VISVESVARAYA TECHNOLOGICAL UNIVERSITY

Jnana Sangama, Belagavi, Karnataka -590014

A PROJECT REPORT

ON

DESIGN AND ANALYSIS OF WING FOR FIXED WING VTOL DRONE

Submitted in partial fulfilment of the requirements for the award of the degree of

BACHELOR OF ENGINEERING

IN

AUTOMOBILE ENGINEERING

Submitted by

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CERTIFICATE

Certified that the project work entitled **DESIGN AND ANALYSIS OF WING FOR FIXED WING VTOL DRONE** carried out by Mr Melvin Jason H (1NH19AU035), Mr. Saaim Saad, (1NH19AU038), Mr. Rajarshi Chatterjee (1NH19AU044) and Mr. Shreyas Shanbogh, (1NH19AU054) Bonafede students of New Horizon College of Engineering in partial fulfilment for the award of Bachelor of Engineering in Automobile Engineering of the Visveswaraiah Technological University, Belgaum during the year 2022-23. It is certified that all corrections/suggestions indicated for Internal Assessment have been incorporated in the Report deposited in the departmental library.

The project report has been approved as it satisfies the academic requirements in respect of Project work prescribed for the said Degree.

Name & Signature of the Guide	**Name& Signature of the HOD**	**Signature of the Principal**
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External Viva

Name of the examiners Signature with date
1.
2

DECLARATION

We **Rajarshi Chatterjee, Saaim Saad, Shreyas Shanbogh, Melvin Jason H,** students of VII semester BE Automobile Engineering, New Horizon College of Engineering hereby declare that this project work entitled **“DESIGN AND ANALYSIS OF WING FOR FIXED WING VTOL DRONE”** is an original and Bonafede work carried out by our group and submitted in partial fulfillment of the award of Bachelor of Engineering in Automobile Engineering during the year 2022-23. We also declare that the entire work embodied in this dissertation has been carried out by our group and no part of it has been submitted for any degree of any institution previously.

CERTIFICATE

This is to certify that the above declaration by the candidates is correct to the best of my knowledge and belief.

Place: **JAYASHEEL KUMAR KA**

Date: **Department of Automobile Engineering**

ABSTRACT

VTOL (vertical take-off and landing) refers to aircraft that can lift off and landvertically. Rotorcraft, like helicopters, use spinning blades to generate lift for vertical flight. Powered-lift planes, like the Harrier and V-22 Osprey, combine vertical lift withconventional fixed wing design to achieve VTOL capabilities. VTOL technology allows aircraft to take off and land nearly anywhere and perform maneuvers not possible for traditional planes. Companies such as Uber and Lilium are working on VTOL systems for use in flying taxis. Airbus has also created a hybrid car prototype that can fly using VTOL, and NASA has developed the battery-powered GL-10, whichcan take off and land vertically but flies like a conventional plane. VTOL drones are aircraft that can perform vertical take-off and landing, often with multiple rotors or propellers providing lift. They are used for a range of purposes, including aerial photography, surveying, search and rescue, and delivery. VTOL drones can operate in urban or confined areas, do not need a runway, and are often more energy efficientthan fixed-wing aircraft. However, they may be more expensive and complex to designand operate. Despite these challenges, VTOL drone technology is rapidly advancing and is expected to have a significant impact on the future of aviation. There have been recent efforts to make VTOL drones more modular and industry relevant, including theuse of various types of wings to determine the most efficient

Acknowledgement

We express our heartfelt thanks to Dr. Mohan Manghnani, Chairman, New Horizon Educational Institutions for providing this endower. We would also like to thank Dr. Shridhar Kurse, HOD, Automobile Dept, NHCE and Dr. Manjunatha, Principal of NHCE who has given us a constant support with motivation in completion of the mini project. We sincerely thank Mr. Karthik AV, Senior Assistant Professor, Department of Automobile Engineering, NHCE who has guided us throughout in completion of the mini project. We thank the entire staff members of Automobile Department, NHCE and everyone who has directly or indirectly helped us in completion of the project

TABLE OF CONTENTS

LIST OF FIGURES

CHAPTER 1

OBJECTIVE

VTOL stands for "vertical take-off and landing" and refers to aircraft that can take off and land vertically. Rotorcraft, such as helicopters, use lift generated by rotating blades to achieve vertical flight, while powered-lift planes, such as the Harrier and V-22 Osprey, use a combination of vertical lift and conventional fixed wing design to achieve vertical take-off and landing. VTOL technology allows aircraft to take off and land almost anywhere and perform manoeuvres not possible with a conventional plane. Some companies, such as Uber and Lilium, are working on developing VTOL systems for use in flying taxis. Airbus has also developed a prototype hybrid car that can fly using VTOL technology, and NASA has created the battery-powered GL-10, which can take off and land vertically but flies like a conventional plane. VTOL drones are aircraft that are capable of vertical take-off and landing. They are often equipped with multiple rotors or propellers to provide lift, allowing them to hover and maneuverer in the air with great precision. VTOL drones are used for a variety of applications, including aerial photography, surveying, search and rescue, and delivery of goods. They offer many advantages over traditional aircraft, including the ability to operate in urban or confined spaces, as well as the ability to take off and land vertically, which eliminates the need for a runway. VTOL drones are also typically more energy efficient than their fixed-wing counterparts, as they do not need to generate lift through forward motion. However, VTOL drones can be more complex to design and operate and may be more expensive than traditional aircraft. Despite these challenges, VTOL drone technology is quickly advancing, and it is expected to play a significant role in the future of aviation. Recent developments have taken place to make the concept of VTOL drone more industry relevant and modular which can be used for various such applications. One such development is the use of various kinds of wings to ascertain the most fitting wing model would provide most efficient characteristics.

CHAPTER: 2

PROBLEM STATEMENT

The commercial drones that are operational today are available for a multitude of segments, thus we do not see variations or optimizations made to the wing. Particularly for a VTOL type configuration of drone. We try to create a new wing configuration for the VTOL based on the most suitable design considerations from the research work that has been performed over the time.

CHAPTER: 3

INTRODUCTION

Vertical take-off and landing (VTOL) aircraft are able to take off and land vertically, without the need for a runway. This allows them to operate in a variety of environments and locations, including urban areas, forests, and other areas where traditional aircraft would be unable to land. There are several different types of VTOL aircraft, each with its own unique design and capabilities.

One common type of VTOL is the helicopter, which uses rotors to generate lift and allow for vertical take-off and landing. Other types of VTOL aircraft include tiltrotors, which have rotors that can tilt between a vertical and horizontal position, and fan-in-wing aircraft, which use a combination of lift fans and wings to achieve VTOL capability.

In addition to these types, there are also several different wing designs that are used on VTOL aircraft. These include delta wings, which are triangular in shape and highly effective at producing lift; canard wings, which are small wings located near the front of the aircraft; and lifting body designs, which use the shape of the aircraft itself to generate lift. Each of these wing designs has its own unique set of benefits and drawbacks, and the best choice for a particular VTOL will depend on its intended use and mission requirements.

CHAPTER 4

LITERATURE REVIEW

1. DESIGN AND PERFORMANCE ANALYSES OF A FIXED WING BATTERY VTOL UAV

-Özgür Dündar, Mesut Bilici , Tarık Ünler

In this study, a vertical take-off and landing (VTOL) fixed-wing unmanned aerial vehicle (UAV) with a four-propeller multi-rotor system was designed and analysed for performance. The design focused on low drag and high lift coefficient to minimize power requirements and maximize endurance. A battery was selected for the VTOL-FW UAV, which has a take-off weight of 4.7 kg and a wingspan of 2 meters. Power requirements for various flight conditions, including cruise flight, take-off, climbing, and landing, were calculated using a Simulink model to represent energy consumption. The endurance of the VTOL-FW UAV was then determined based on the energy consumption values. The results showed that the use of four propellers for vertical take-off and landing and hovering increases total drag, which reduces endurance. In addition, the transition from hovering to cruise significantly reduces the battery's energy. It is concluded that the VTOL-FW UAV concept is suitable for use in hilly and forested areas, especially if long endurance is not required. In future work, the VTOL-FW UAV, named "Kuzgun," will be manufactured and tested using 3D printing technology with polylactic acid reinforced with carbon fiber. Energy consumption and power values will also be checked during real flight tests using suitable sensors on Kuzgun.

2. A REVIEW ON VERTICALTAKE-OFF AND LANDING (VTOL) TILT - ROTOR AND TILT WING UNMANNED AERIAL VEHICLES (UAVS)

-Akshat Misra, Sudhakaran Jayachandran, Shivam Kenche

This paragraph discusses the concept of vertical take-off and landing (VTOL) aircraft and the various technologies that have been developed for this purpose. It mentions that many problems have been encountered and solved in the development of VTOL aircraft, and that there are several points to consider in future design, including the potential for hybrid UAVs with tilt wing configurations, the use of neural network based PID systems to stabilize altitude and control tilt during take-off and transition, and the use of both front and rear propellers for thrust and stability during hovering mode. The paragraph also notes that traditional tilt-rotor mechanisms have been extensively researched, but that other technologies may be more effective and cheaper. Finally, the paragraph suggests that a trade-off analysis can be used to determine the optimal design of VTOL aircraft.

3. VTOL UAV – A CONCEPT STUDY

-Daniel Moëll,Joachim Nordin

This thesis focuses on the development of a conceptual design tool for vertical take-off and landing unmanned aerial vehicles (VTOL UAVs). The goal of the design tool is to provide quick, accurate, and easy-to-use results. To achieve this, a compromise must be made between calculation accuracy and calculation time. The design tool has a graphical user interface that allows users to easily create a design for a helicopter from a fictional mission. The design tool considers the helicopter as a complete system, taking into account all of its subparts and prioritizing them as necessary. The thesis aims to demonstrate that it is possible to create a user-friendly design tool for VTOL UAVs with a simple design process and good agreement with real-world flight test data.

4. AERODYNAMIC AND STABILITY ANALYSIS OF A VTOL FLYING WING UAV

-C Bliamis, I Zacharakis, P Kaparos, and K Yakinthos

This work focuses on the aerodynamic and stability characteristics of the MPU RX-4, a flying wing unmanned aerial vehicle (UAV) with vertical take-off and landing (VTOL) capabilities. During the preliminary design phase, alterations were made to the external geometry and the sizing of key parts was completed. A stability analysis was also performed using semi-empirical correlations, changed for lightweight flying wing UAVs, and validated with computational fluid dynamics (CFD) computations. The necessary trim angle for stable flight during cruise was calculated, and the stability and control derivatives of the UAV were estimated and compared to those of similar tailless UAVs.

5. FAST AIRFOIL SELECTION METHODOLOGY FOR SMALL UNMANNED AERIAL VEHICLES

- Ioannis K. Kapoulas , J. C. Statharas , Antonios Hatziefremidis and A. K. Baldoukas

This study aims to provide useful data for selecting airfoils for low Reynolds number applications, specifically for small unmanned aerial vehicles (SUAVs). Data acquisition software was used to construct a diagram showing the maximum lift coefficient versus the ideal lift coefficient for low Reynolds number airfoils, and tables of supplementary airfoil characteristics are provided. The authors estimate that using the proposed methodology and data can save 85% of engineering time in the airfoil selection process, as no new airfoil simulations are required. The study encourages SUAV designers to expand the airfoil database using the proposed methodology.

6. REALISTIC SIMULATIONS OF DELTA WING AERODYNAMICS USING NOVEL CFD METHODS

-Stefan Görtz Royal Institute of Technology (KTH)

This thesis presents the results of a study on the vortical flow over delta wing configurations at high angles of attack. The study found that vortex breakdown is practically an inviscid phenomenon and can be accurately predicted using the Euler or Navier-Stokes equations with a suitable numerical grid. Time-accurate computations are necessary to accurately predict the breakdown location and capture asymmetry in the flow and Detached-Eddy Simulations (DES) are promising for time-accurate viscous computations. The study also applied the lessons learned to the simulation of a realistic delta-wing aircraft configuration and found that a virtual-reality environment can facilitate the analysis of unsteady flow simulations. The algorithmic efficiency of dual time stepping was also improved using the Recursive Projection Method.

7. STRUCTURAL ANALYSIS OF FIXED WING DRONE(UAVS)

- Sanjeev kumar, National institute of technology (NIT) Silchar

This study focused on the design and analysis of UAVs (unmanned aerial vehicles) or drones. The design considered low drag and high lift coefficient to minimize power requirements and maximize endurance. A battery selection was made, and power requirements were calculated for various flight conditions. The endurance of the UAV was determined based on mission requirements, and it was found that the use of four propellers for vertical take-off and landing leads to an increase in total drag, reducing endurance. The VTOL-FW UAV is seen as a useful concept for use in hilly and forested areas where long endurance is not necessary. In future work, the UAV will be manufactured using 3D printing technology with the material polylactic acid reinforced with carbon fiber and flight tests will be conducted to verify the simulation results. The study also explored the potential for using composite materials, such as a composite of balsa wood and carbon fiber, in the manufacturing of UAVs. This composite was found to be the most feasible and efficient material for UAV manufacturing due to its high bending and torsional strength, corrosion resistance, and ability to be molded into various shapes and sizes.

8. A COMMON FRAMEWORK FOR THE DESIGN OPTIMIZATION OF FIXED-WING, MULTICOPTER AND VTOL UAV CONFIGURATIONS

- Félix Pollet, Scott Delbecq, Marc Budinger, Jean-Marc Moschetta & Jonathan Liscouët

This paper presents a design optimization methodology for drones, including multicopters, fixed-wing, and FW-VTOL (fixed-wing vertical take-off and landing) types. The methodology includes design models for geometry, structures, aerodynamics, propulsion, and stability, and formulates an optimization problem. The complexity of the problem is reduced through the use of monotonicity analysis and NVH (noise, vibration, and harshness) formulation. The methodology is implemented in a sizing tool that is suitable for preliminary design and can be applied to a wide range of UAVs. The validity of the methodology is demonstrated through comparison with existing fixed-wing drones and a case study. The case study found limited benefit of the FW-VTOL configuration compared to the multicopter due to the added mass of the dual propulsion system but suggested that improving the FW-VTOL performance through optimization of the VTOL propulsion system and careful selection of the power source could be beneficial. The sizing tool could also be improved by refining structural models and considering material selection.

(9) AERODYNAMIC PERFORMANCE OF THE NACA 2412 AIRFOIL AT LOW REYNOLDS NUMBER

Dr. John E Matsson, Oral Roberts University

In this research project, the students designed and built an airfoil section and a multi-manometer and used these tools to measure the coefficient of lift on a NACA 2412 airfoil at different angles of attack. Their experimental methods were successful, as the coefficient of lift they measured closely matched the results predicted by computer simulations. This project provided a valuable opportunity for the students to gain practical experience, which can be difficult to come by in an undergraduate engineering program due to the large amount of material that needs to be covered. The combination of classroom instruction and hands-on learning created a highly effective learning environment.

(10) WING DESIGN

Mohammad Sadraey, Daniel Webster College

This chapter discusses the design of an aircraft's wing, which is a crucial component that enables the aircraft to fly. The wing's main function is to generate lift, but it also produces drag and a pitching moment. The wing designer tries to maximize lift and minimize drag and pitching moment. The design process for the wing follows the principles of systems engineering, taking into account various requirements such as performance, stability and control, producibility, operation, cost, and flight safety. Performance requirements include maximum speed, takeoff distance, range, and endurance, while stability and control requirements include lateral and directional stability and controllability during potential wing stalls.

CHAPTER 5

METHODOLOGY

Fig-5.1

Methodology flow chart

CHAPTER 6

DESIGN AND ANALYSIS

DESIGN METHODOLOGY

(1) Selection of number of wings

(2) Selection of wing vertical location

(3) Determination of wing shape, dimensions and geometry.

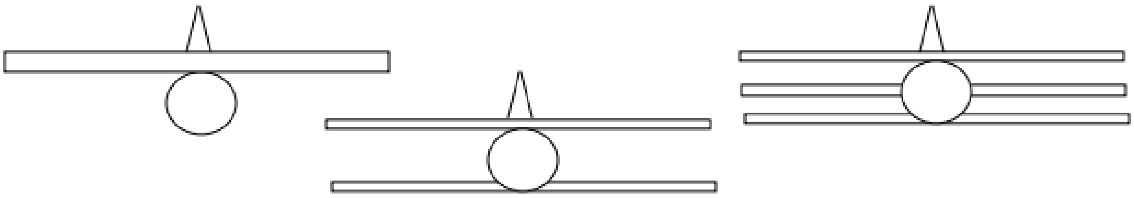
(4) Determination of Airfoil

(5) 2d-Sketch of wing

(6) 3d-Modelling of wing

(7) Analysis and CFD testing of results

6.1 Selection of number of wings



1. Monoplane, 2. Biplane, 3. triwing

Fig 6.1.1 types of wings

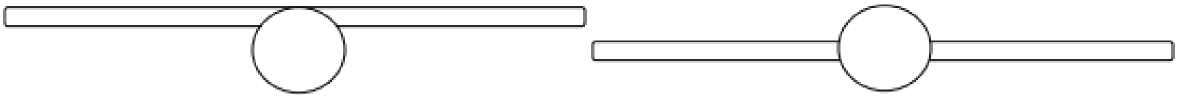
The selection of number of wings of an airplane depends on multiple criteria. Most of them being the limits of manufacturing or the impact of wing on the structure or weight of the overall aircraft. Apart from that it also majorly depends on the limitations of the use and manoeuvrability of the aircraft under certain environmental and load conditions. The limits of manufacturing technology were the justification for choosing more than one wing.

When opposed to two wings, a single wing often has a larger wingspan (with the same total area). A long wing's structural support to remain level and rigid could not be provided by earlier manufacturing techniques. This justification is no longer applicable due to improvements in manufacturing techniques and the development of new, durable aerospace materials such sophisticated light aluminium and composite composites. The restrictions on the wingspan of the aircraft were another factor. Therefore, adding more wings is a means to shorten the wingspan. Thus, in ordinary modern aircraft, a single wing (which comprises both left and right parts) is essentially the only practicable alternative. The modern wing designer may still be compelled by a few other design factors to favour several wings, though.

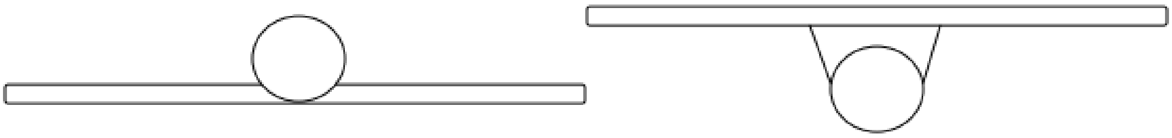
The requirements for aircraft controllability are the most important. Because it has a reduced mass moment of inertia about the x axis, an aircraft with a shorter wingspan has better roll control. Therefore, having more than one wing that results in a reduced wingspan is an alternative if you want to roll more quickly. In the 1940s and 1950s, several manoeuvrable aircraft had biplane or even three wings. On the other hand, the drawbacks of a non-monoplane alternative include increased weight, less lift, and restricted pilot visibility.

Considering the above research and criteria, the wing is taken as a mono wing type configuration which will presumably suit the drone requirements, thus giving the optimal performance.

6.2 Selection of wing vertical location



a. High wing *b. Mid wing*



c. Low wing *b. Parasol wing*

Fig 6.2.1 schematic of different wing locations

The wing's vertical placement in relation to the fuselage centreline is one of the wing factors that may be decided upon early in the wing design process. This wing characteristic will have a direct impact on the design of other aircraft parts, such as the centre of gravity, landing gear, and the tail. In theory, there are four possibilities for the wing's vertical position, as shown in the above figure.

6.2.1 High Wing

The high wing configuration in aircraft has several advantages, including ease of loading and unloading cargo, safer engine and propeller clearance, protection from hot exhaust gases, ability to use struts, improved takeoff and landing from water, improved control for hang glider pilots, increased lateral stability due to the dihedral effect, increased lift and lower stall speed, better visibility for the pilot, less risk of debris or humans entering the engine, a smoother aerodynamic shape for the fuselage, more space in the fuselage, and longitudinal stability due to the wing drag. However, it can also result in a heavier aircraft structure when struts are used.

6.2.2 Mid Wing

The mid wing configuration in aircraft has several features that are intermediate between the high wing and low wing configurations. It requires cutting the wing spar in half to save space in the fuselage, which can result in a heavier aircraft structure that requires reinforcing at the intersection with the fuselage. It may also be more expensive and more aerodynamically streamlined than the other configurations, and it does not typically use struts to reinforce the wing structure. One advantage is that the pilot can use the wing as a step to get into the cockpit in small general aviation aircraft.

6.2.3 Low Wing

The low wing configuration in aircraft has several advantages, including better take-off performance due to the ground effect, better visibility for the pilot, the option to have the retraction system in the wing or fuselage, shorter and lighter landing gear, the ability for the pilot to walk on the wing to access the cockpit, a lighter aircraft structure, less frontal area, lower drag, less induced drag, and more attractive appearance. It also has higher lateral control and a lighter tail. However, it generates less lift and has a higher stall speed, resulting in a longer take-off run, lower airworthiness, and poorer landing performance. It is also laterally less stable but more manoeuvrable than the high wing configuration.

6.2.4 Parasol Wing

The parasol wing configuration is a type of high wing configuration that is commonly used in hang gliders and amphibian aircraft. It has many features that are like the high wing configuration, but it is generally heavier and has more drag due to the use of longer struts.

Based on the above major differentiator and factors that have been mentioned, the high wing type configuration for the drone is being used that matches our requirements.

6.3 Determination of wing shape, dimensions and geometry

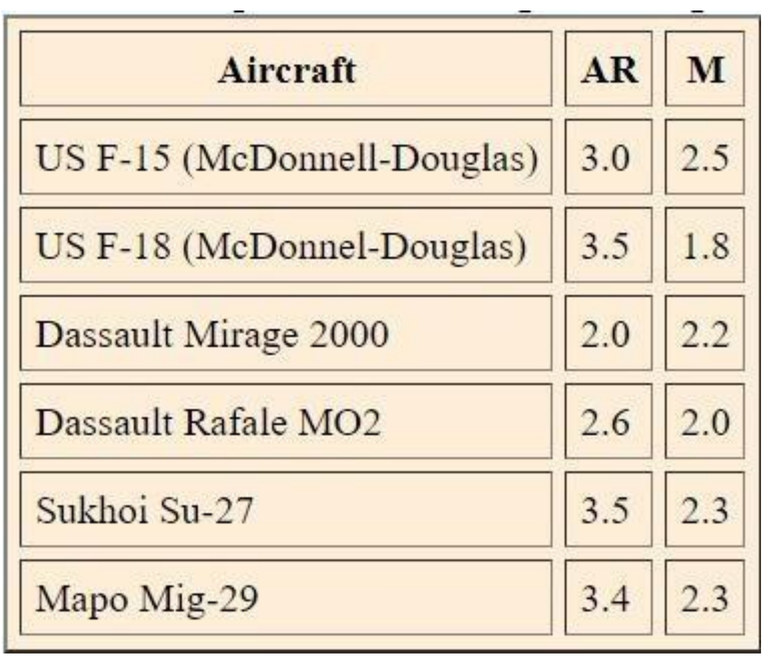
- An aspect ratio of 4 is considered based on relative data available various on delta wings Keeping the aspect ratio as a design factor, root chord length of o.35 m was taken, the wingspan was taken as 0.80 m.

- The total area calculated was 0.1616 square meter.

- Based on existing and relevant data available on VTOL drone, the total weight during flight was taken as 10 kgs and the velocity considered was 20 m/s.

- Lift force = ½ *density of fluid * total area * velocity squared *coefficient of lift

- At cruising velocity, the weight of the aircraft W is equal to the lift force L
  By re arranging the formula for lift produced at this condition the calculated coefficient of lift at cruising is 0.4



Aircraft	AR	M
US F-15 (McDonnell-Douglas)	3.0	2.5
US F-18 (McDonnel-Douglas)	3.5	1.8
Dassault Mirage 2000	2.0	2.2
Dassault Rafale MO2	2.6	2.0
Sukhoi Su-27	3.5	2.3
Mapo Mig-29	3.4	2.3

Fig 6.3.1 AR ratio of fighter planes

6.4 Selection of Airfoil

Based on the Cl value calculated, the Airfoil is taken as NACA2412. The NACA 2412 airfoil is a wing profile that is often used in the design of aircraft. It has a relatively thick profile, with a maximum thickness of 24% of the chord length (the distance from the leading edge to the trailing edge of the airfoil) at 12% of the chord length from the leading edge. This thick, symmetrical airfoil is typically used on low-speed aircraft, such as trainers and general aviation aircraft, because it has good lift characteristics and is relatively easy to manufacture. It is not typically used on high-speed aircraft because it has a higher drag coefficient compared to thinner airfoils that are designed specifically for high-speed flight. As the flight requirements of the drone is to be able to produce the most lift and give better performance characteristics at higher values of angle of attack, this Airfoil deems to the most suitable Airfoil for the drone flight requirements.

The NACA 2412 airfoil is often used in delta wing aircraft, which are characterized by a triangular wing shape. Delta wings are known for their high lift and low drag characteristics, and the NACA 2412 airfoil is well-suited for these types of aircraft because it can produce high lift at low speeds. Delta wings are typically used on military aircraft, supersonic jets, and other high-performance aircraft that require a combination of high lift and low drag. In addition to its use in delta wing aircraft, the NACA 2412 airfoil may also be used in other types of aircraft that require high lift at low speeds, such as gliders and agricultural planes.

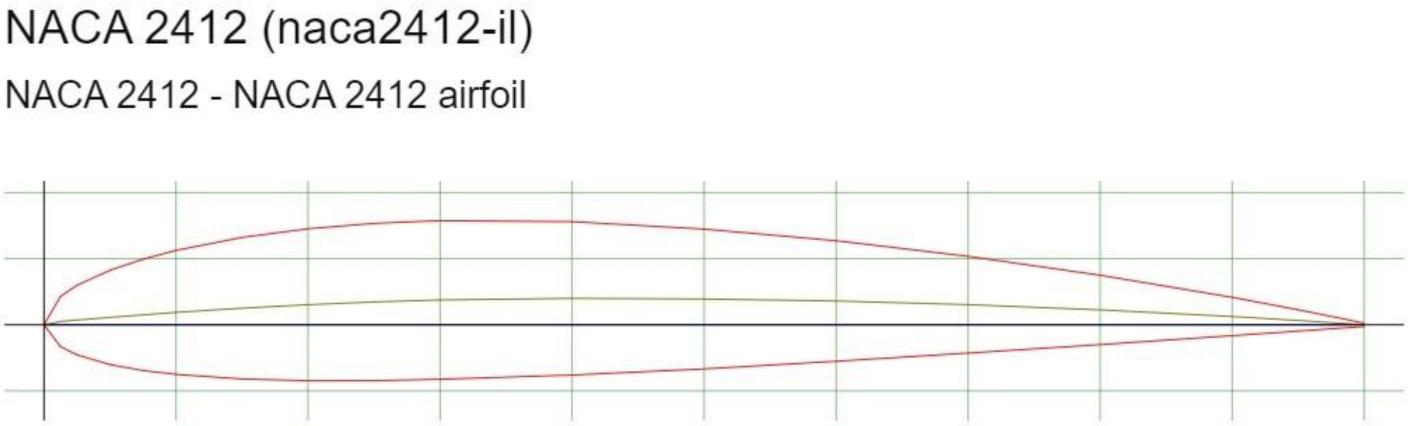
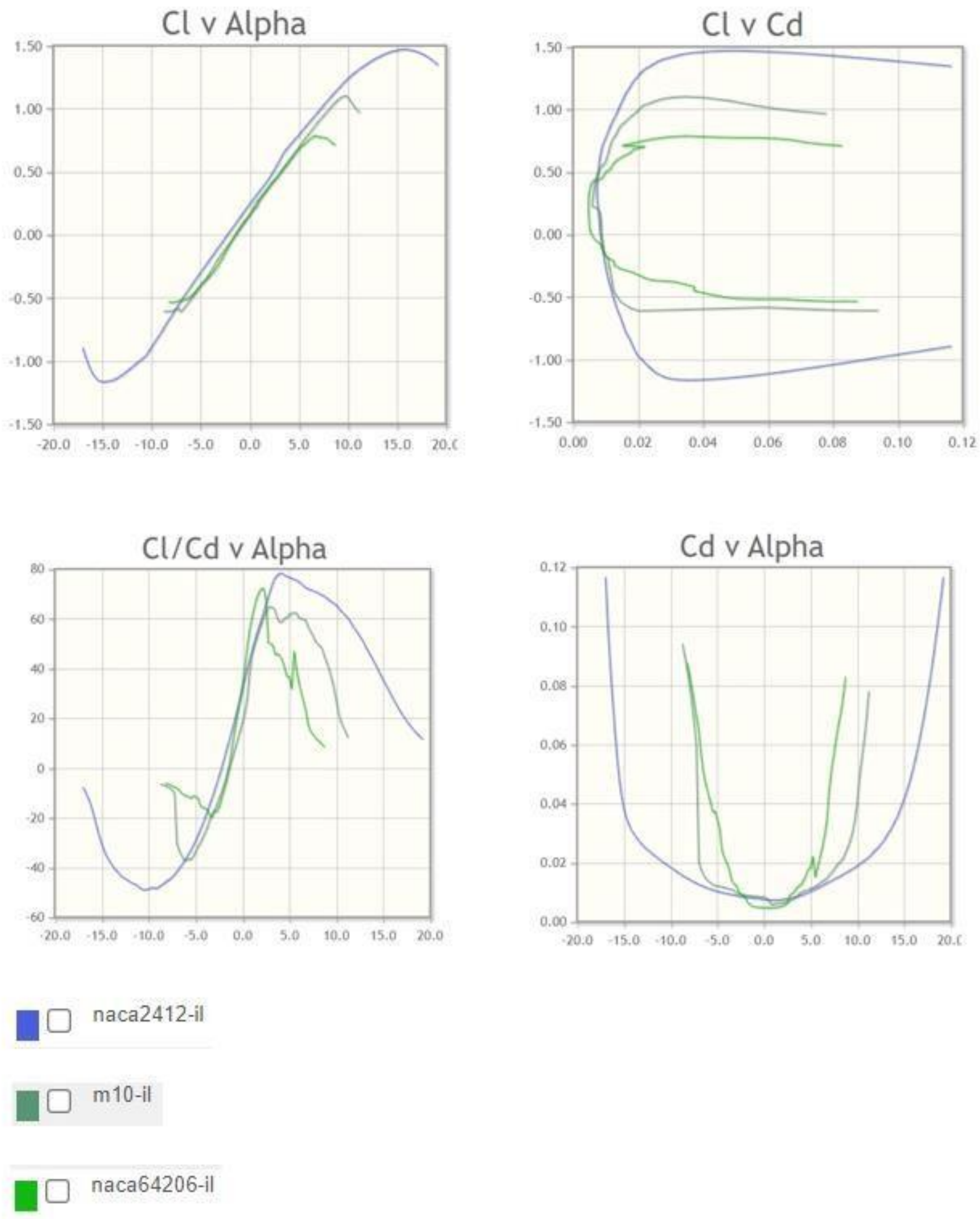


Fig 6.4.1 airfoil NACA 2412


Cl v Alpha
1.50
1.00
0.50
0.00
-0.50
-1.00
-1.50
-20.0
-15.0
-10.0
-5.0
0.0
5.0
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15.0
20.0
Cl v Cd
1.50
1.00
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0.00
-0.50
-1.00
-1.50
0.00
0.02
0.04
0.06
0.08
0.10
0.12
Cl/Cd v Alpha
80
60
40
20
0
-20
-40
-60
-20.0
-15.0
-10.0
-5.0
0.0
5.0
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Cd v Alpha
0.12
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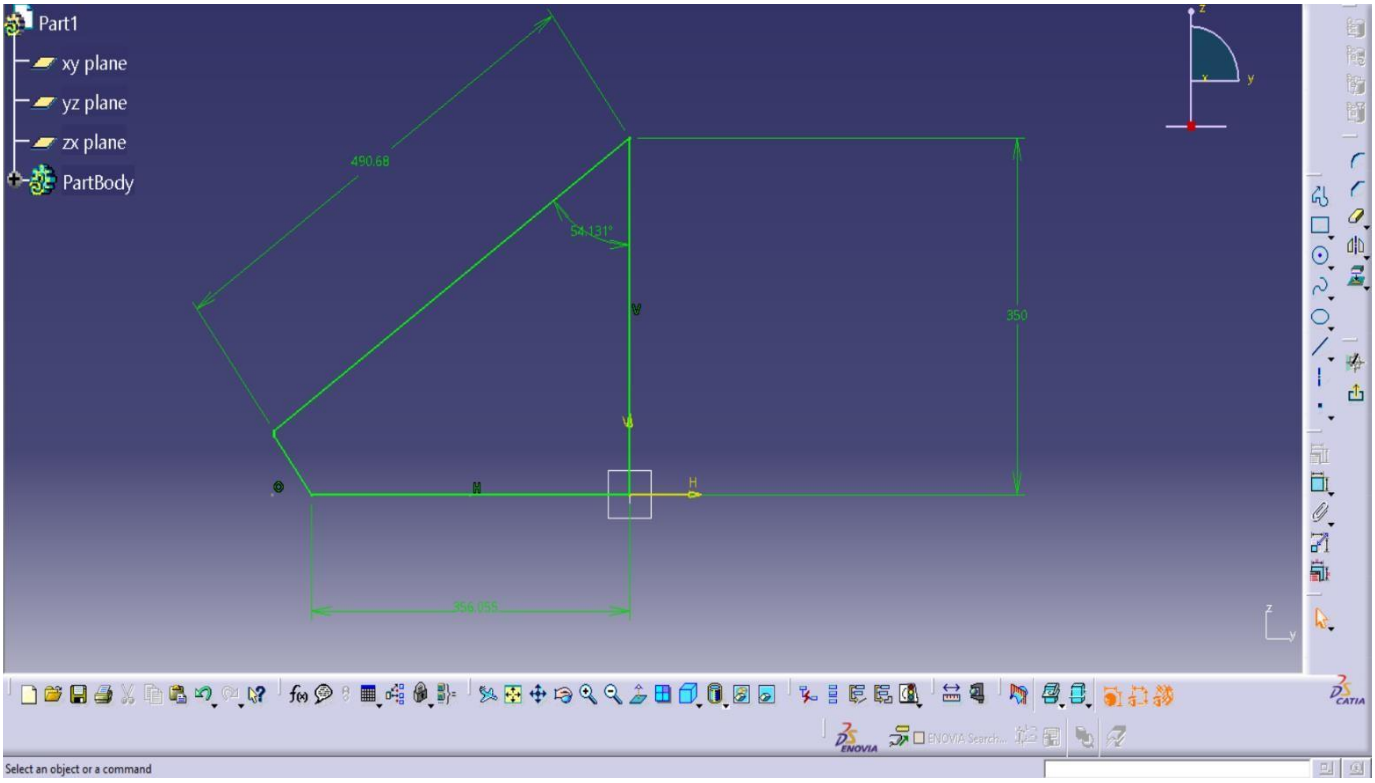
☐ naca2412-il
☐ m10-il
☐ naca64206-il

Fig 6.4.2

The above charts are plotted for various parameters of the selected Airfoil against other kinds of airfoils used in the wing design industry. First, in order to select the right air foil for the wing, the calculated design lift coefficient calculated must be satisfied at a given angle of attack for any kind of air foil. Reynolds number is calculated and based on that a range between 450,000 and 500,000 for UAVs with 8–10 kg take-off weight to evaluate the profiles. The three profiles considered based on the above-mentioned parameters are NACA 2412, NACA M10 and NACA 64206. Based on the calculated lift coefficient the NACA 2412 meets the required coefficient of lift at an angle of attack of 3, the NACA M10 and the NACA 64206 produces the required coefficient of lift at an angle of attack of 4.5. We can also observe from the graph plotted between coefficient of lift Cf and angle of attack alpha that NACA 2412 has a higher coefficient of lift at respective angle of attack when compared to NACA M10 and NACA 64206. From the graph plotted between coefficient of drag Cd and the angle of attack alpha we can deduce that NACA 2412 produces less coefficient of drag at respective angles when compared to NACA M10 and NACA 64206. Looking at the graph plotted between the ratio of coefficient of lift to the coefficient of drag against the angle of attack we can understand that the NACA 2412 produces the highest ratio when compared to the NACA M10 and NACA 64206. The above-mentioned profiles are chosen because it provides the design lift coefficient value of 0.46 at a minimum angle of attack and gives relatively low moment coefficient. Based on the above comparison between air foils NACA 2412, NACA M10 and NACA 64206 we can depict that NACA 2412 produces the maximum coefficient of lift to relatively less coefficient of drag and at a minimum angle of attack.

6.5 2-D Sketch of wing



Select an object or a command

Fig 6.5.1 2D sketch of wing in catia

The 2-D design of the wing was created in Catia v5. An aspect ratio of 4 was chosen based on data available from existing delta wing aircrafts. Comparing dimensions of various drone wings, the root chord length was set to 0.35 m. The wingspan I was is considered as 0.80 m. The swept is set at an angle of 36 degrees.

6.6 3-D Sketch of Wing

The design created in 2-d is imported to Autodesk fusion 360 to create a 3-d model with the dimensions. The Airfoil plot is also imported into the 3d modeler to apply the Airfoil the designed delta wing configuration.

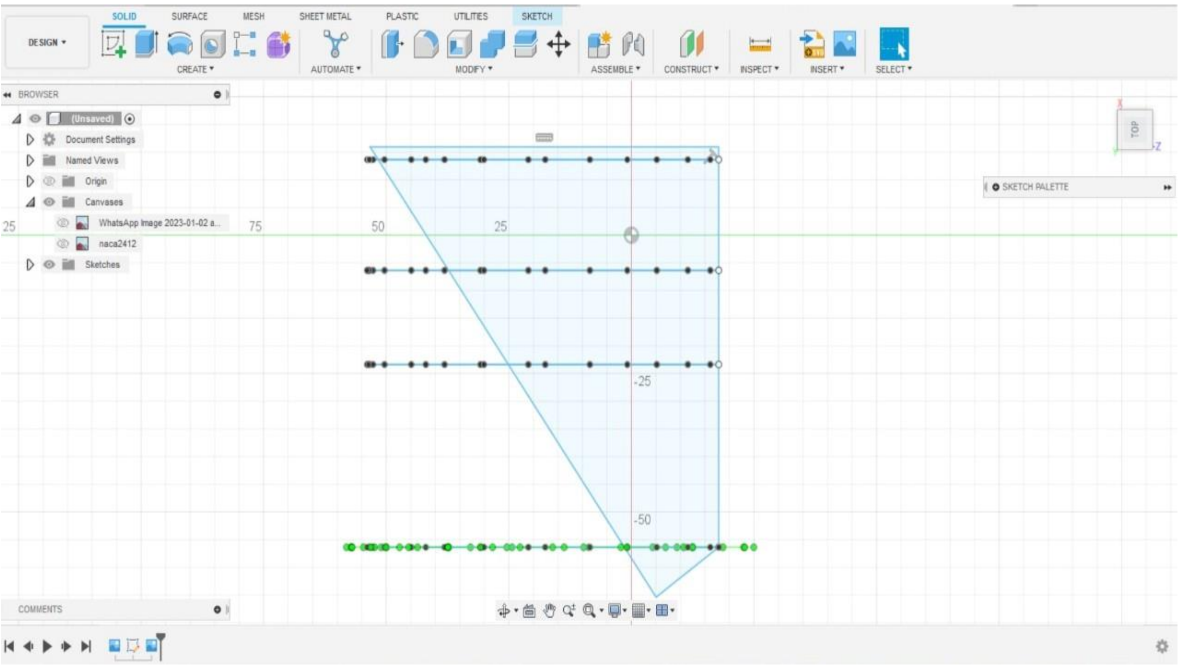


Fig 6.6.1 3D sketch -1

Step (1)- The 2d geometry is traced using the exact dimensions on selected coordinate plane. Similarly, the Airfoil geometry is also traced on the coordinate plane and multiple copies made to cover the complete scale of the sketch.

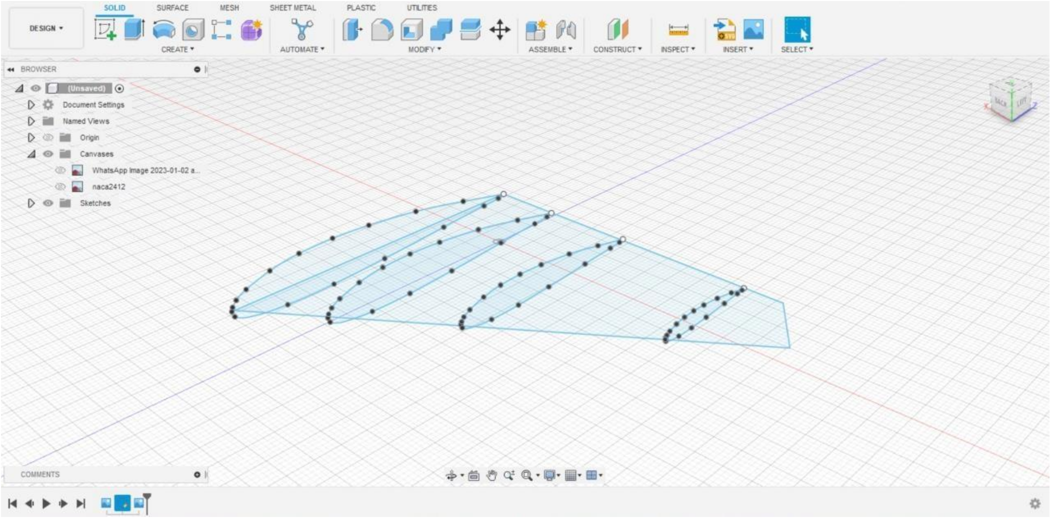


Fig 6.6.2 3D sketch -2

Step (2)- The consecutive Airfoil cross-sections are scaled keeping the scaling ratio as per the 2d sketch ratio. This operation ensures that the 3d model designed will have a proper edge and faces will be symmetrical without any distortions.

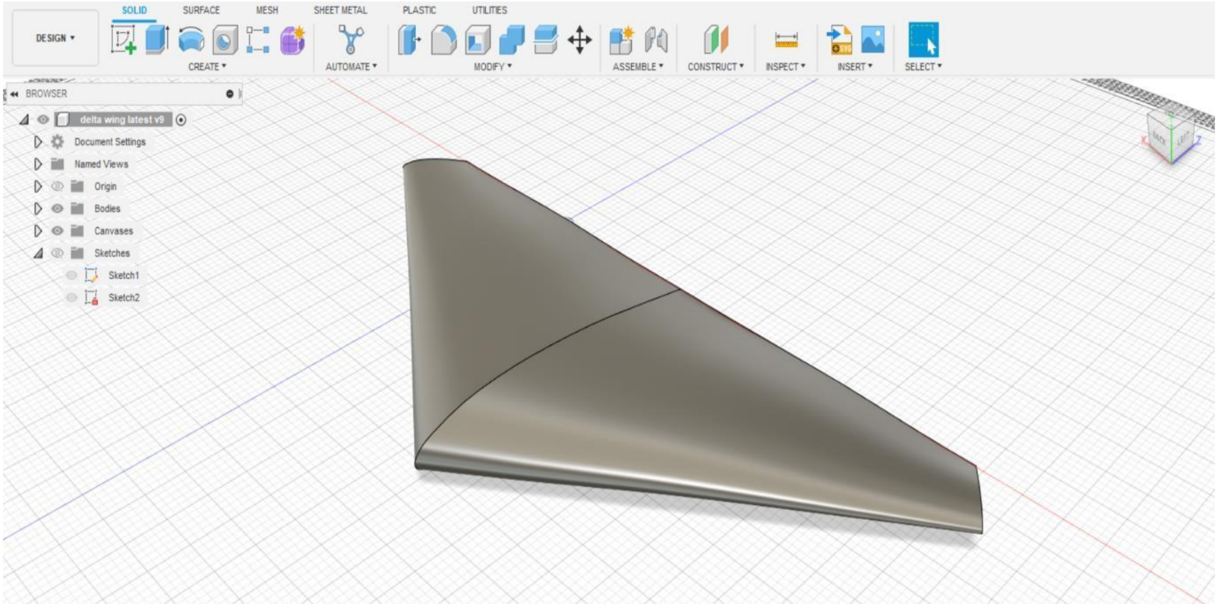


Fig 6.6.3 3D3D sketch -3

Step (3)- On successful arrangement of the airfoil cross sections, the loft command is used to create the body and faces of the aircraft. This generates the required model of the NACA2412 airfoil with the cropped delta specification of wing, for the drone.

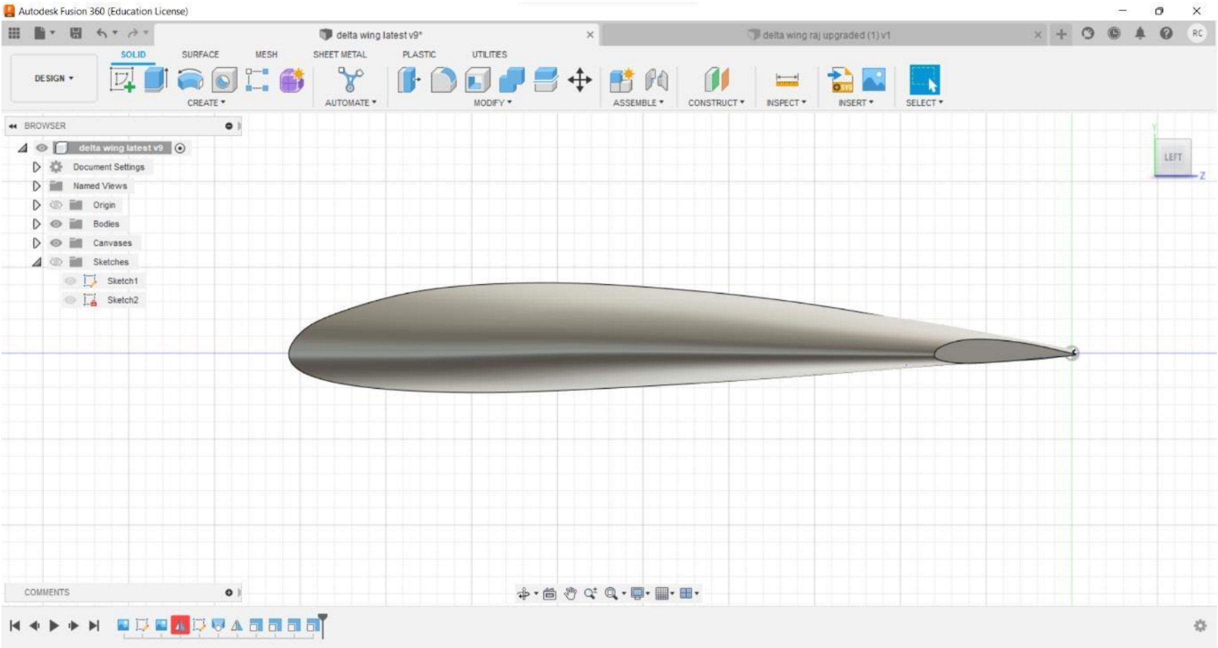


Fig 6.6.4 3D sketch -4

6.7 Analysis and CFD testing of results

CFD is the process in which the differential equation governing the Fluid Flow is replaced with a set of algebraic equations (the process is called discretization), which in turn can be solved with the aid of a digital computer to get an approximate result. After importing the VTOL (vertical take-off and landing) components into Ansys we define the analysis types by applying loads and initial conditions for the finite element solution. During mesh generation loading boundary conditions of inlet outlet wall and symmetry conditions are then applied to these elements and node of the cropped delta wing structure. For simulation of fluid flow analysis, the VTOL model was transferred to CFX/ FLUENT pre-processor. In this process details for fluid and solid domains were assigned. Material used for fluid type domain in our case is air at 250 C. Inlet and outlet details in fluid and Boundary Conditions were applied prior flow analysis we obtain the pressure counter and velocity streamline of fluid flow.

Ansys interface

This is the user interface of Ansys workbench. We can perform various calculations and different types of analysis using different options. For the analysis of the designed VTOL wing we use Fluid flow (fluent solver)

This further is divided into various sub sections which needs to be fulfilled in order to perform the CFD analysis (Computational fluid Dynamics). The various factors are:

- Geometry
- Meshing
- Setup
- Solutions
- Result

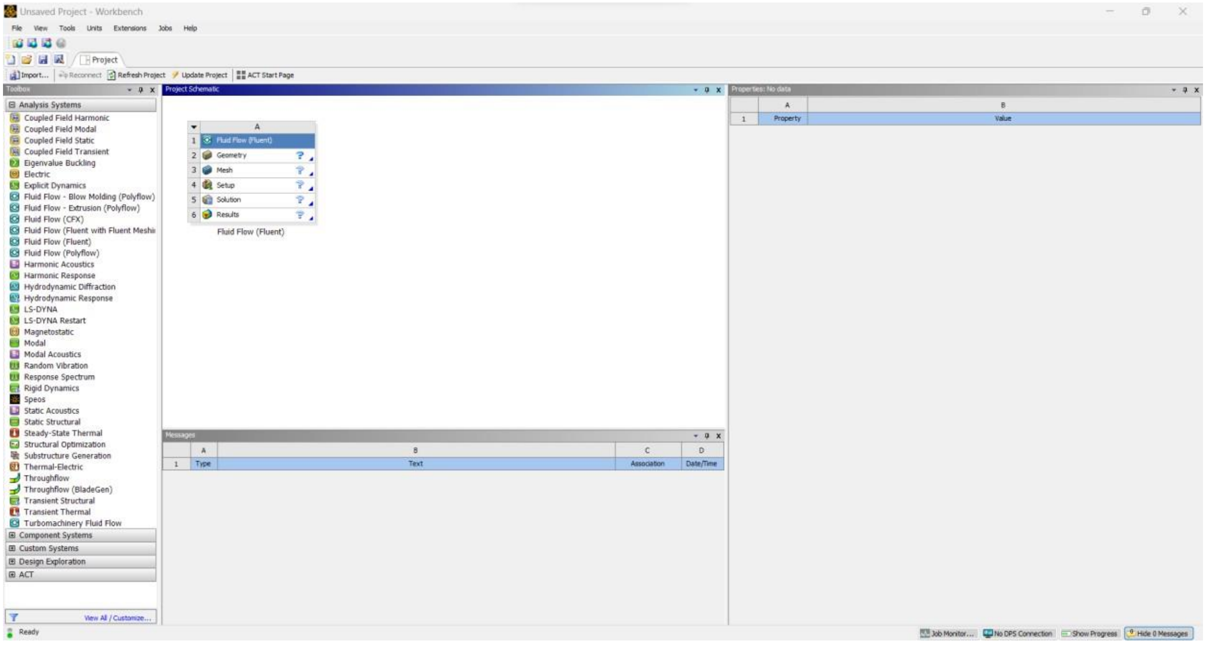
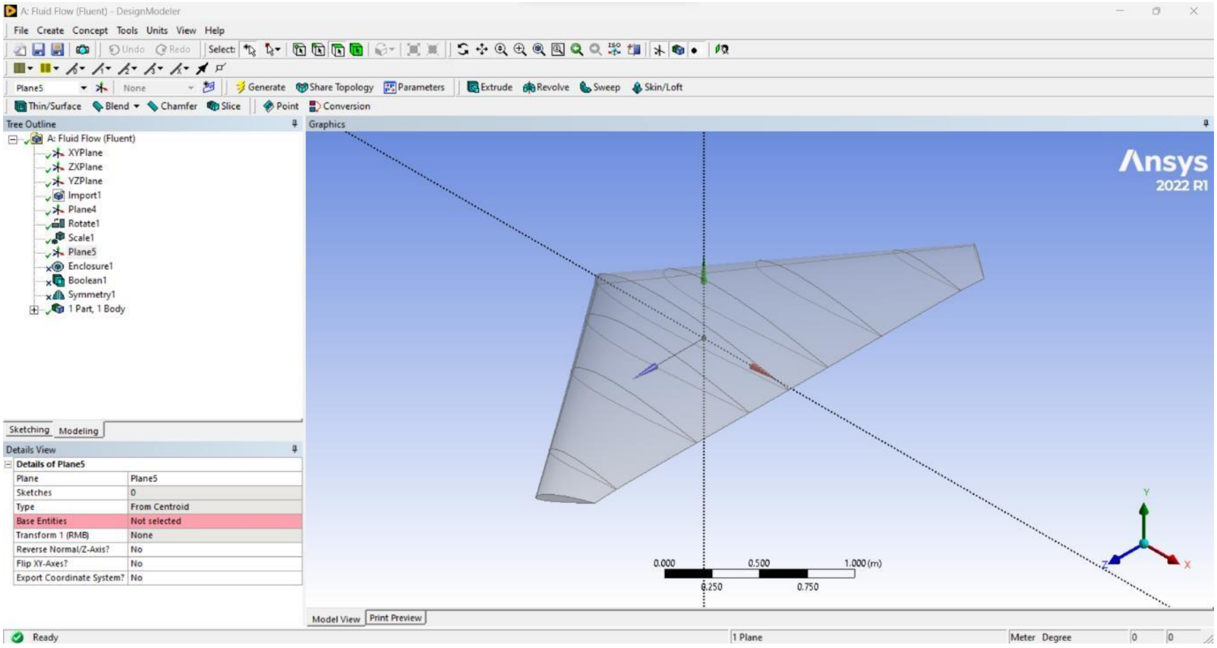


Fig 6.7.1 Ansys Workbench

Design Modeler

After importing the geometry in the required format, we use design modeler to edit the geometry and different parameters like move scale and orientation. After the desired orientation is met, we create an enclosure where the analysis will be done also known as the analysis boundary.



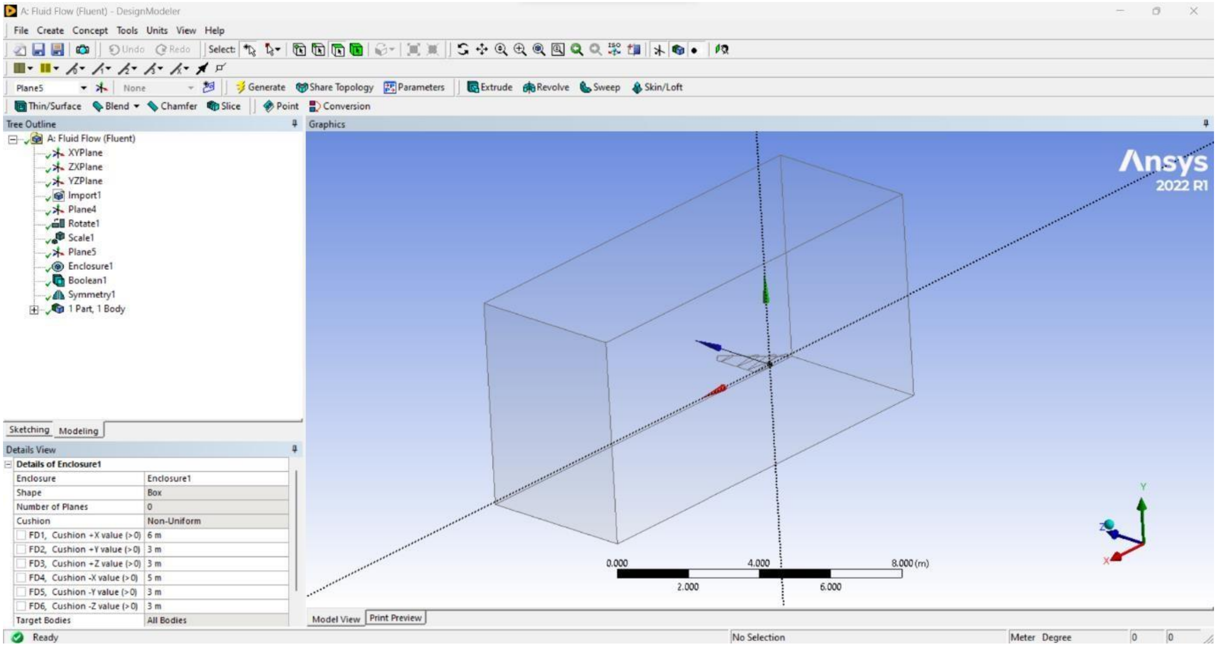
Details View

Details of Plane5

Plane	Plane5
Sketches	0
Type	From Centroid
Base Entities	Not selected
Transform 1 (RMB)	None
Reverse Normal/Z-Axis?	No
Flip XY-Axes?	No
Export Coordinate System?	No

Fig 6.7.2 Analysis 1

After the various prepartion is done an enclosure is created around the wing. This will be the fluid domain present around the wing and in this case it will be air medium. After the enclosure is generated a boolean operaion is performed to create a cavity around which the analysis will be performed. The entire enclosure is then cut into a single symmetry which greatly reduces the processing time, generate node and time taken to perform the entire analysis.



Details View

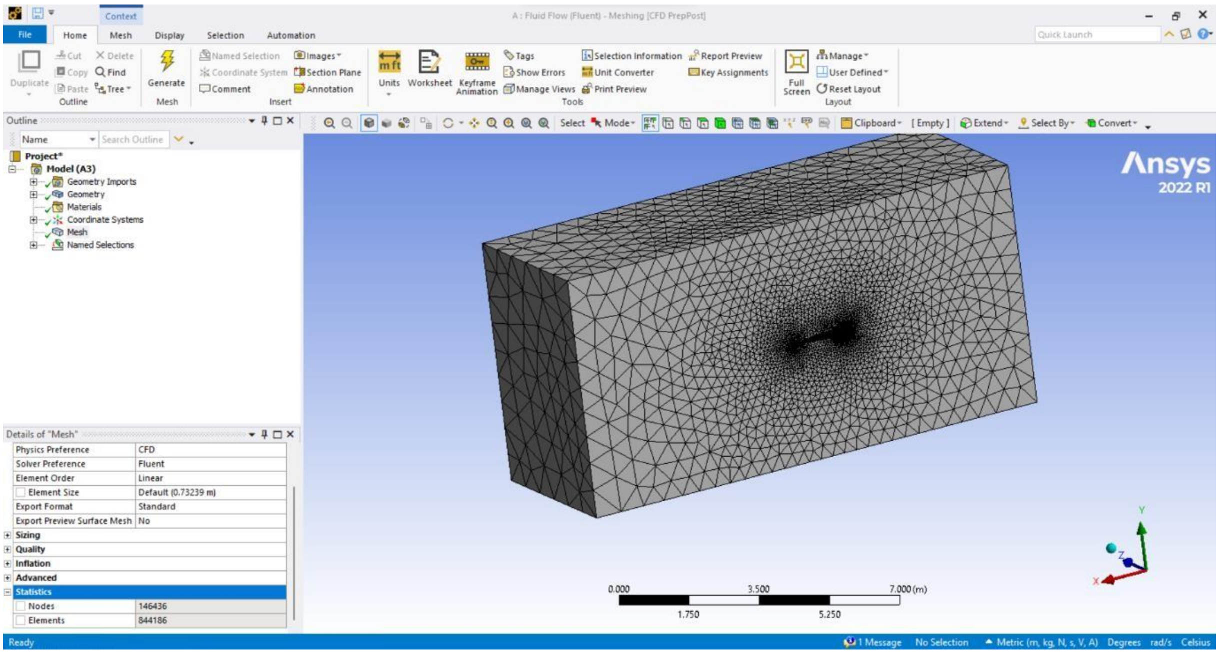
Details of Enclosure1

Enclosure	Enclosure1
Shape	Box
Number of Planes	0
Cushion	Non-Uniform
☐ FD1, Cushion +X value (>0)	6 m
☐ FD2, Cushion +Y value (>0)	3 m
☐ FD3, Cushion +Z value (>0)	3 m
☐ FD4, Cushion -X value (>0)	5 m
☐ FD5, Cushion -Y value (>0)	3 m
☐ FD6, Cushion -Z value (>0)	3 m
Target Bodies	All Bodies

Fig 6.7.3 Analysis 2

Meshing

After the entire preprocessing is done the entire enlosure is subjected to meshing which breaksdown the enitre geomtry into smaller elements. These elements are treated as individual componets and calculations are performed on them individually. As the meshing size increases the result is more accurate and presice but on the contrary it also increase the load on the processor and inceases the calulation time. An equilibrium needs to be met in order to get accurate results as well as take less time for processing.



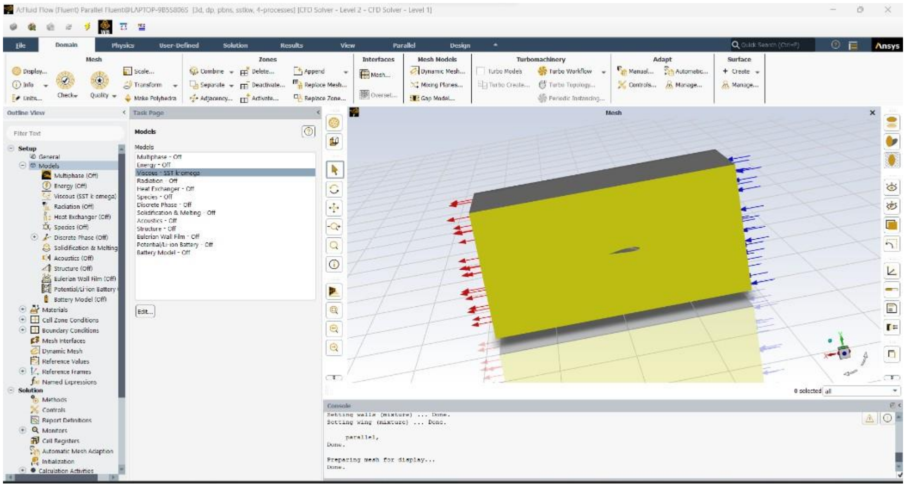
Details of "Mesh"

Physics Preference	CFD
Solver Preference	Fluent
Element Order	Linear
☐ Element Size	Default (0.73239 m)
Export Format	Standard
Export Preview Surface Mesh	No
⊞ Sizing	
⊞ Quality	
⊞ Inflation	
⊞ Advanced	
⊟ Statistics	
☐ Nodes	146436
☐ Elements	844186

Fig 6.7.4 Analysis 3

Model selection

After the meshing is done and all criterias are met the proper model need to be selected in order to get the desired output. Here we use standard k -episilon model. K-epsilon (k-ε) turbulence model is **the most common model used in computational fluid dynamics (CFD) to simulate mean flow characteristics for turbulent flow conditions**. It is a two equation model that gives a general description of turbulence by means of two transport equations (partial differential equations, PDEs).



Models

Multiphase - Off
Energy - Off
Viscous - SST k-omega
Radiation - Off
Heat Exchanger - Off
Species - Off
Discrete Phase - Off
Solidification & Melting - Off
Acoustics - Off
Structure - Off
Eulerian Wall Film - Off
Potential/Li-ion Battery - Off
Battery Model - Off

```
Setting walls (mixture) ... Done.
Setting wing (mixture) ... Done.

    parallel,
Done.

Preparing mesh for display...
Done.
```

Fig 6.7.5 Analysis 4

Transport equations for standard k-epsilon model:

For turbulent kinetic energy k:

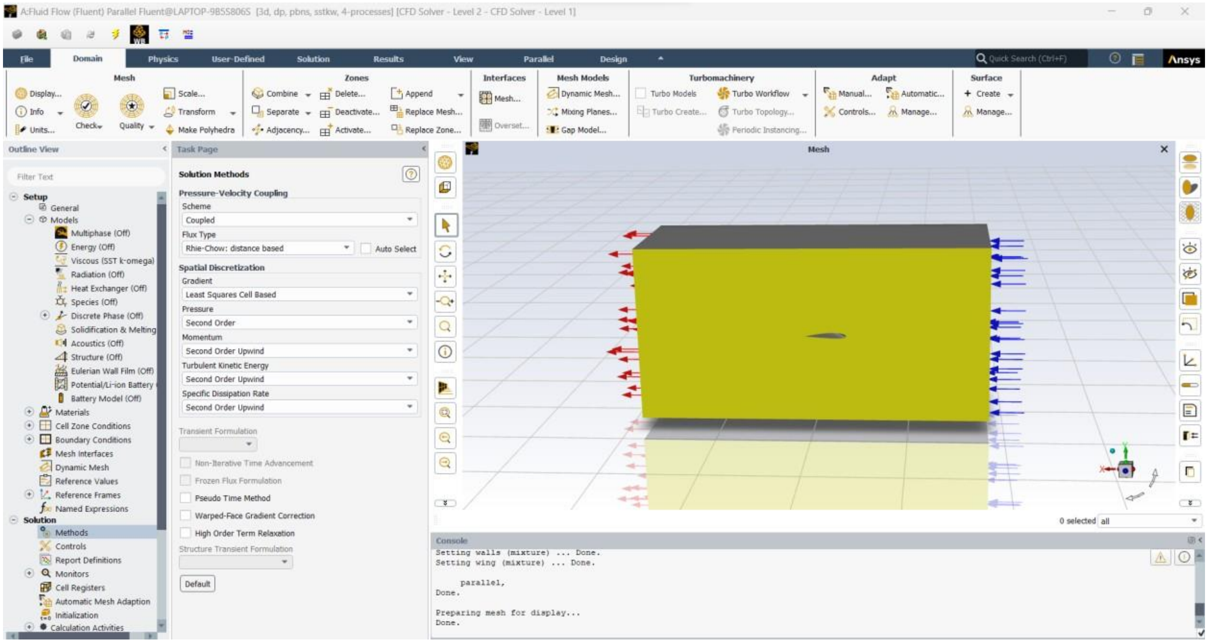
$$\frac{\partial}{\partial t}(\rho k)+\frac{\partial}{\partial x_i}(\rho k u_i)=\frac{\partial}{\partial x_j}\left[\left(\mu+\frac{\mu_t}{\sigma_k}\right)\frac{\partial k}{\partial x_j}\right]+P_k+P_b-\rho\epsilon-Y_M+S_k$$

For dissipation ϵ

$$\frac{\partial}{\partial t}(\rho\epsilon)+\frac{\partial}{\partial x_i}(\rho\epsilon u_i)=\frac{\partial}{\partial x_j}\left[\left(\mu+\frac{\mu_t}{\sigma_\epsilon}\right)\frac{\partial\epsilon}{\partial x_j}\right]+C_{1\epsilon}\frac{\epsilon}{k}(P_k+C_{3\epsilon}P_b)-C_{2\epsilon}\rho\frac{\epsilon^2}{k}+S_\epsilon$$

Method selection

After the model we select the second oderer upwind method.



Solution Methods

Pressure-Velocity Coupling

Scheme: Coupled

Flux Type: Rhie-Chow: distance based ☐ Auto Select

Spatial Discretization

Gradient: Least Squares Cell Based

Pressure: Second Order

Momentum: Second Order Upwind

Turbulent Kinetic Energy: Second Order Upwind

Specific Dissipation Rate: Second Order Upwind

Transient Formulation

☐ Non-Iterative Time Advancement

☐ Frozen Flux Formulation

☐ Pseudo Time Method

☐ Warped-Face Gradient Correction

☐ High Order Term Relaxation

Structure Transient Formulation

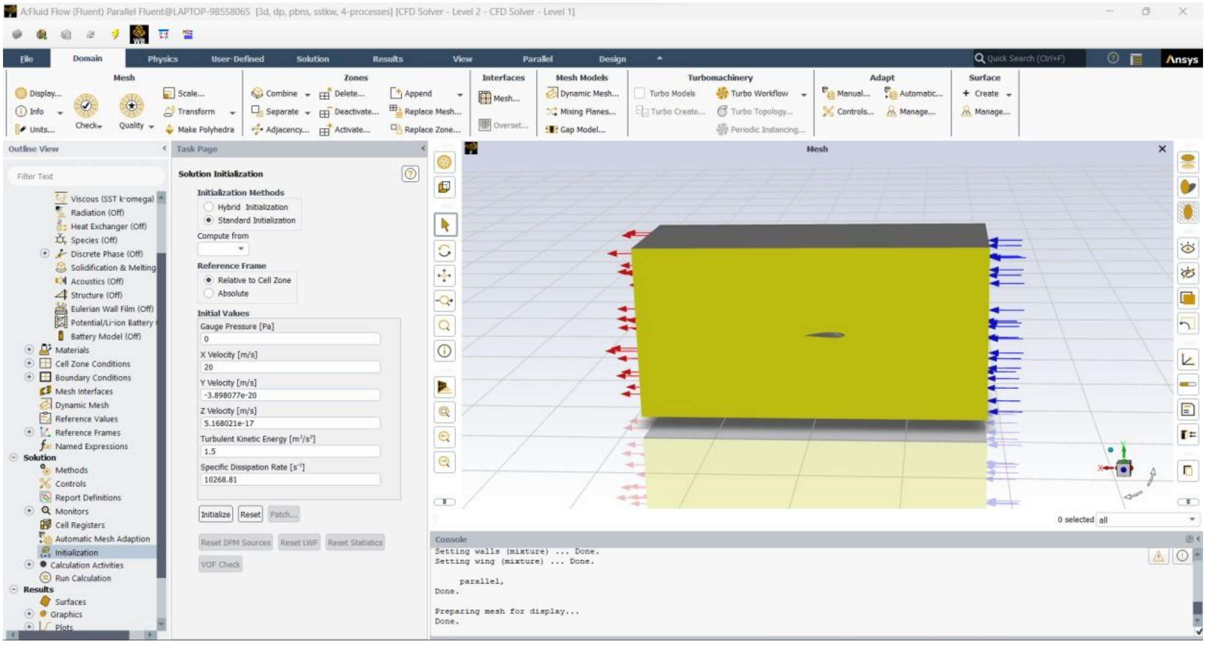
Default

```
Setting walls (mixture) ... Done.
Setting wing (mixture) ... Done.

     parallel,
Done.

Preparing mesh for display...
Done.
```

Fig 6.7.6 Analysis 5

Initialization

After the entire set up process and selecting the model and method we initalize the boundry condition as we have only one inlet and one outlet.



Solution Initialization

Initialization Methods

○ Hybrid Initialization

● Standard Initialization

Compute from

Reference Frame

● Relative to Cell Zone

○ Absolute

Initial Values

Gauge Pressure [Pa]: 0

X Velocity [m/s]: 20

Y Velocity [m/s]: -3.898077e-20

Z Velocity [m/s]: 5.168021e-17

Turbulent Kinetic Energy [m²/s²]: 1.5

Specific Dissipation Rate [s⁻¹]: 10268.81

Initialize Reset Patch...

Reset DPM Sources Reset LWF Reset Statistics

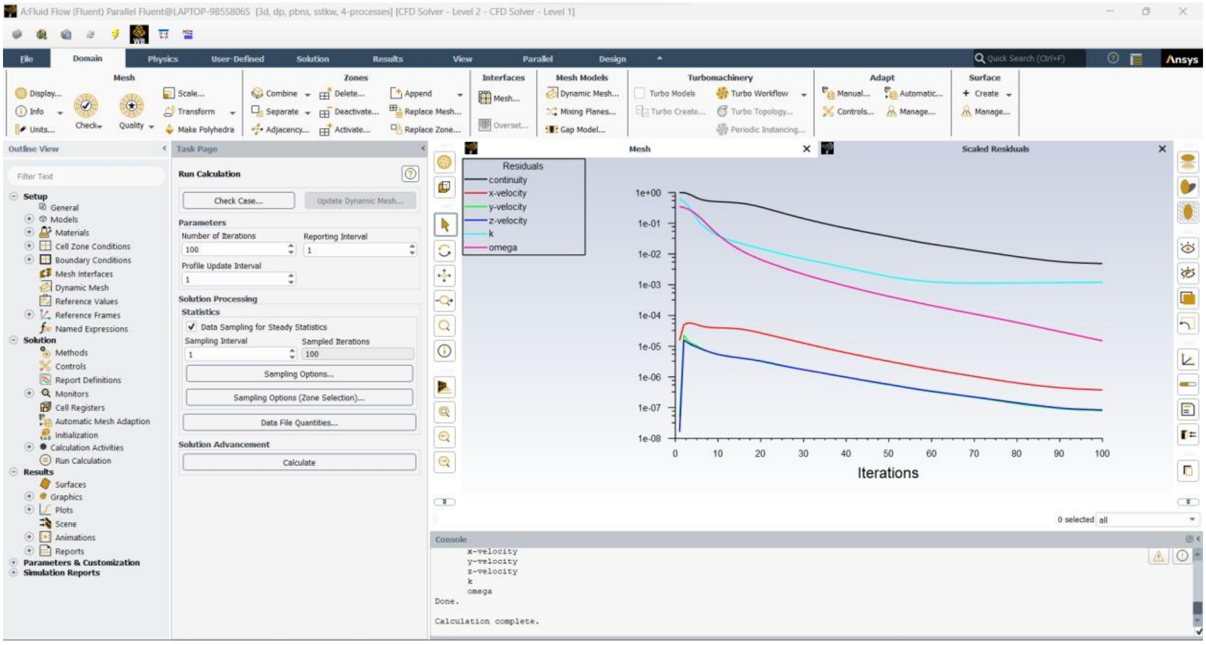
VOF Check

```
Setting walls (mixture) ... Done.
Setting wing (mixture) ... Done.

     parallel,
Done.

Preparing mesh for display...
Done.
```

Fig 6.7.7 Analysis 6

Calculation

After The entire preprocessing is complete then we check for any defects and if everthing is performed correctly we move ahead with the calculation. We have conducted the calculation for 100 iterations with various parameter like omega and epsilon.



A:Fluid Flow (Fluent) Parallel Fluent@LAPTOP-9BS5806S [3d, dp, pbns, sstkw, 4-processes] [CFD Solver - Level 2 - CFD Solver - Level 1]

Run Calculation

Parameters

Number of Iterations: 100

Reporting Interval: 1

Profile Update Interval: 1

Solution Processing

Statistics

☑ Data Sampling for Steady Statistics

Sampling Interval: 1

Sampled Iterations: 100

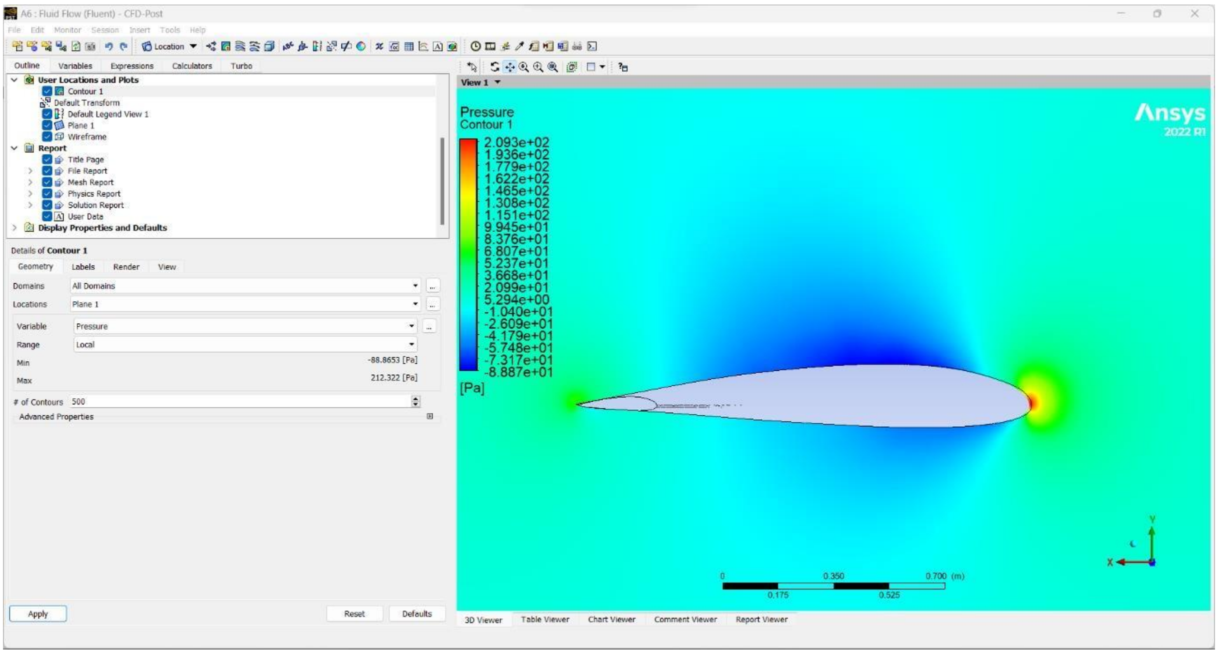
```
       x-velocity
       y-velocity
       z-velocity
       k
       omega
Done.

Calculation complete.
```

Fig 6.7.8 Analysis 7

Results

After the post processing we can use different tools in ansys to view the results. We first open the model in result viewer and project a plane on the symmetry. We can then perform differtent results like pressure difference and velocity.

Pressure Contour:



A6 : Fluid Flow (Fluent) - CFD-Post

Details of Contour 1

Domains: All Domains

Locations: Plane 1

Variable: Pressure

Range: Local

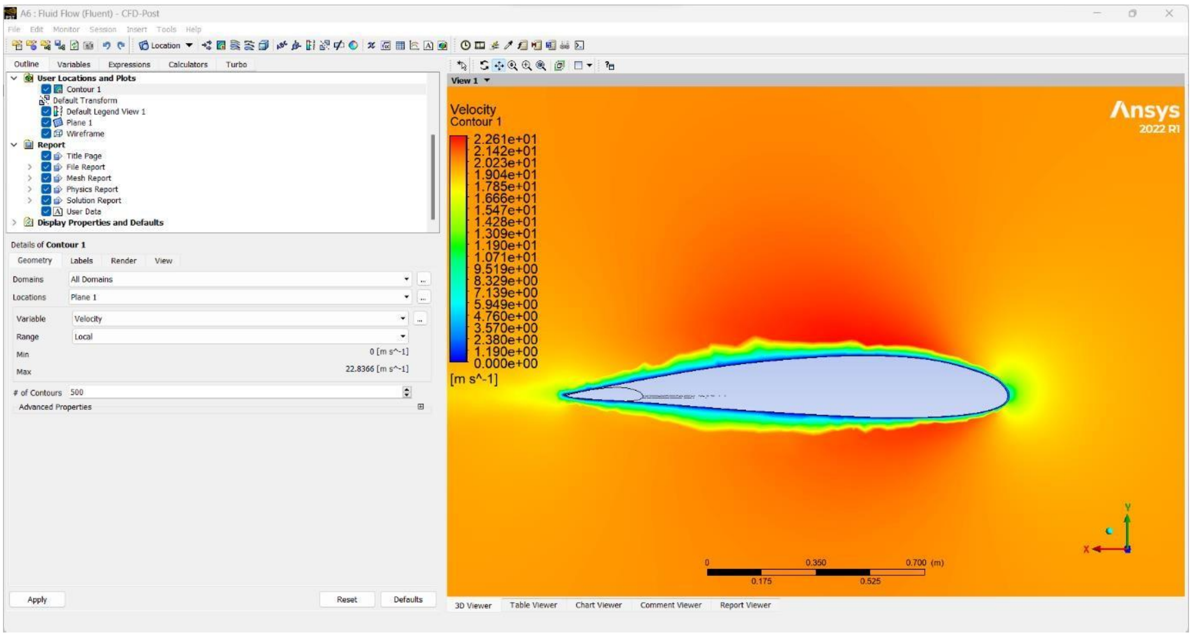
Min: -88.8653 [Pa]

Max: 212.322 [Pa]

\# of Contours: 500

Fig 6.7.9 Pressure Contour

Velocity Contour:



A6 : Fluid Flow (Fluent) - CFD-Post

Details of Contour 1

Domains: All Domains

Locations: Plane 1

Variable: Velocity

Range: Local

Min: 0 [m s^-1]

Max: 22.8366 [m s^-1]

\# of Contours: 500

Fig 6.7.10 Velocity Contour

CHAPTER 7

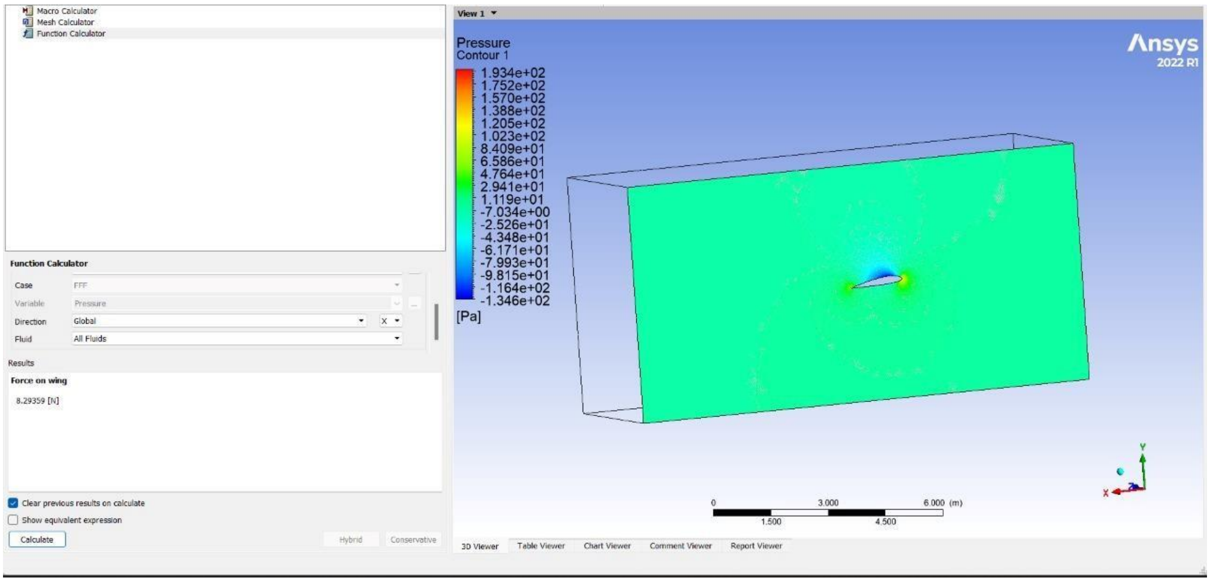
RESULTS AND CONCLUSION

The cropped delta wing design for a vertical take off and landing drone was accomplished with a calculated aspect ratio of 4. It has a wing span of 0.80 m and the root chord length of 0.35. The total area of the wing is 0.1616 squared meter. The total weight is 10 kg. The maximum velocity used for design is 10 m/s. The coefficient of lift is calculated as 0.46 at an angle of attack of 5 degrees. Based on the above data the air foil selected is NACA 2412. After performing the CFD analysis on the cropped delta wing design, the lift produced at an angle of attack of zero degree is 24.2087 N and the drag produced is 4.09613 N. The lift produced at an angle of attack of 3 degrees is 87.1569 N and the drag produced is 5.85403 N. At an angle of attack of 5 degrees the lift produced is 128.893 N and the drag produced is 8.29359 N. The wing loading is calculated as 61.88 kg/meter squared. The following results are plotted in the table below

PARAMETERS	VALUES
Wing span	0.80 meters
Root chord length	0.35 meters
Aspect ratio	4
Coefficient of lift	0.46
Total weight	10 kgs
Air foil	NACA 2412
velocity	10 m/s
Area of wing	0.1616 squared meter
Wing loading	61.88 kg/meter squared

ANGLE OF ATTACK (DEGREES)	COEFFICIEN OF LIFT	LIFT (NEWTON)	DRAG (NEWTON)
0	0.3	24.2087	4.09613
3	0.46	87.1569	5.85403
5	0.8	128.893	8.29359

In this study, design and performance analysis of a cropped delta wing for a fixed wing VTOL the geometric and aerodynamic design is done for low drag and high lift coefficient to improve the overall efficiency of the drone. The wing is designed in the shape of a cropped delta wing to increase lift at low speeds, improve the wing loading capacity and achieve a larger wing area with the same aspect ratio. From the analysis performed on the wing we are able to deduce that at low angles of attack we are able to produce more lift and less drag and thus improves the load carrying capacity of VTOLS when compared to their original payload values. The designed cropped delta wing can be adapted to existing fixed wing VTOL designs to improve their efficiency and make the overall design more compact.



Function Calculator

Case: FFF
Variable: Pressure
Direction: Global X
Fluid: All Fluids

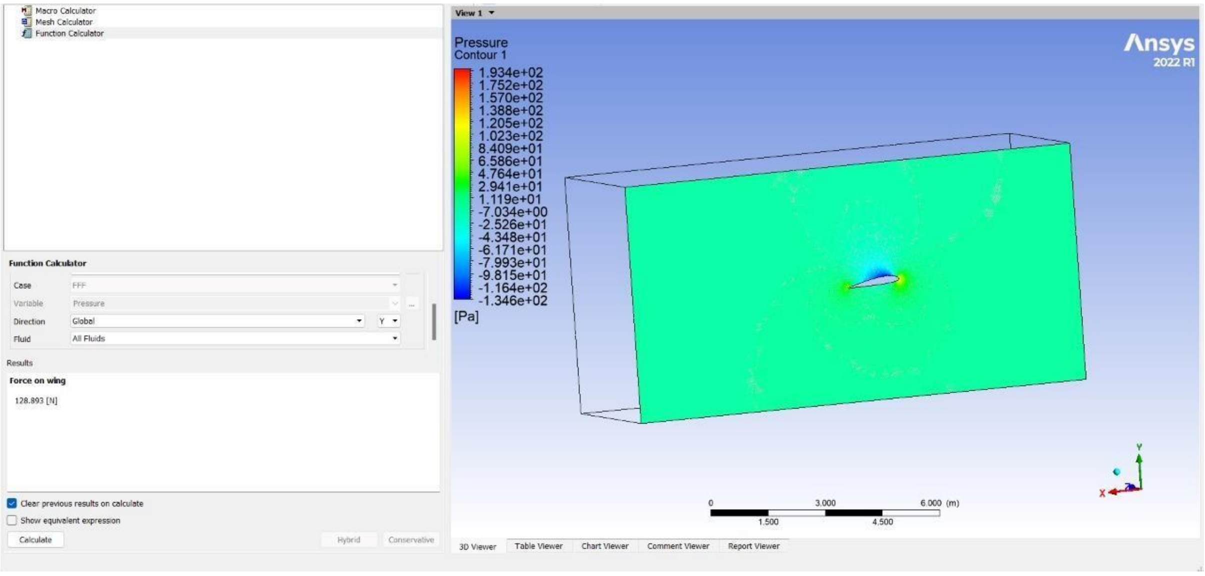
Results

Force on wing

8.29359 [N]

☑ Clear previous results on calculate
☐ Show equivalent expression

Fig 7.1 Result 1



Function Calculator

Case: FFF

Variable: Pressure

Direction: Global Y

Fluid: All Fluids

Results

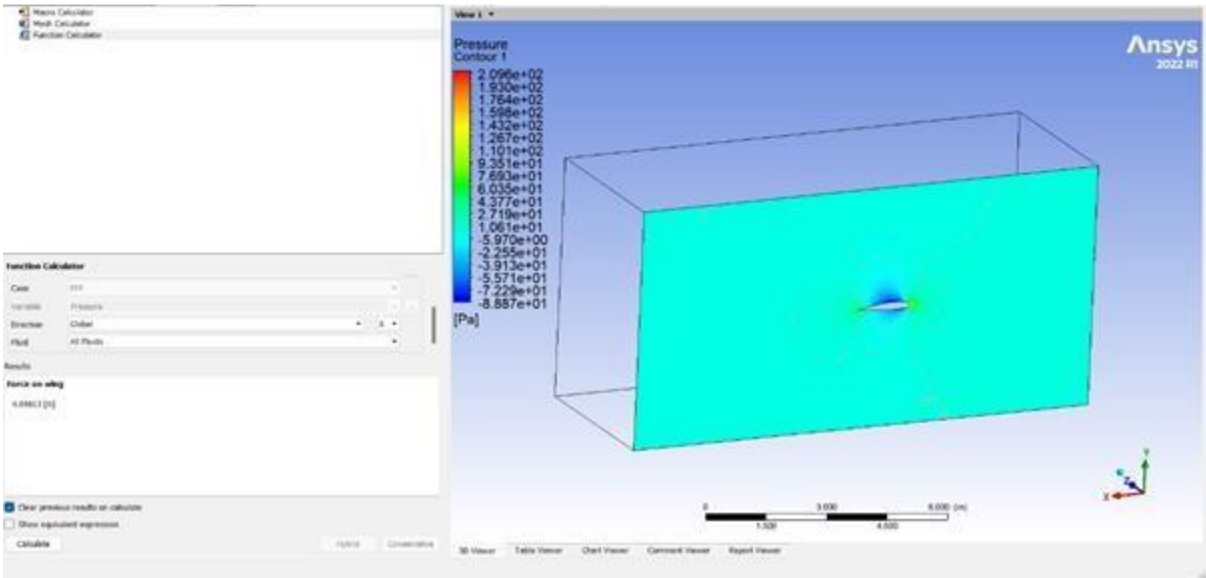
Force on wing

128.893 [N]

☑ Clear previous results on calculate

☐ Show equivalent expression

Fig 7.2 Result 2



Function Calculator

Case: FFF

Variable: Pressure

Direction: Global X

Fluid: All Fluids

Results

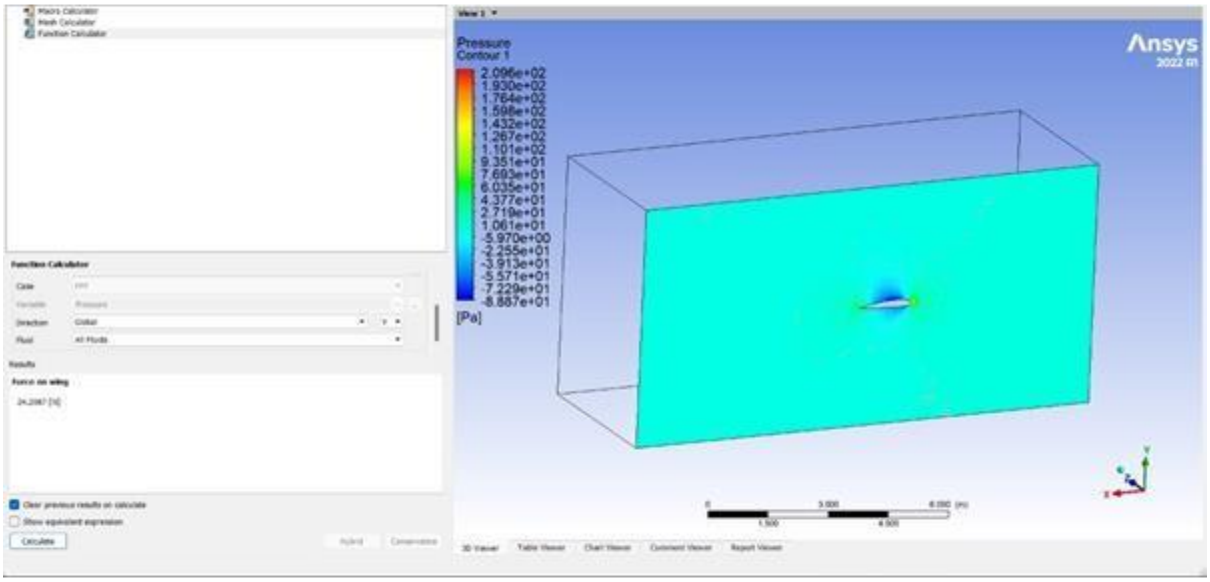
Force on wing

4.09813 [N]

☑ Clear previous results on calculate

☐ Show equivalent expression

Fig 7.3 Result 3



Function Calculator

Case: FFF

Variable: Pressure

Direction: Global Y

Fluid: All Fluids

Results

Force on wing

24.2087 [N]

☑ Clear previous results on calculate

☐ Show equivalent expression

Fig 7.4 Result 4

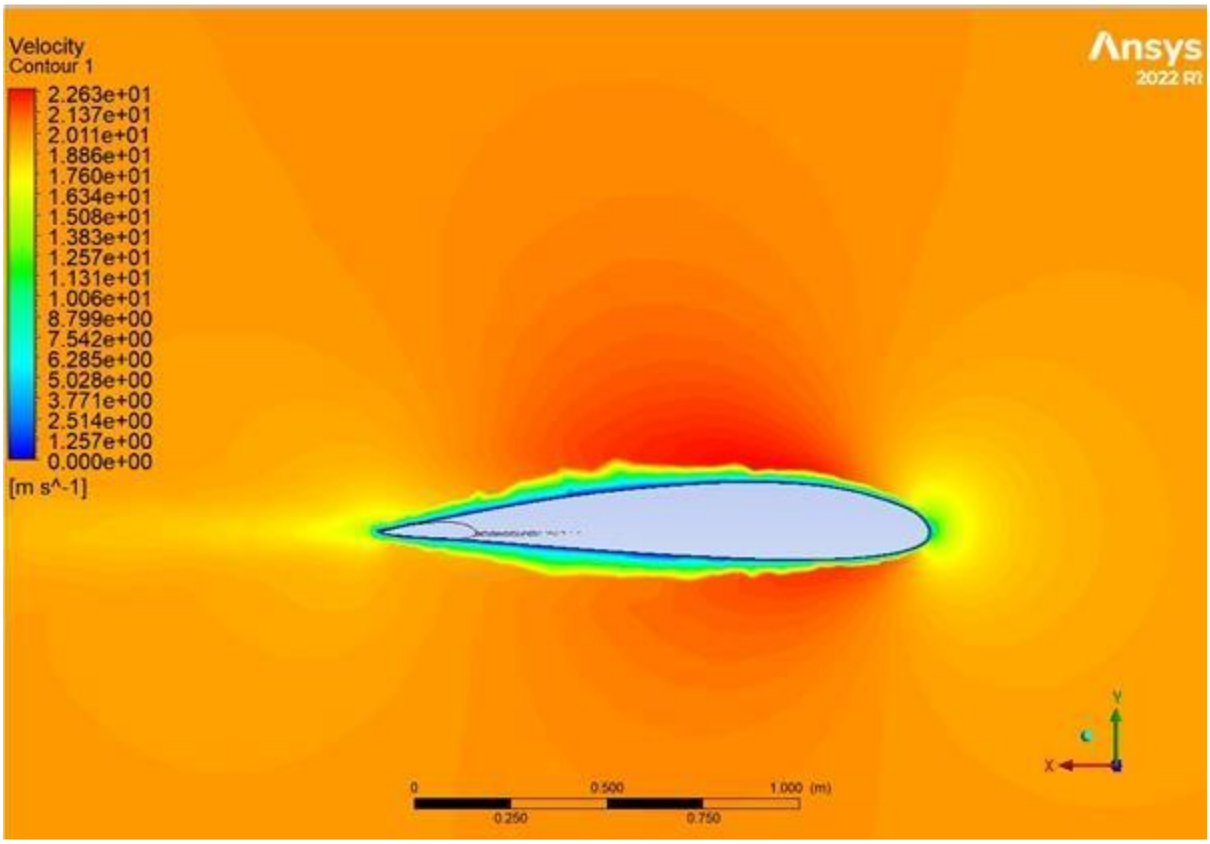


Fig 7.5 Result 5

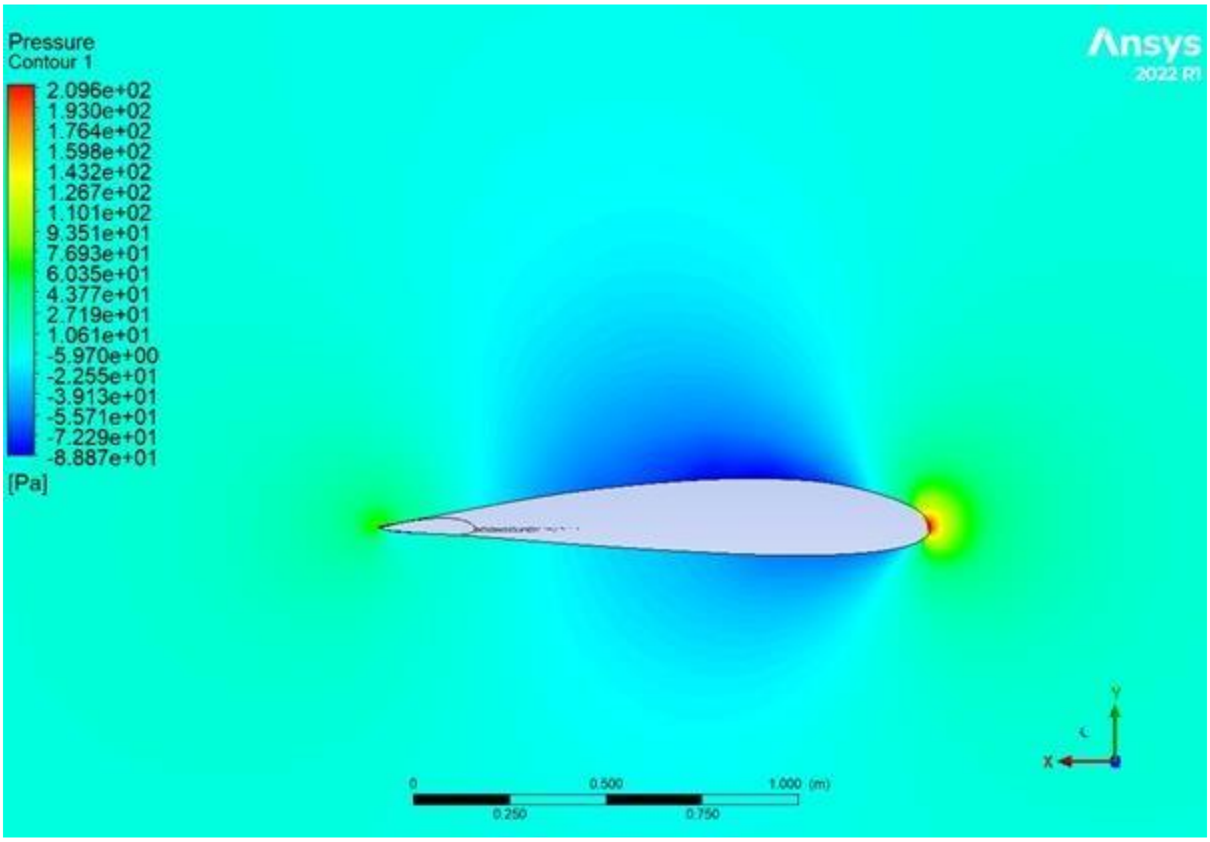


Fig 7.6 Result 6

CHAPTER 8

FUTURE SCOPE

The designed cropped delta wing has increased the VTOL operational parameters to a large extent and the fully fabricated operational VTOL can be used for the following uses: -

1. Military operations: VTOL aircraft can take off and land in confined spaces, making them suitable for use on aircraft carriers or in urban environments. The wing designed with increased payload capacity is suitable and the manoeuvrability is increased as the stall to attack angle characteristics.
2. Search and rescue: VTOL aircraft can hover in one place, making them useful for searching for missing persons or conducting rescue operations. The use of optical and thermal sensors will increase the capability. Delta wings generate a lot of lift, which is necessary for VTOL aircraft to take off and land vertically.
3. Agriculture: VTOL drones can be used for precision agriculture, such as crop dusting or monitoring crop health using image sensors and lidar.
4. Package delivery: VTOL aircraft can be used to deliver packages to hard-to-reach or urban locations.
5. Public transportation: VTOL aircraft could potentially be used for urban air transportation, providing a fast and efficient way to travel within cities.
6. Exploration and surveillance: VTOL aircraft can be used to explore and survey hard-to-reach or hazardous areas, such as disaster zones or oil rigs.

CHAPTER 9

REFERENCES

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2. https://www.hindawi.com/journals/je/2022/1803638/
3. https://www.diva-portal.org/smash/get/diva2:126844/FULLTEXT01.pdf
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12. https://grabcad.com/library/heliplane-drone-volt-1
13. https://grabcad.com/library/northrop-grumman-b-2-spirit-1
14. https://peer.asee.org/aerodynamic-performance-of-the-naca-2412-airfoil-at-low-reynolds-number.pdf
15. https://onlinelibrary.wiley.com/doi/10.1002/9781118352700.ch5

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