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"Structural Design of Unmanned Aerial Vehicle Wing Using Fem"

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ABSTRACT

In this study, the application of computational methods in design is successfully explored. The strength and stiffness analysis of the UAV wing was performed using an FEA software ANSYS. The available CAD model and aerodynamic CFD analysis of the vehicle were used as design input. The aerodynamic loads were applied on the structure as pressure functions using a novel approach employing Artificial Neural Networks. Effects of variability in geometry, material and lay-up were also analyzed to find the best possible combination with optimal strength and stiffness amid minimum weight and cost. The finally designed wing has two spars and used an all composite structure. The wing is lighter in weight as compared to a similar wing made from Aluminum, and sufficiently strong enough to meet all in-flight load conditions and factor of safety.

1.1 INTRODUCTION OF THE PROBLEM

UAV is an acronym for Unmanned Aerial Vehicle, which is an aircraft with no pilot on board. UAVs can be remote controlled aircraft (e.g. flown by a pilot at a ground control station) or can fly autonomously based on pre-programmed flight plans or more complex dynamic automation systems.UAVs are currently used for a number of missions, including reconnaissance and attack roles.

FIGURE 1.1.1 UAV model

UAV systems have many elements other than the air vehicle, they are usually categorized by the capability or size of the air vehicle that is required to carry out the mission. However, it is possible that one system may employ more than one type of air vehicle to cover different types of mission, and that may pose a problem in its designation.

An airfoil (American English) or aero foil (British English) is the shape of a wing, blade (of a propeller, rotor, or turbine), or sail (as seen in cross-section). A wing is a type of fin that produces lift, while moving through air or some other fluid. As such, wings have streamlined cross-sections that are subject to aerodynamic forces and act as an airfoils. A wing's aerodynamic efficiency is expressed as its lift-to-drag ratio. The lift a wing generates at a given speed and angle of attack can be one to two orders of magnitude greater than the total drag on the wing. A high lift-to-drag ratio requires a significantly smaller thrust to propel the wings through the air at sufficient lift.

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UAV is smaller than a manned aircraft used in the same role, and is usually considerably cheaper in first cost. Operating costs are less since maintenance costs, fuel costs and hangarage costs are all less. The labour costs of operators are usually lower and insurance may be cheaper, though this is dependent upon individual circumstances.

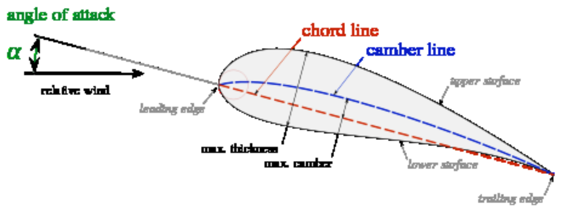

Fig: 3.1.1 Airfoil Nomenclature

2.2 STATE OF THE ART/ LITERATURE SURVEY

In 1949 a monumental work, Theory of Wing Sections (Including a Summary of Airfoil Data), was published by Abbott and von Doenhoff. This work summarized the work done to that point by NACA and included wind tunnel test results for many of the airfoil sections then in use. It is still considered the definitive reference on wing sections. The work of Abbott, von Doenhoff and others continued at Langley until 1958, when the Russians launched Sputnik I. NACA was disbanded and absorbed into the newly formed National Aeronautics and Space Administration (NASA). Boundary Layer theory, first introduced by Ludwig Prandtl in 1904, gave future designers the mathematical tools for airfoil analysis, but not until the advent of high-speed computers were researchers able to exploit this theory to the fullest. Modern day airfoils are designed using a process known as conformal mapping, where a known two-dimensional shape (in this case an airfoil section) is algebraically transformed into a simple shape (an off-center circle) in the complex plane and a simple flow is then analyzed around it. Results of this analysis are then mapped back into the real plane. While this method yields results which compare quite favorably with wind tunnel testing, the ability to slightly alter the shape with the intent of optimizing aerodynamic performance can currently only be accomplished between successive iterations. The speed of new computers and efficiency of new algorithms are such that one should be able to analyze fluid flow in the real plane, "tweaking" the airfoil shape along the way to produce the desired results.

3.2 PROPOSED WORK

In the design of UAV, the design of wing plays the vital role. During this project, the main objective is to simulate the wing verification methodology and study the parameters influences the wing performance.Selection and modeling of airfoil: The configuration of airfoil selected is NACA 25411 and its characteristics are presented in Table 1. It would give an airfoil with a maximum thickness of 11% chord, maximum camber located at 27% of the chord, with a decision lift coefficient of 0.3. Airfoil is modelled as 2D wing, since it will have the same cross sectional shape over the length. It is modeled in GAMBIT, which is capable of creating meshed geometries that can be read easily with FLUENT. The model generated is shown in Fig. 1a. There will be 25 simulations in total for five numbers of Re and 5 angles of attack. The primary forces which influence the effectiveness of airfoil are shown in Fig. 1b. Meshing has been done based on cluster points near the leading and trailing edges, keeping in mind the transition in mesh size.

Table 3.1.1 Characteristics of the air foil

Airfoil	NACA25411
Thickness	0.11
Camber	0.25
Leading edge radius	0.0133
Trailing edge angle	14.56

MODELLING

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4.2Create a FLUENT template in the Project Schematic window

To find the optimum wing design by calculating the lift, drag forces and to find Optimum condition of the unmanned aerial vehicle and velocity of air attacking to the vehicle.

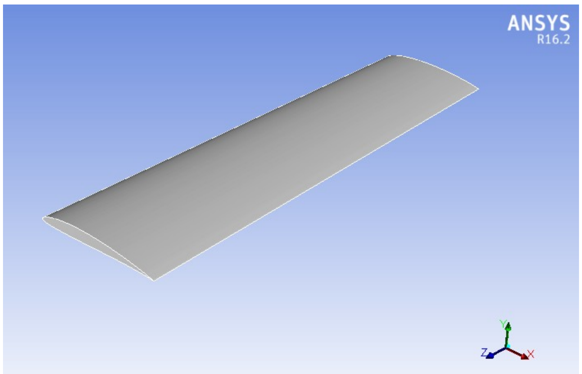

FIGURE 4.3.1: Wing Profile generation

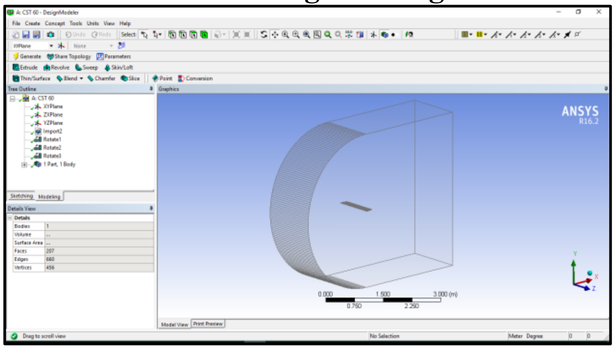

FIGURE 4.3.2: Fluid domain generated for analysis around wing aero foil profile

CFD ANALYSIS

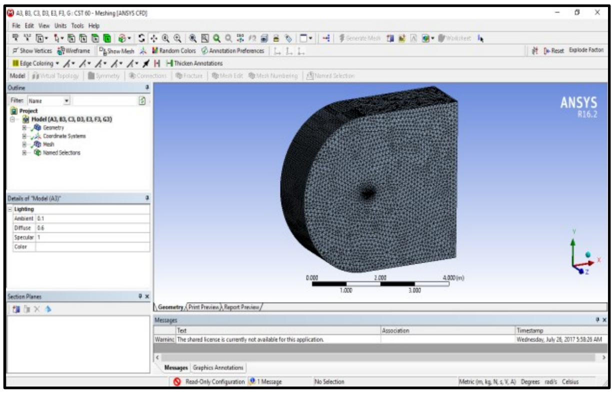

FIGURE 5.2.2: FE Model generated in ANSYS Workbench

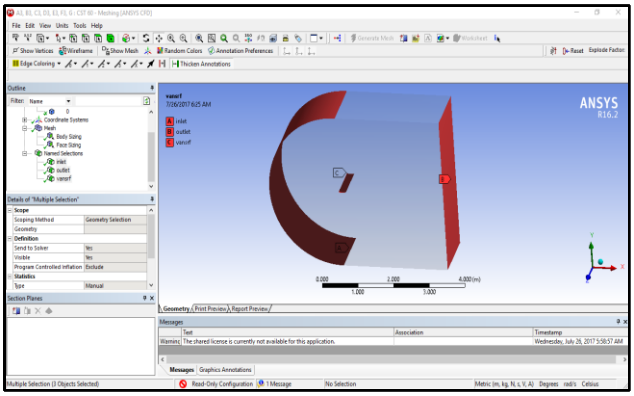

FIGURE 5.3.1: Cell Zones defined for FLUENT Boundary Conditions

5.5 Set solver model

Selection of Viscous Laminar Flow

5.6 Define the fluid as Air

5.7 Define the cell zones and boundary conditions

Select inlet. Edit. Select "Magnitude and Direction" from the drop down menu for Velocity Specification Method. Change velocity magnitude to "300" m/s, and OK.

FLUID ANALYSIS RESULTS

6.1 Introduction

CFD analysis results includes coefficient of lift and coefficient of drag for the different positions of wing profiles and different wing profiles are taken into consideration to find optimum wing profile.The results of the simulation of flow around the carrying capacity surface for the flying type wing is affected by two main factors, as follows: the first is the nature and quality (density) of the mesh network and the second is the quality of turbulent flow model used. A comparison between the numerical and experimental (wind tunnel and flight tests) results based on distribution of the velocity vector and distribution of the Reynolds tensor is required. Although the obvious influence of the viscous / inviscid model is observed in the final results we can use both in future CFD analysis. The total pressure variation and velocity distribution is observed on the selected edges at different angle of attack 5degree, 15degree, 25degree and 35 degrees. The Velocity distribution, pressure distribution s at different angle of attack and graph between lift and drag coefficients are calculated for different positions of wing profile to find optimum wing profile of unmanned aerial vehicle.

6.2 Results

Thus, we evaluate the performance and characteristics of an airfoil by looking at the following graphs.

1. The variations of lift coefficient versus angle of attack
2. The variations of lift-to-drag ratio versus angle of attack

6.2.1The variations of lift coefficient versus angle of attack

The maximum lift coefficient (Clmax) is the maximum capacity of an airfoil to produce non-dimensional lift; i.e. the capacity of an aircraft to lift a load (i.e. aircraft weight). The maximum lift coefficient is usually occurs at the stall angle. The stall speed (Vs) is inversely a function of maximum lift coefficient, thus the higher Clmax leads in the lower Vs. Thus the higher Clmax results in a safer flight. Therefore, the higher maximum lift coefficient is desired in an airfoil selection process.

6.2.2 The variations of drag coefficient versus lift coefficient

The last interesting graph that is utilized in the process of airfoil selection is the variations of lift to-drag ratio (Cl/Cd) as a function of angle of attack. As it is noted, this graph has one maximum point where the value of the lift-to-drag ratio is the highest at this point. The angle of attack corresponding to this point is an optimum candidate for a loitering flight.

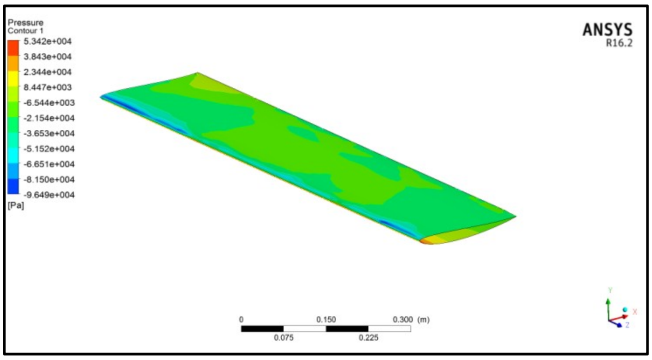

FIGURE 6.2.2.2: Pressure Distribution over the wing at angle of attack 25degrees

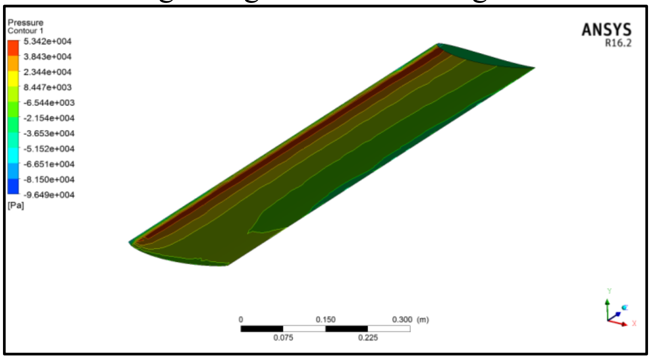

FIGURE 6.2.2.3: Pressure Distribution on bottom side of the wing at angle of attack 25degrees

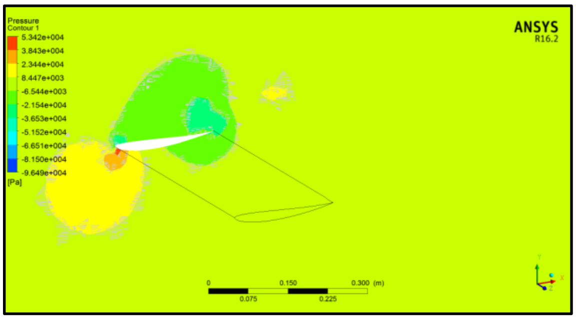

FIGURE 6.2.2.4: Pressure distribution at middle of the Wing at angle of attack 25degrees

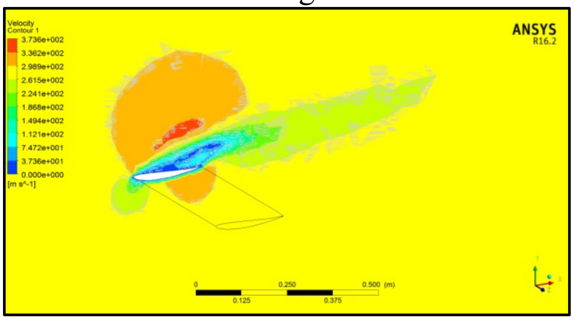

FIGURE 6.2.2.5: Velocity distribution at middle of the Wing at angle of attack 25degrees

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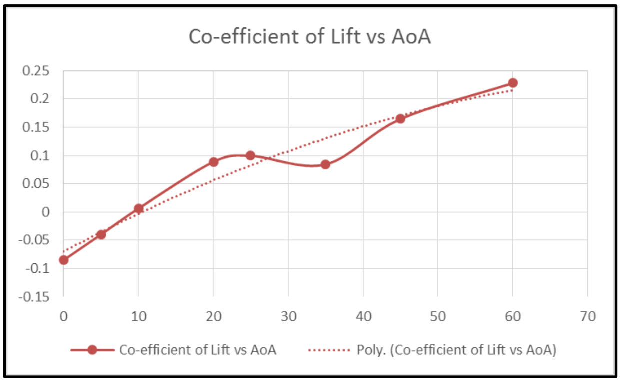

FIGURE 6.2.2.13: Co-efficient of Lift vs. Angle of Attack

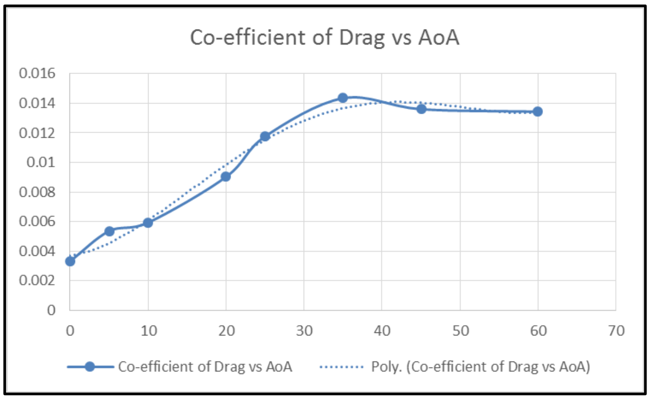

FIGURE 6.2.2.14: Co-efficient of Drag vs. Angle of Attack

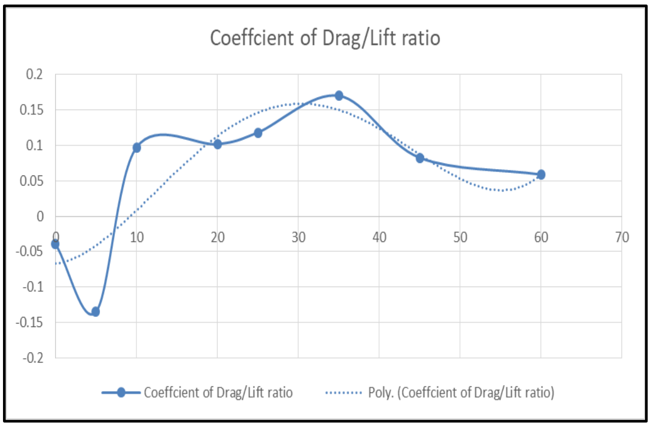

FIGURE 6.2.2.15: Ratio of Co-efficient of Drag/Co-efficient of lift vs. Angle of Attack

CONCEPTS VALIDATION BY PERFORMANCE COMPARISON

7.2 Details of Basic Configurations/Concepts

Five Basic configurations chosen for Verification as listed below:

Concept 1: Tapered Leading Edge and Straight Trailing Edge

Concept 2: Straight Leading Edge and Tapered Trailing Edge

Concept 3: Tapered Leading and Trailing Edge

Concept 4: Swept Forward Wing

Concept 5: Swept Back Wing

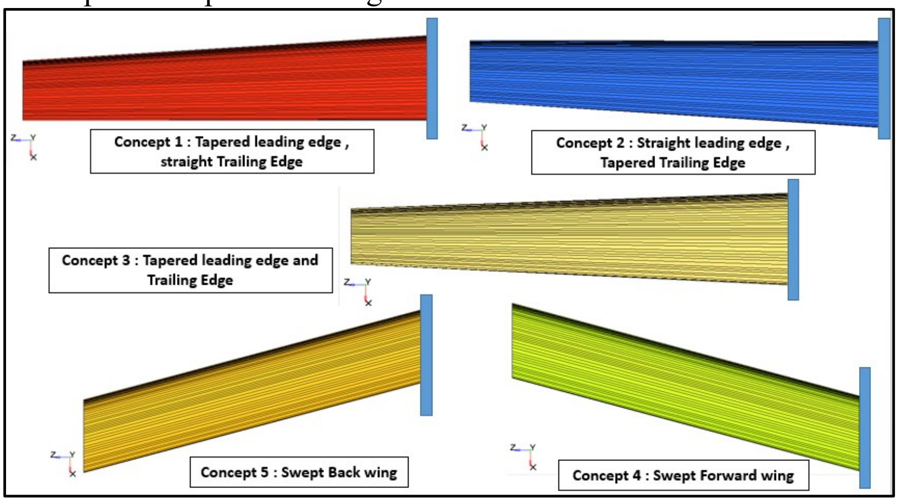

FIGURE 7.2.1: Concepts of Basic Wing configurations

The configuration shown below are simulated under the similar load conditions of 300m/s inlet velocity. The pressure and velocity contours are studied and reported. The co-efficient of lift and drag are also calculated. Using the ratio of Coefficient of lift and co-efficient of drag, it is observed that the concept 5 is more ideal/optimum among chosen five concepts.The current methodology of simulation and analyzing the results will be

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appropriate for choosing the right concept among many further concepts. The maximum ratio of coefficient of lift and co-efficient of drag is defines the optimum wing profile.

Table: 7.2.2 Basic Configuration Calculation of Coefficient of Drag Lift Calculation Ratio

Concept	Configuration	Co-efficient of Drag [Cd]	Co-efficient of Lift [Cl]	Ratio [Cl/Cd]
Concept 1	Tapered Leading Edge and Straight Trailing Edge	-0.0303	0.2354	-7.7690
Concept 2	Straight Leading Edge and Tapered trailing Edge	-0.03122	0.23944	-7.6694
Concept 3	Tapered Leading and Trailing Edge	-0.0292	0.2261	-7.7432
Concept 4	Swept Forward Wing	-0.0376	0.2746	-7.3032
Concept 5	Swept Back Wing	-0.0277	0.2336	-8.4332

The configuration shown above are simulated under the similar load conditions of 300m/s inlet velocity. The pressure and velocity contours are studied and reported. The co-efficient of lift and drag are also calculated. Using the ratio of Coefficient of lift and co-efficient of drag, it is observed that the concept 5 is more ideal/optimum among chosen five concepts.

7.2.1 Concept-1: Tapered Leading Edge and Straight Trailing Edge

Unmanned Aerial Vehicle wing of tapered leading edge and straight leading edge is analyses with different angle of attack in different positions of wing and flow of air at different positions are shown below. Drag and lift forces on wing of tapered leading edge and straight trailing edge and velocity of air is calculated by taken optimum angle of attack of air and wing. Lift and drag ratio is calculated from the 5 types of wing profiles from the study of these concepts we need to find optimum angle of attack and wing profile is suitable for the air craft is selected.

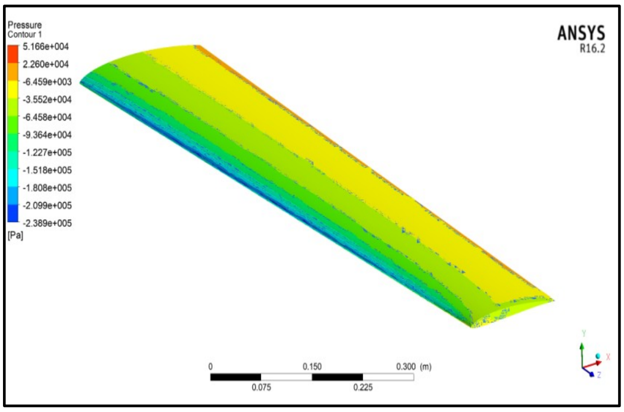

FIGURE 7.2.1.2: Concept 1 – Pressure on Top face of wing

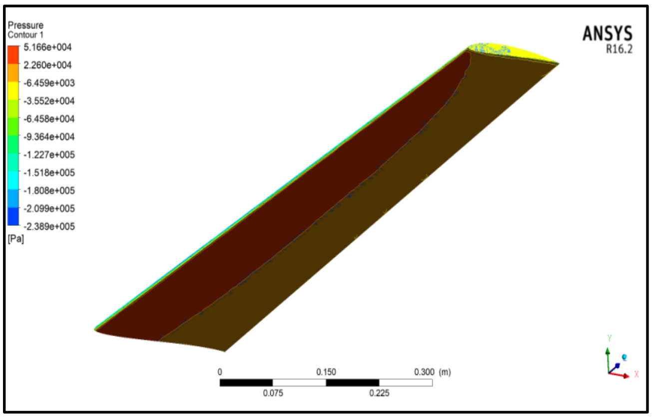

FIGURE 7.2.1.3: Concept 1 – Pressure on Bottom face of wing

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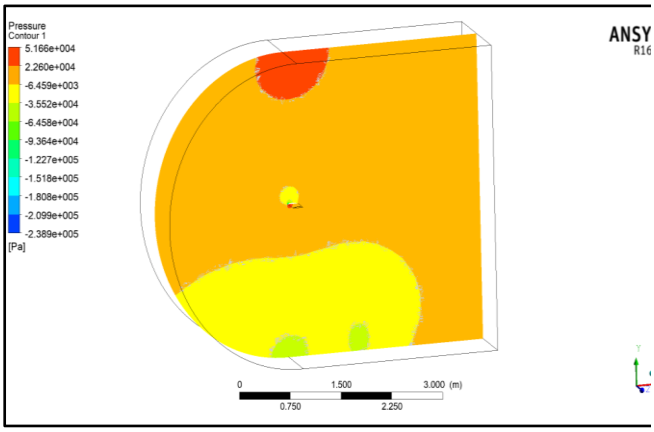

FIGURE 7.2.1.5: Concept 1 – Pressure Profile at Mid-wing region

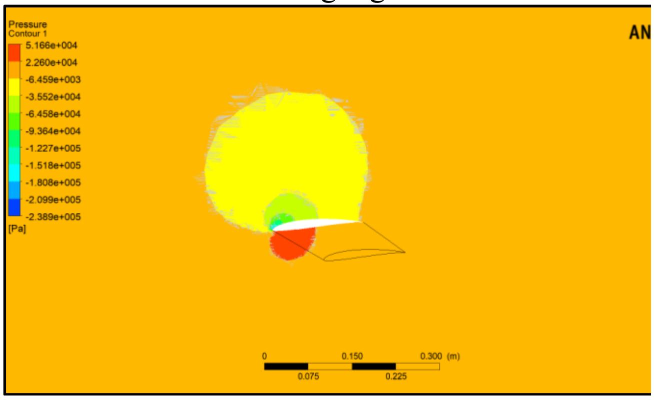

FIGURE 7.2.1.6: Concept 1 – detailed view Pressure Profile at Mid-wing region

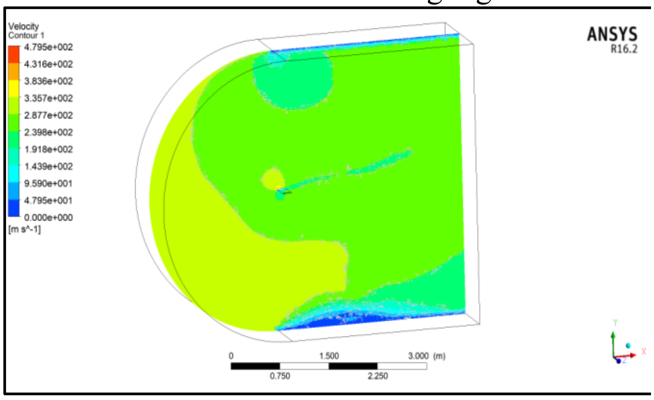

FIGURE 7.2.1.7: Concept 1 – Velocity Profile at Mid-wing region

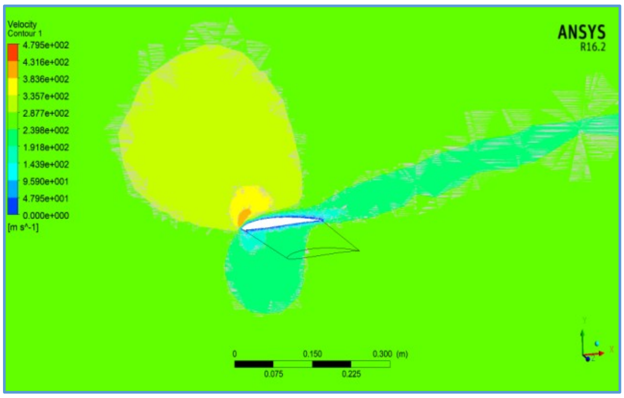

FIGURE 7.2.1.8: Concept 1 – Detailed view of Velocity Profile at Mid-wing region

8.1 CONCLUSION AND FUTURE SCOPE

With the help of CFD software ANSYS-Fluent, successful analysis of aerodynamic performance ofNACA25411 airfoil has been carried at various angles of attack (4, 6, 8, 10 degree) with constant using K-Epsilon method

It is observed from the results that the velocity of upper surface is higher than the velocity of the lower surface. The pressure coefficient of the airfoil's upper surface was negative and the lower surface was positive, thus the lift force of the airfoil is in the upward direction.

From the Graphs between coefficients of lift and drag vs angle of attack , it can be concluded that to increase the value of lift force and lift coefficient we have to increase the value of angle of attack. This leads to rise in drag force and drag coefficient as well, but the increase in drag force and drag coefficient is quite low in comparison to lift force and lift coefficient.

After importing UAV fuselage into Ansys,we define the analysis types by applying loads and initial conditions for the finite element solution. In mesh generation loading boundary conditions of inlet outlet wall and symmetry conditions are then applied to this elements and nodes of the UAV fuselage. For simulation of fluid flow analysis import this UAV .In this process we give details for fluid and solid domains. Material used for fluid type domain is air at 25C and for solid type aluminum is used. Applying

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inlet and outlet details in fluid and wall details in solid for fluid flow analysis after simulation we obtain the pressure counter and velocity streamline of fluid flow analysis of UAV fuselage

From the study on Angle of attack influence of lift and drag, based on the 'Ratio of Co-efficient of Drag/Co-efficient of lift vs. Angle of Attack' we can conclude that for aero foil profile of 'NACA25411' the optimum angle is 35degrees.Stall was started with around 20° attack angle. Lift coefficient decreased whereas; drag coefficient increased.

Based on the study of ratio of Coefficients of lift and drag, it is concluded that the concept 5 [Swept back wing] is optimum among the chosen five basic wing concepts.

The methodology detailed in the project can be followed to validate and verify the performance and compare various wing concepts and design parameters in order to select the optimum design of wing profile.

As UAS operations expand in the future, and civilian operations become accepted, it is to be expected that the Air Accidents Investigation Board (AAIB) will become formally involved in determining the cause of any accidents and advising as to the means of their reduction. This may introduce legislation requiring UAV to carry data recorders as is currently required for manned aircraft, and possibly voice recorders in the control station.

Some UAV currently transmit housekeeping data to the control station where it is recorded. The data is obtained from sensors in the aircraft, and may include aircraft position data, communications status, airspeed, control information, fuel state, electrical power status, temperatures, etc. This information is used to alert the operators to any deterioration in the aircraft condition so that appropriate action can be taken to prevent or minimise the risk of failure. Where the aircraft is operating for periods of autonomy in radio silence and during that period suffers a fatal failure, the data may not have been received. In those circumstances, on-board recording would be needed for later investigation.

The current, obviously unsatisfactory, situation where no formal and legal airworthiness and operating rules are available in the UK for civil UAS prompted the setting up in 1997 of the Unmanned Aerial Vehicle Systems Association, a UK trade association for the UAS industry.

Military UAV are specified by the military customers and their design and manufacture is contracted to approved teams previously experienced in manned military aircraft and their systems. The design for airworthiness, manufacture, testing and operation will be carried out by methods specified in military documents.

Systems' testing is carried out in the dedicated airspace of military test sites or ranges under the supervision of military controllers. The operation of military systems is, apart from exercises, carried out in theatres of conflict. Operations are conducted to minimize the risk of civilian injury particularly with respect to the prevention of 'collateral damage victims' in wartime.

A UAV fitted with a payload capable of emitting sources of detection used by anti-ship missiles can be deployed appropriately to attract the incoming enemy missiles. The loss of a number of unmanned UAV would be a small price to pay in saving the loss of costly naval vessels and their crew so UAV are using in missile decoy.

UAV is used in detection of illegal imports, persistent watch for suspicious shipping out at sea is best maintained by a MALE UAV. From this any approach to land, in other than at recognized customs ports, can be reported to the Customs and Excise Authority (C&EA). The subsequent patrol of vulnerable remote coastal areas by C&EA UAS can detect and record evidence of the import of illegal substances or persons. This is better accomplished by a stealthy, slow-flying UAV which will not alert the criminals to the possibility that they have been detected and

may remain over the scene to direct local forces to apprehend them on site or in transit.
UAV is used in aerial photography, using a combination of video and high-resolution still cameras (film or digital) pictures may be obtained of geographic and constructed features, such as historic houses, castles, bridges, etc. The UAV is cheaper, and less intrusive in its use, than manned aircraft. Hover flight is advantageous for positioning
Survey of crops is feasible using infrared and colour cameras to detect the onset of disease through changes in crop colour.

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