tail with fuselage having the streamlined aerodynamic shape. The complete design was made to reduce the gross weight, total drag and to take off and land vertically. The designing of the model is completed using CatiaV5.
The isometric view of the designed model VTOL we can see in the fig 10.

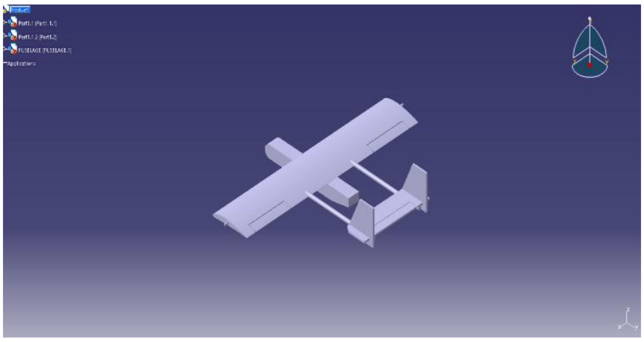

Fig-10: Isometric view of VTOL

3.3.1 Fuselage Design

Fuselage design was done by keeping in mind the better aerodynamic shape to get the least drag. The wing is placed at the aft of the fuselage top and the boom type tail section is chosen. In the cg point the fuselage holds compartment to the electronic bye to secure the electric equipment's.

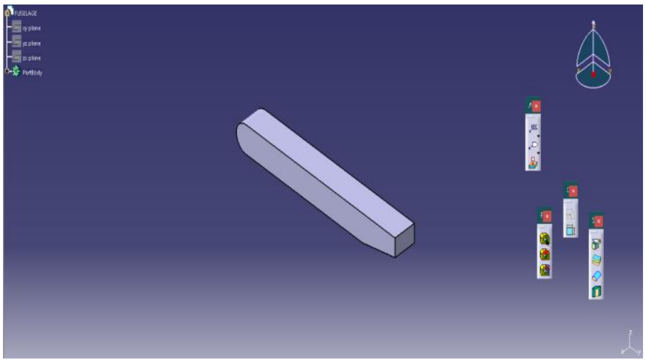

Fig-11: Isometric view of the fuselage

3.3.2 Wing design

After deciding the wing plan form, different combination of spans and chords were analyzed in ANSYSY CFX to see the drag and lift produced by each design. The wing span was fixed to 1350mm and the chord is fixed to 45mm. From ANSYS software we found that the airfoil is producing the max lift coefficient at the zero angle of attack. So, we keep the same angle of incidence means is maintained to wing to fuselage. One carbon fiber circular rod has passed through CG of complete aircraft to fix gear system and motors on it. The complete wing design is shown below.

Table-2: Wing specification

Specification	Values
Area	270000
MAC distance	337.5
MAC length	200
Aspect ratio	6.75
Sweep1	1
Sweep2	45
CG 1	40.5
CG2	62.5
Lift	65.4352N
Drag	8.56553N
Angle of incidence	0

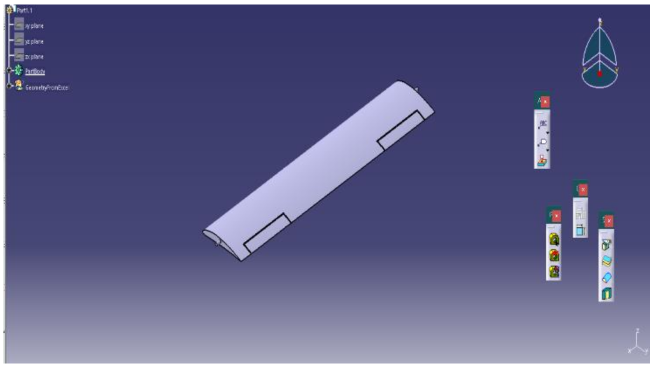

Fig -12: Solid wing design

3.3.3 Empennage design

The twin boom tail design is selected for the VTOLA because in loading and unloading of the aircraft will be easier due to cargo door is placed at the aft of the fuselage. In case of the conventional aircraft the nose part has the cargo, door some are in side doors due to this the area will consume more and opening and closing of the door will take more space.

Table- 3: Specification of the empennage

Parameters	Values
Horizontal stabilizer span	380mm
Horizontal stabilizer chord	140mm
Horizontal stabilizer taper ratio	1
Horizontal stabilizer plan form	Rectangular
Vertical stabilizer height	170
Vertical stabilizer root chord	140
Vertical stabilizer tip chord	60
Vertical stabilizer taper ratio	0.4285
Vertical stabilizer plan form	Tapered

3.4 ANALYSIS OF VTOL

The designed VTOLA was analyzed in ANSYS fluent to see the pressure contours variation on overall the body. The analysis was done at the velocity of 45m/s. A uniform enclosure domain was generated of 1.5*1*1m. The mesh generated was 'fine and unstructured mesh' with the element size of 5mm as shown in the following figure respectively. The relevance was set to 100 and the mesh was done on proximity and curvature. From the analysis coefficients of lift and drag are obtained 93.7123N and 10.7522N and L/D of the complete design as 8.7156. This L/D shows the performance of an aircraft.

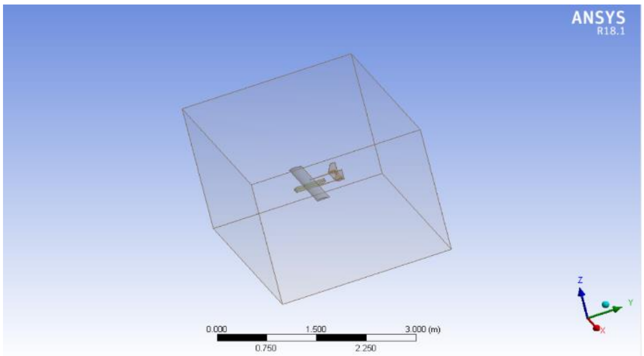

Fig- 13: Model with domain enclosure

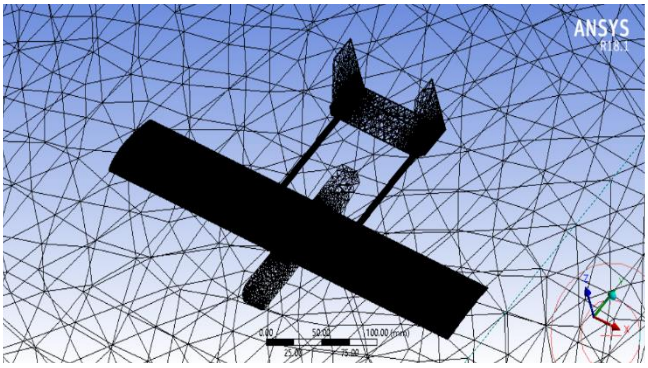

Fig- 14: Complete fine and unstructured mesh

Table- 4: Boundary conditions

Parameters	Type
Inlet	Velocity
Outlet	Pressure
VTOLA	Wall
Wall	Wall
Material	Fluid/ air
Time	Steady
Solution initialization	Standard
Nodes	31005
Elements	1357673

The pressure contours of the model are shown in the figure. In this picture the pressure at the leading edge is more and smooth over the upper surface of the body. At nose of the fuselage the maximum pressure is obtained around 38.5Pa at the air velocity of 25m/s. And we see the streamlines over the VTOLA in the figure 16.

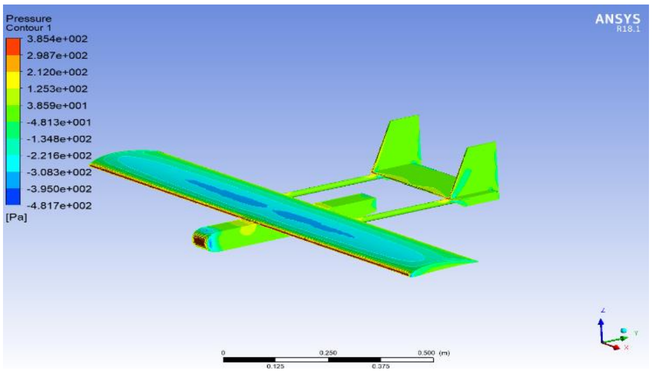

Fig- 15: Pressure contours over the VTOLA

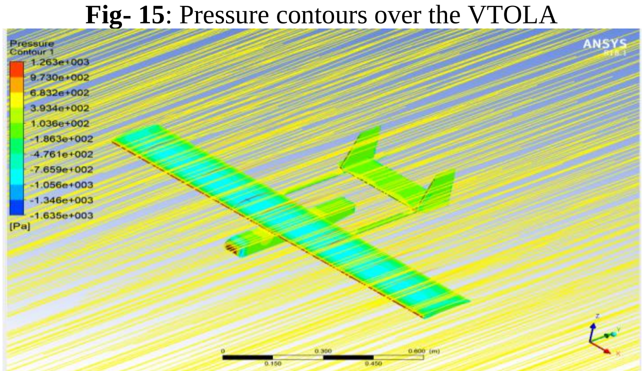

Fig- 16: Streamlines over the VTOLA

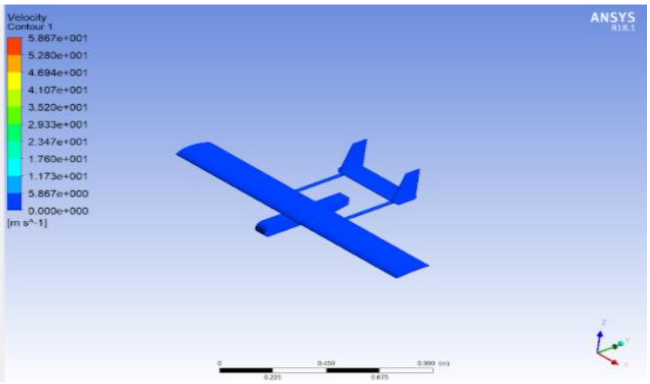

Fig- 17: Velocity contours over the VTOLA

The velocity contours are seeming like the same overall the due to the constant velocity is given to the model.

3.5 STRUCTURAL ANALYSIS OF WING

The designed rib structured wing is built in CATIAV4. The wing consists of total 16 ribs with one circular carbon fiber rod and two I-section of 10*3mm acting as spars for the wing. This carbon fiber is passed through the CG of the wing. The spacing between ribs is less at root and is gradually is increased towards the tip of the wing in the way the carbon fiber extended till the tip of the wing. The bending moment of a cantilever bean is maximum at the fixed end. Due to the bending moment is more at the root the ribs are added in that area.

The 'fine and unstructured mesh' is applied at 100 relevance and the mesh was done on proximity and curvature. For all the ribs balsa or white pine material is used to construct the ribs and spars of the wing structure and the complete structured model design done in CATIAV5 and analysis part was done using static structural in the ANSYS. The below figure shows the wing structure.

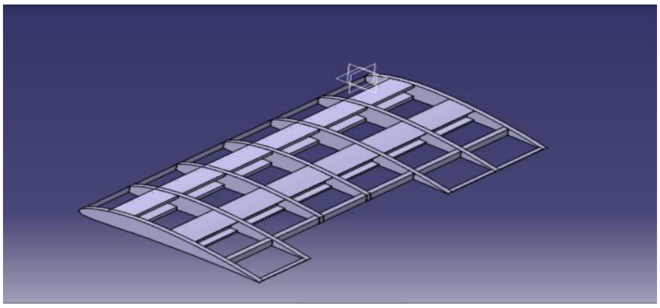

Fig- 18: Wing structures with ribs and spar apart

The total deformation and stress of the wing found by the ANSYS-STATIC STRUCTURAL analysis and results are noted the deformation and stress and standard earth gravity is given respectively.

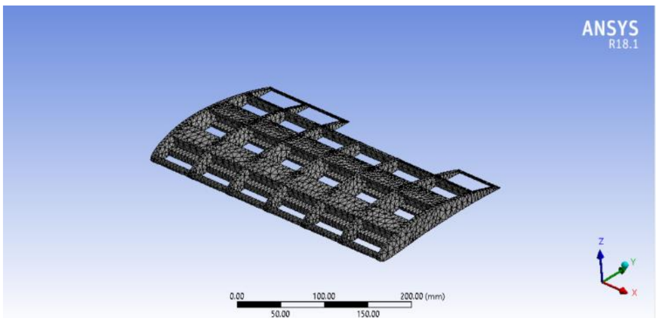

Fig- 19: Mesh of the wing structures with ribs and spar

3.5.1 Modal analysis of wing

The modal analysis was also performed on the wing structure using the same platform. The material properties were applied in such a manner. Once again, we use same unstructured mesh to the modal at 100 relevance for five modes of the wing and respective deformation plots were found. These frequencies indicate the resonant frequency of each mode. The following table shows the values if the frequencies and deformation for each modes of the wing.

Table- 5: Frequency and deformation at different modes

Mode	Direction	Frequency (Hz)	Deformation
1	Primary X	0.11533	124.4
2	Primary Y	0.2412	139.84
3	Secondary Y	0.27715	243.23
4	Torsional	0.6705	185.75
5	Tertiary Y	0.87433	226.93

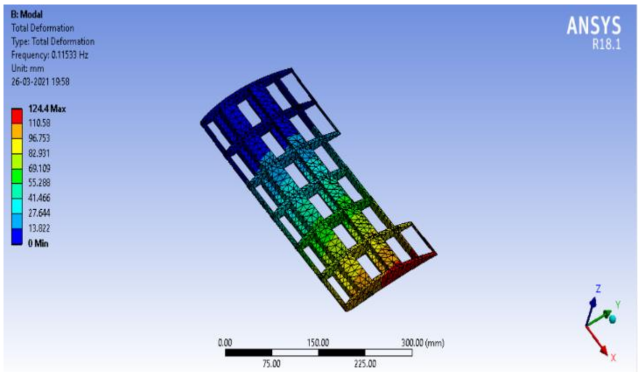

Fig- 20: Mode 1 analysis at Primary X

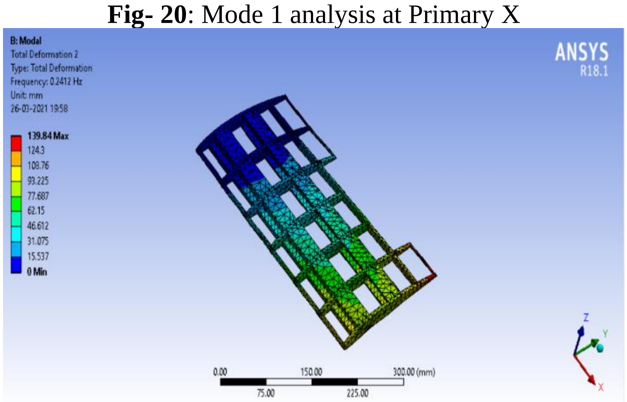

Fig- 2: Mode 2 analysis at Primary Y

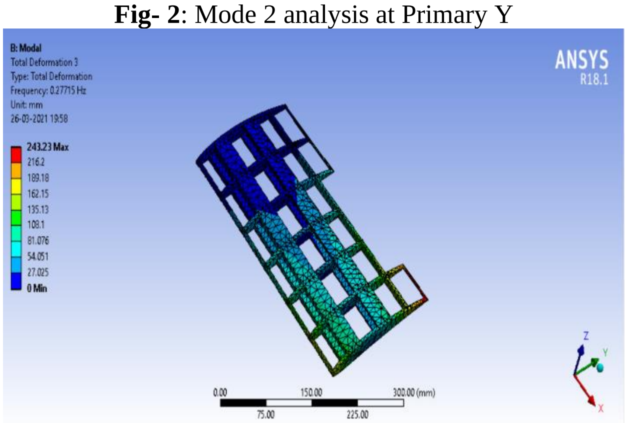

Fig- 22: Mode 3 analysis at secondary Y

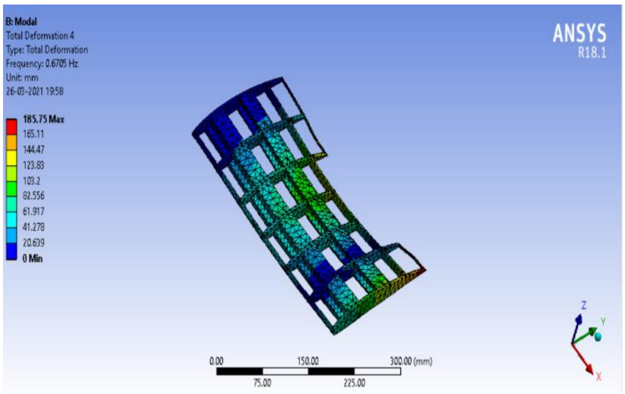

Fig- 23: Mode 4 torsional stiffness

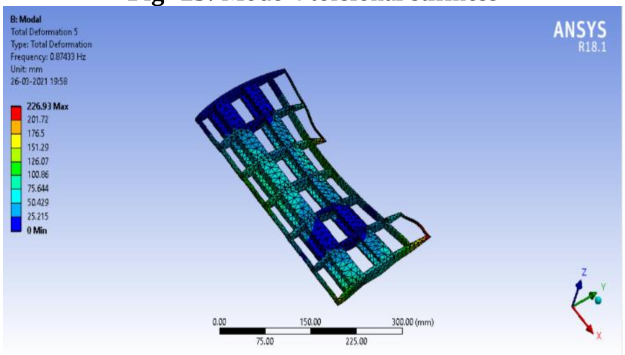

Fig- 24: Mode 5 tertiary Y

3.6 AVIONICS COMPONENTS

The components of the electronic which we used mainly consisting of motors, propellers, ESC, servos, battery, connectors and the cables. Motors and propellers are used to generate the thrust required for the takeoff and cruise. Battery is used to give the electricity to run the motors.

Transmitter and receiver: SANWA SD-5G 2.4GHz Transmitter with RX600 receiver.

ESC: Standard 20A BLDC ESC Electronic Speed Controller with Connector.

Servo motor: Tower Pro MG90S - Metal Gear.

Motor: EMAX MT2213 935KV Brushless DC Motor.

Flight control board: KK2.1.5 Multi-rotor LCD Flight Control Board.

3.7 FABRICATION OF VTOL

By studying the literature surveys and doing cost analysis we decided to select three materials for our design which are Birch wood, White pine wood and Covering films.

The fuselage and the tail section were made using the birch wood. The inner structure of the wing was fabricated using white pine wood, and the covering of the wing structure is done using the covering films. The total weight of the model is 1.6 kilogram.

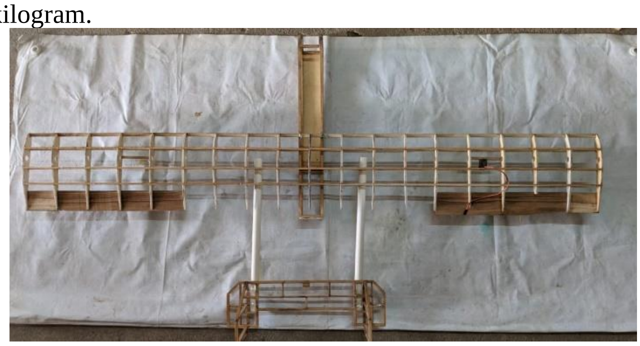

Fig- 25: Assembled VTOL

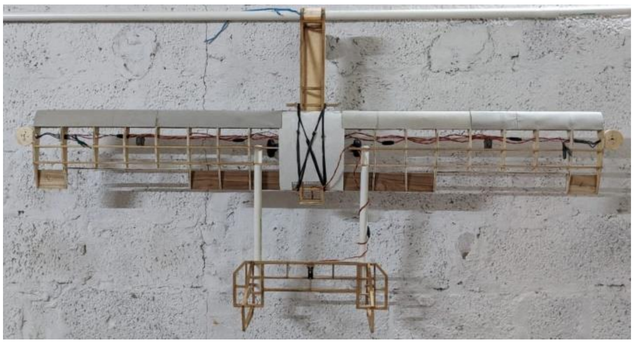

Fig- 26: Structure of VTOL with wirings

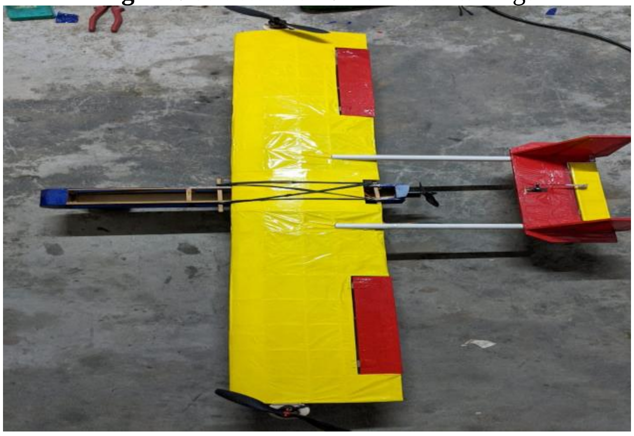

Fig- 27: Final completed VTOL model

4. CONCLUSION

The selected airfoils were analyzed with XFLR and ANSYS. The lift and drag values for the airfoils have been plotted. After analyzing these airfoils, the graphs can be compared and airfoil can be selected. Among the 3 airfoils, the high lift airfoil – NACA 6412 was chosen due to its better characteristics amongst the three. The design of the complete model and structure was done using Catia. The designed model was analyzed using Ansys workbench. The fluent analysis was done in Ansys software. The wing structure and modal analysis was done using Ansys.

Three different materials are chosen for the fabrication of the VTOL model which are birch wood, white pine wood, covering films. Avionics components were selected for the model. Fabrication of electrical vertical take-off and landing model is completed

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Before introducing our thesis work, we would like to thank the people without whom the success of this thesis would have been only a dream.

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