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Analysis of an RC Aircraft WingWith Flexible Sweep, Anhedral and Dihedral Angles

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Abstract:

Unmanned Aerial Vehicles (UAVs) have a wide range of applications, including cargo transport, mapping, and surveillance. However, during flight, UAVs, particularly remote-controlled (RC) aircraft, face challenges such as gusty winds, crosswinds, changing weather conditions, and uneven terrain, making stable flight difficult. Depending on the specific use case, the roll stability and maneuverability of RC aircraft become critical factors. Current UAVs are typically designed with fixed-wing configurations, such as dihedral, anhedral, or straight wings. This limits their performance to the capabilities of the chosen configuration. Therefore, there is a need for an RC aircraft that can adapt its wing configuration in-flight, allowing it to switch between dihedral, anhedral, and variable swept positions, giving the pilot greater control. Dihedral wings improve roll stability, anhedral wings enhance roll maneuverability, and backward-swept wings reduce wave drag and shockwaves at high speeds. This work aims to design a cargo RC aircraft with a mechanism that integrates all these wing configurations. The aircraft and mechanism are modelled in 3D using Fusion 360, and air foil and plane analysis are conducted in XFLR5 to evaluate aerodynamic parameters. Additionally, Computational Fluid Dynamics (CFD) analysis is performed on the different wing configurations to assess their changing aerodynamic characteristics.

Keywords: Aircraft; maneuverability, Unmanned Vehicle

1. Introduction

Unmanned Air Vehicles (UAVs) are increasingly prominent in both unconventional and asymmetric military roles, as well as in a variety of civilian applications. Their growing use stems from their versatility, cost-effectiveness, and ability to operate in environments that are too dangerous or inaccessible for manned aircraft. As UAVs are designed for a wide range of missions, they must meet conflicting performance requirements, such as speed, endurance, and manoeuvrability, which can change depending on the operational environment.

One approach to meeting these diverse mission requirements is through dynamic on-board reconfiguration capabilities, allowing UAVs to adapt their flight characteristics during operation. Conventional fixed-wing aircraft designs, while efficient for certain types of flight, often impose limitations on UAVs' ability to operate in highly dynamic or varied conditions. For instance, a fixed-wing aircraft designed for high-speed performance may struggle in low-speed, high-endurance scenarios, and vice versa. This is where wing morphing—the ability to change the shape of the wings during flight—comes into play as a promising solution. Wing morphing allows UAVs to modify their aerodynamic properties in response to different mission requirements, improving performance in a variety of flight conditions. By changing wing shape, UAVs can optimize lift, drag, and other factors that directly influence speed, agility, fuel efficiency, and the ability to operate in confined or turbulent environments.

In military roles, especially in asymmetric warfare where threats are unpredictable and environments vary from urban landscapes to remote mountainous regions, UAVs with morphing wings can perform reconnaissance, surveillance, and precision strikes more effectively. In civilian roles, such as search and rescue, environmental monitoring, or delivery services, morphing UAVs offer enhanced flexibility and efficiency. The integration of wing morphing technology represents a significant step toward achieving more versatile UAV designs capable of handling the broad spectrum of modern operational demands.

UAVs require stability to handle disturbances like gust loads, crosswinds, and uneven stick moments. Traditional UAV designs use fixed-wing configurations with dihedral, anhedral, or straight wings. Each configuration has its advantages and limitations. For instance, a dihedral wing offers good roll stability but limited maneuverability, while an anhedral wing improves maneuverability but may reduce stability. Straight, un-swept wings experience higher drag as they approach the speed of sound due to shockwaves, whereas forward-swept wings delay shockwave onset and reduce drag.Forward-swept wings also allow the aircraft to maintain airflow at steeper climb angles, reducing the risk of stalling. Therefore, a UAV with adjustable dihedral and sweep angles can combine the benefits of both dihedral-anhedral configurations and variable sweep configurations. This allows the pilot to control roll stability and maneuverability based on flight conditions, offering a significant advantage.

William P. Rodden [1] The dihedral effect of a flexible wing is considered a critical aeroelastic concern due to its influence on lateral-directional dynamic stability. Dihedral plays a key role in stability, and significant dihedral changes can occur due to symmetrical bending of the wing during longitudinal maneuvers that exceed the limit load factor. To take advantage of recent advancements in lifting surface theory, the estimation of dihedral effect has been reframed in terms of both structural and aerodynamic impact coefficients. Experimental results, along with other cited examples, suggest that the aeroelastic shift in dihedral effect at the limit load factor can match the values predicted using rigid models.

W. F. Phillips [2] The dihedral effect of a wing can be addressed analytically. For a typical aircraft, the wing's dihedral angle significantly influences the change in rolling moment caused by sideslip. Dihedral impacts the roll stability derivative by causing the lift on the left and right semi-spans to respond differently to sideslip, leading to an imbalance that contributes to the aircraft's roll stability. This asymmetry in lift distribution is crucial for maintaining lateral stability during flight.

Hafiz Muhammad Umer et al [3] Morphing aircraft, which can alter their wing shape during flight, offer the potential for superior performance by adapting to varying flight conditions. However, this technology presents significant interdisciplinary challenges that open up numerous design possibilities. Research in this field focuses on understanding how different wing configurations can affect the aerodynamic performance and flight stability of these aircraft. The aim of the study was to investigate the flight dynamics of small-scale UAVs with morphing wings, specifically looking at the effects of in-flight wing sweep and wingspan morphing on aerodynamic performance and stability.

The study used an open-source code based on the Vortex Lattice Method (VLM), which assumes quasi-steady flow, to analyze these effects. Linearized equations of motion were used to assess the longitudinal, lateral, and directional flight characteristics, with trim points being identified for a range of angles of attack in the prestall regime.Key findings of the study include: Wingspan morphing: This type of morphing generally provided better aerodynamic performance and more favorable flight stability characteristics compared to wing sweep morphing. However, beyond a certain wingspan extension, the aerodynamic benefits began to diminish, potentially destabilizing the UAV. Wing sweep morphing: While it did not offer as many aerodynamic advantages as wingspan morphing, wing sweep morphing had a different dynamic effect. In particular, the longitudinal flight modes (related to pitch and vertical motion) responded in the opposite manner for wingspan and sweep morphing schemes. However, in terms of lateral-directional dynamics (yaw, roll, and side-to-side motion), both morphing approaches behaved similarly.

The study concluded that while wingspan morphing tends to be more advantageous, it must be used within certain limits to avoid destabilizing effects. Additionally, the opposite dynamic behaviors observed in longitudinal flight modes between wingspan and sweep morphing schemes offer insights for optimizing UAV designs depending on the specific mission requirements.The research provides a baseline for further exploration of advanced flight dynamics and control strategies for morphing UAVs, with implications for enhancing the adaptability and performance of these vehicles in various applications.

Mestrinho, P. Gamboa, and P. Santos [4] focuses on the study, design, and validation of a variable-span morphing wing for mini UAVs. The project utilized a proprietary aerodynamic shape optimization code that combines a viscous two-dimensional panel method with a non-linear lifting-line or Vortex Lattice Method (VLM) algorithm and sequential quadratic programming. This code was employed to minimize drag and identify the optimal wing span across the UAV's speed range of 12 m/s to 35 m/s, while respecting geometric constraints. A weight model, derived from empirical data on a wing prototype, was used to estimate the weight of the variable-span wing. The results indicate that the variable-span wing can achieve a 20% reduction in drag at maximum speed compared to a fixed wing.

Furthermore, an analysis of asymmetric span control demonstrated that the variable-span wing provides roll control power equivalent to that of an aileron. An electro-mechanical actuation system was developed using an aluminum rack and pinion mechanism. The wing design was created using CAD/CAM tools, and a full-scale model was built for preliminary bench testing of the wing and actuator system[5]

2. Design and calculations of RC Aircraft

The dimensions of wing are calculated using Lift Equation and dimensions of empennage (including horizontal and vertical stabilizer), and fuselage is calculated. Certain values are assumed/considered based on referencing and previous practical experimentation.

Total mass of aircraft considered (including airframe, payload) (m) = 4 kg

Relative velocity of aircraft (v) = 10 m/s

Maximum coefficient of lift (CL) = 1.3

Aspect Ratio (AR) of wing = 3:1

Density of air at STP (d) = 1.225 kg/ m^3

Wing dimensions are calculated using Lift equation given by L = 0.5*d*v2*CL*A

Where as L- Lift force A- is area S- Span C-chord

Area of wing (A) = S*C

Area of Horizontal Stabilizer (A_{Hstab}) = 22% of Wing Area

Area of Vertical Stabilizer (A_{Vstab}) = 1/3 of Horizontal Stabilizer area

3. Modelling of RC Aircraft

The entire aircraft is 3-D modelled in Autodesk Fusion 360 as per the calculated dimensions for wing, tail and fuselage. Additionally, a motor, propeller is also assembled on the nose tip in aircraft design. Landing gear is placed at the bottom of fuselage. The middle section of fuselage is designed to carry the mechanism and also the payload as per the requirement. Air foil sections are placed throughout the wing span with rectangular spar holding them in place. The monokote sheeting is also demonstrated which helps in maintaing the integrity of the entire wing. 2D projections of the aircraft along with dimensions are also included [9].

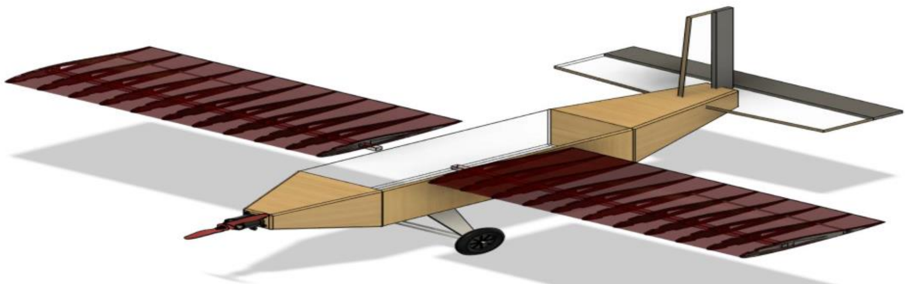

Fig 1: 3D Model of RC aircraft

4.Results and discussions

Entire plane analysis can be carried out in XFLR5 software and results which display the lift, viscous drag, induced drag, moment, downwash profiles along with parameters like coefficient of lift, coefficient of drag, CL/CD ratio are obtained

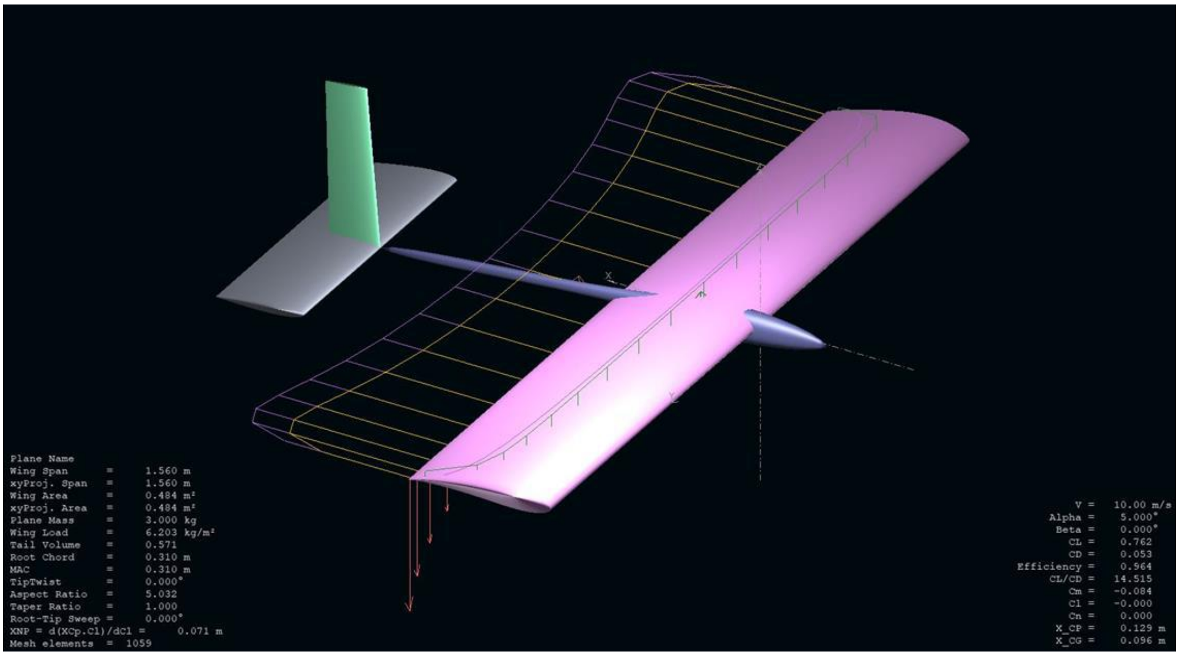

Fig 2: Plane Analysis in XFLR5

Computational Fluid Dynamics Analysis On Wing In Ansys Fluent. Steps Followed to Carryout Wing Analysis In Ansys Fluent Flow analysis is carried out for half of total span length i.e., 0.780 m with 5-degree angle of attack and for various anhedral, dihedral and sweep angles. [6]

Exact configuration details are as follows:

1 Straight wing with span of 0.780 m, 5-degree angle of attack.

2 Dihedral wing with span of 0.780 m, 5-degree angle of attack and 8 degrees' positive dihedral angle.

3Anhedral wing with span of 0.780 m, 5-degree angle of attack and 8 degrees negative dihedral angle.

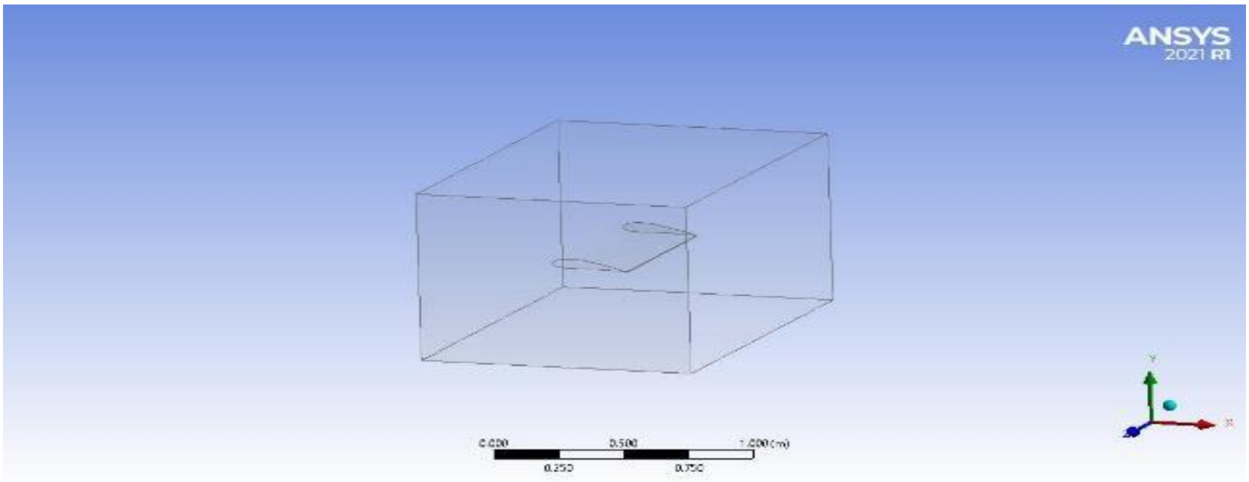

Fig 3: Geometry in Design Modeller

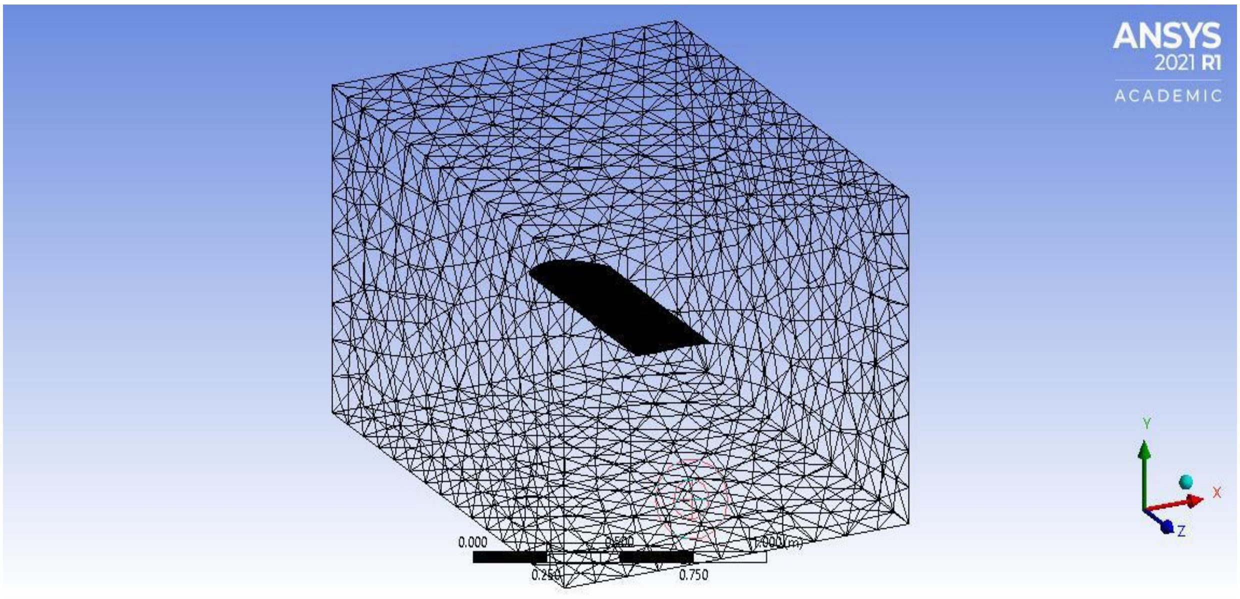

Fig 4: Meshed Geometry

Section Meshing,Numerical Reports And Velocity, Pressure Contours For Different Wing Configurations

The simulation results can be analyzed in form of numerical values obtained along with different [7.8] graphical/visual representations like pressure and velocity contours, streamline flowlines, vector representations etc .In this case, lift, drag coefficients along with lift, drag force are obtained. Velocity and Pressure Contours, Streamlines are used for graphical understanding

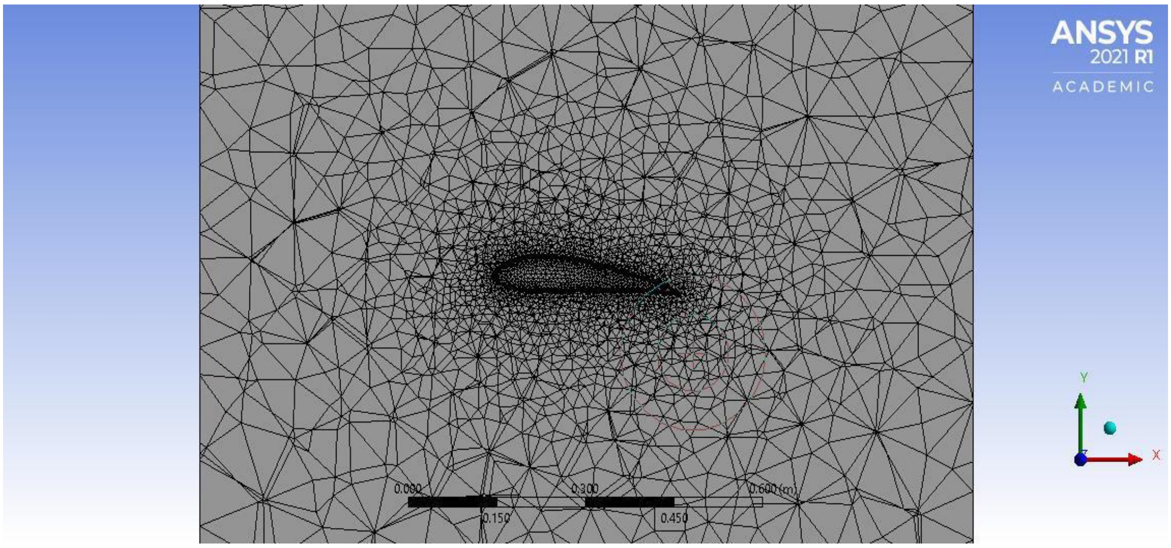

Fig 5: Straight Wing with 5 degree angle of attack

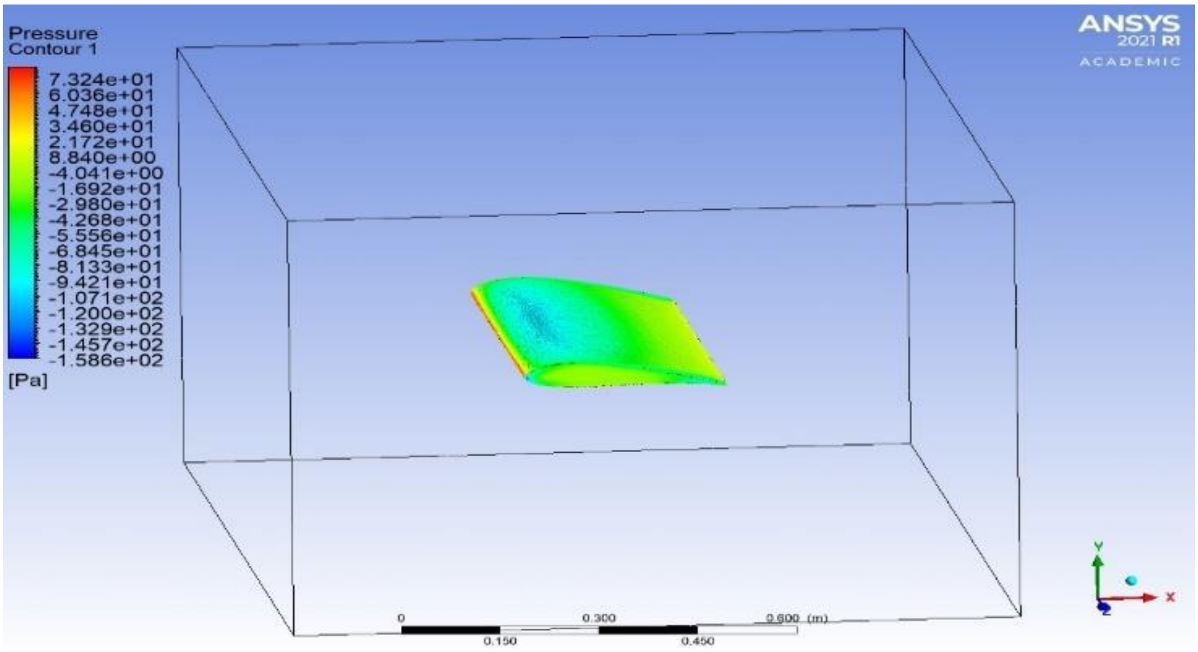

Fig6:PressureContour

Fig 6 and 7 reprresents the pressure contour and velocity profile for a Straight wing with span of 0.780 m, 5-degree angle of attack

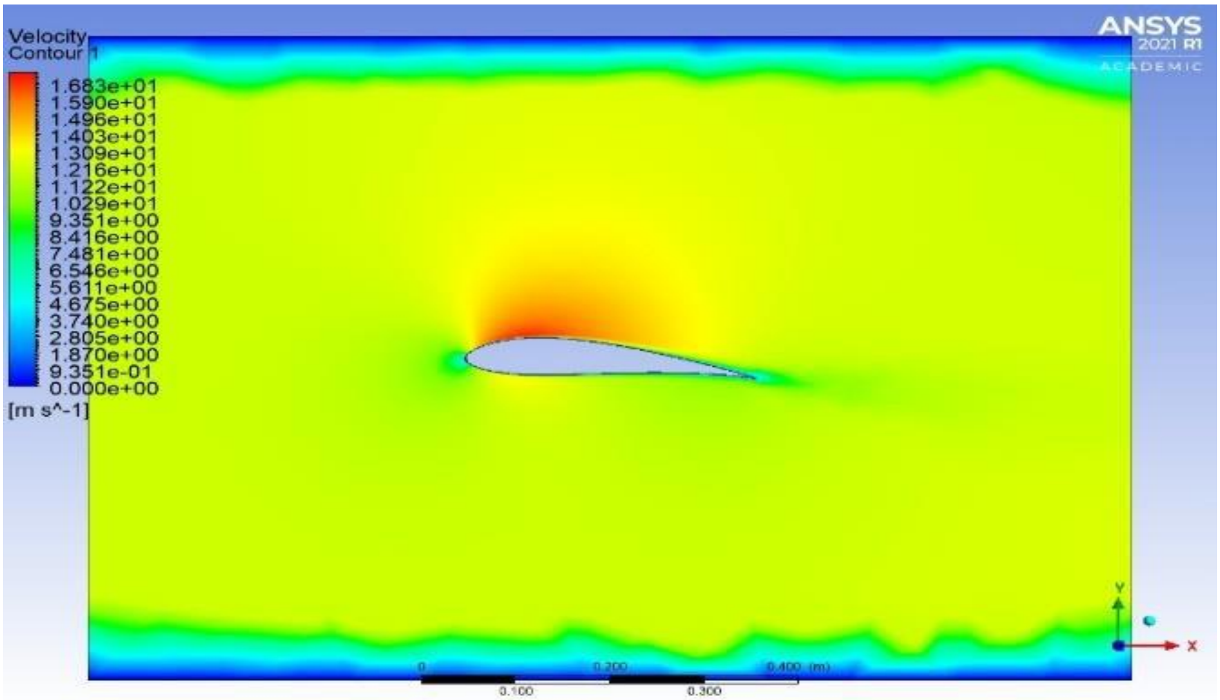

Fig7: Velocity Profile

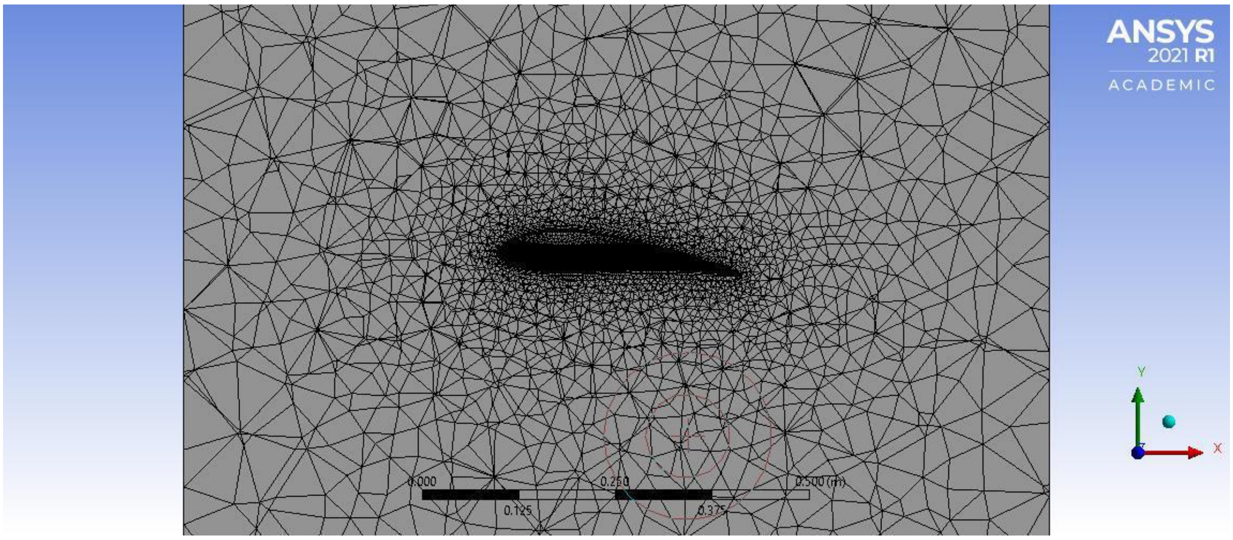

Fig 8: Dihedral Wing (8 degrees dihedral angle) with 5 degree angle of attack

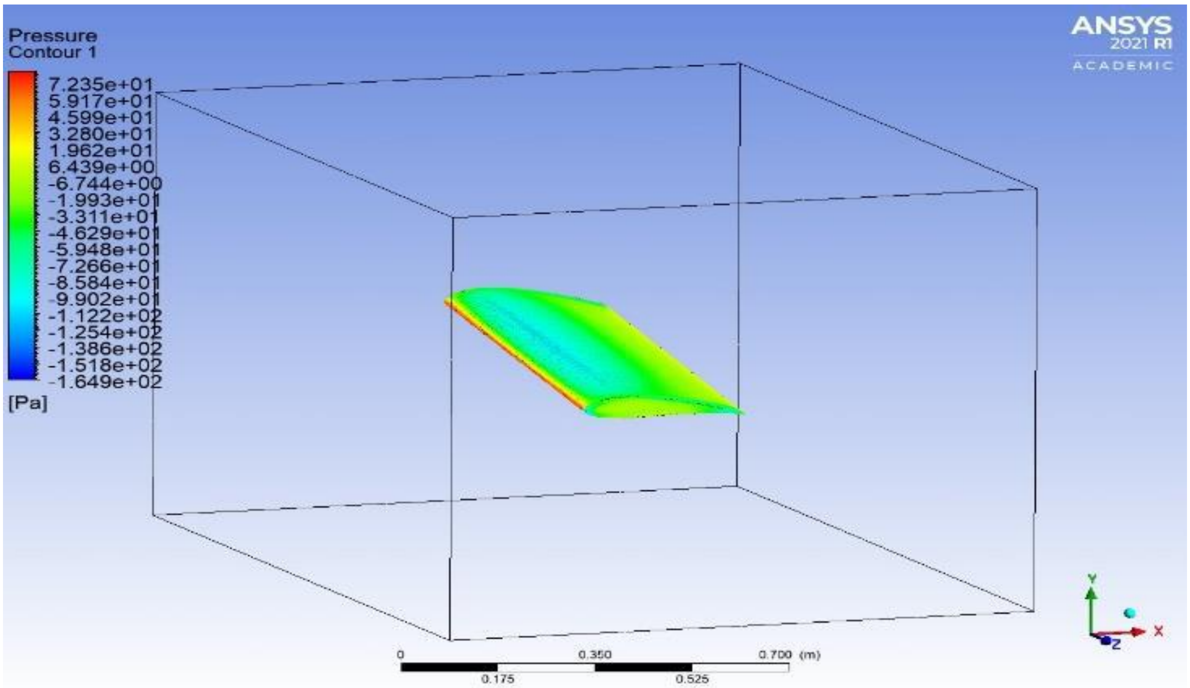

Fig9: Pressure Contour

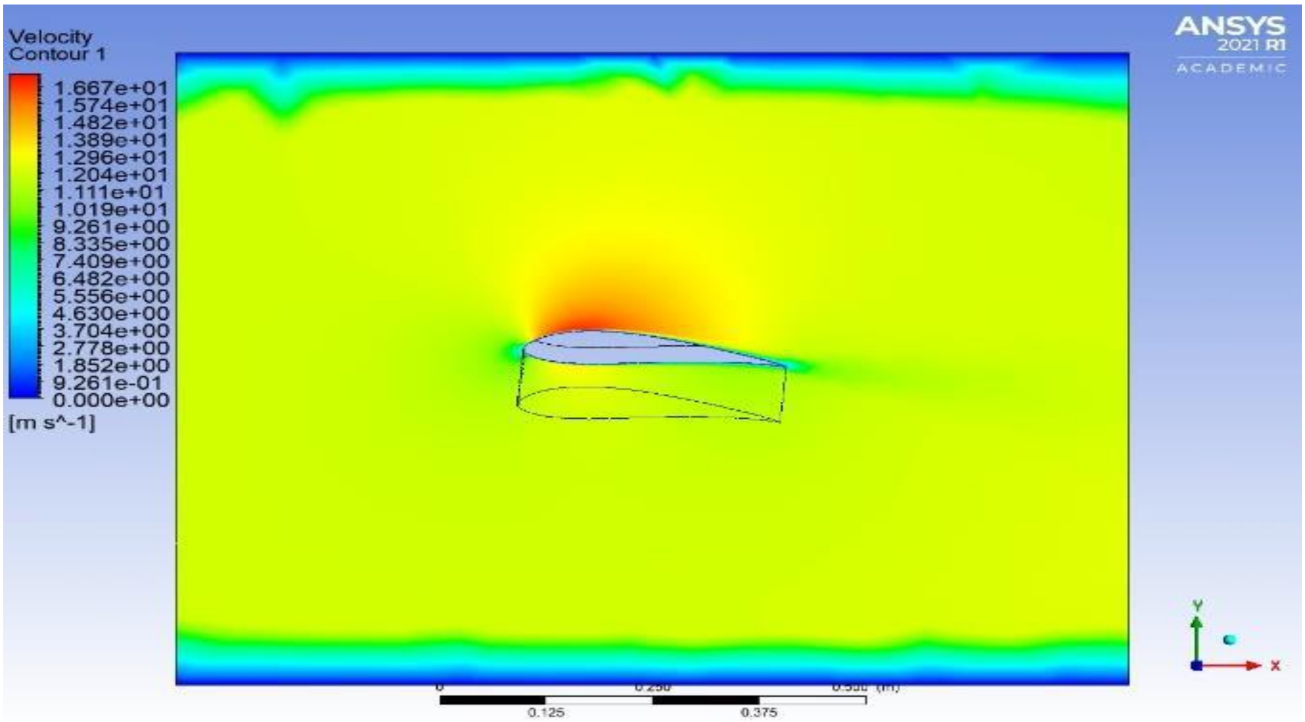

Fig10: Velocity Profile

Fig 9 and 10 reprresents the pressure contour and velocity profile for a Dihedral wing with span of 0.780 m, 5-degree angle of attack and 8 degrees' positive dihedral angle.

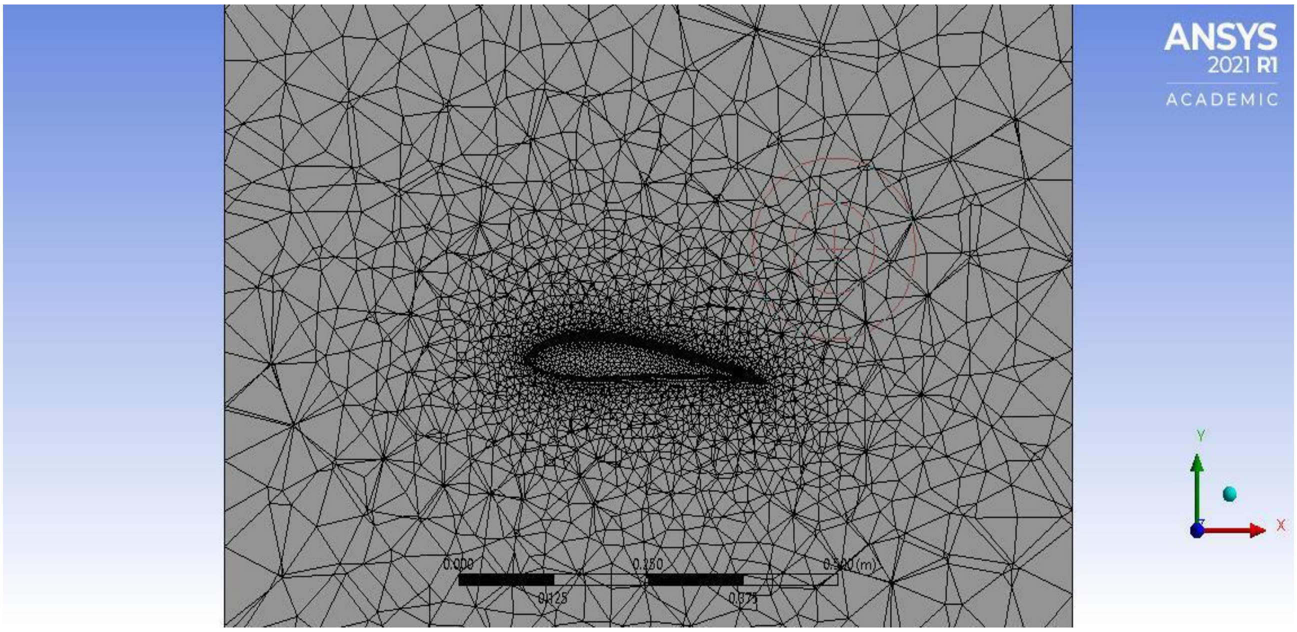

Fig11: Anhedral Wing (8 degrees negative dihedral angle) with 5 degree angle of attack

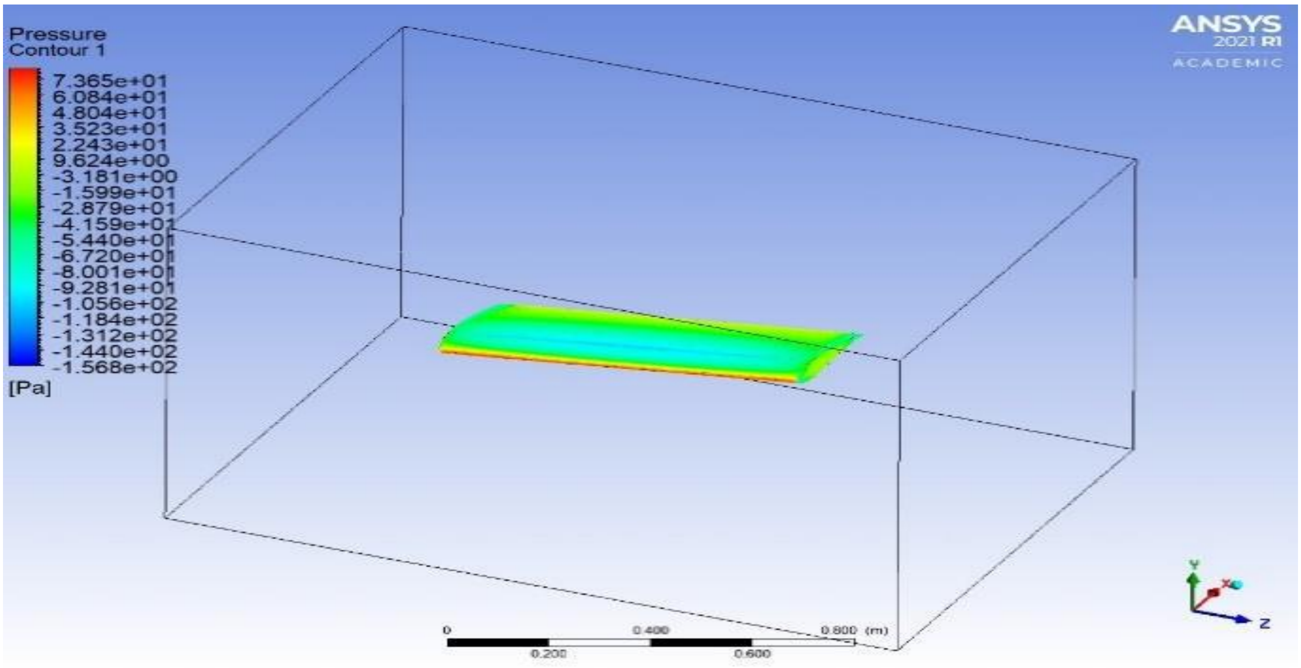

Fig12: Pressure Contour

Fig 12 and 13 reprresents the pressure contour and velocity profile for a Anhedral wing with span of 0.780 m, 5-degree angle of attack and 8 degrees negative dihedral angle.

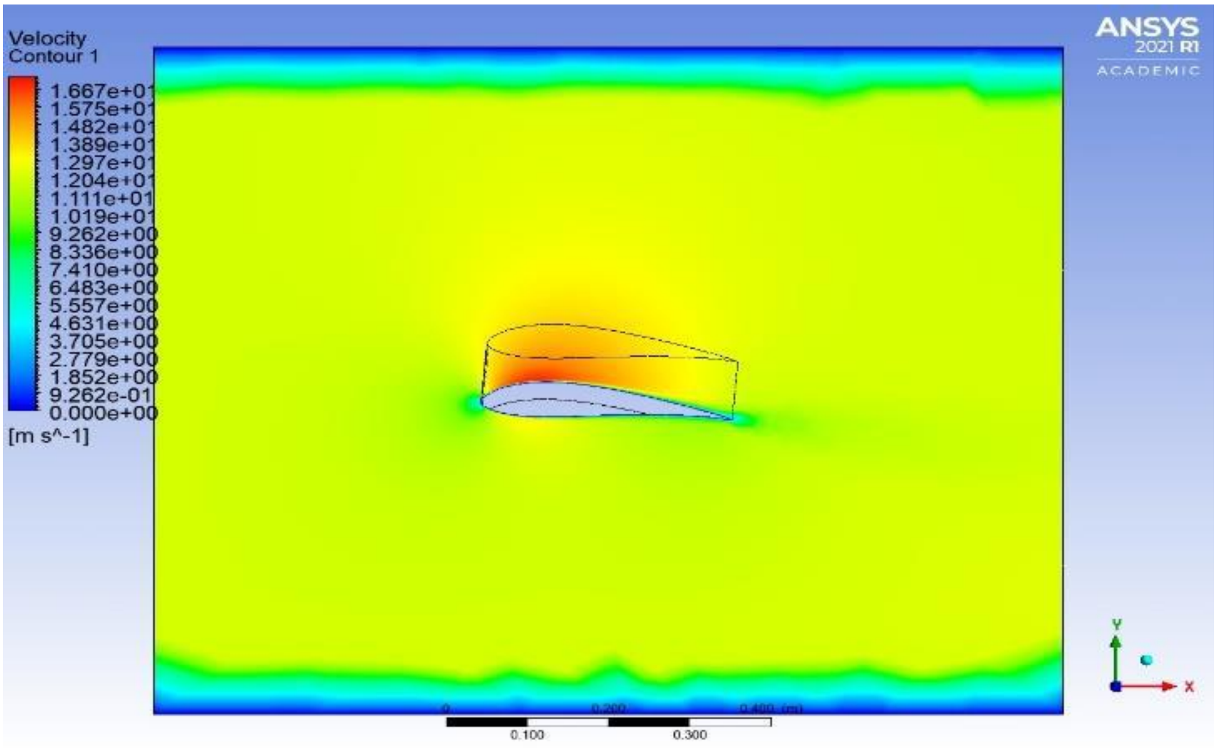

Fig13: Velocity Profile

Conclusions

Air foil and Plane analysis is successfully carried out in XFLR5 Software Flow Analysis for different wing configurations is successfully carried out in Ansys Fluent and values obtained for lift force and lift coefficient lie in acceptable range as per theoretical understanding of these configurations Velocity and Pressure Contours are obtained for different configuration also show satisfactory results Lift force is also maintained for all configurations and doesn't decrease drastically The Lift force obtained through analysis shows that it can manage carrying the airframe weight

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