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Design, Fabrication and Subsonic Flow Analysis of a Blended Wing Body

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Abstract: The design aspects of conventional aircraft has reached a limit due its aerodynamic inefficiency and on the search for better and futuristic aircraft the Blended Wing Body (BWB) aircraft was conceptualized. Over the decades the BWB aircraft is also identified as Flying Wing / Tailless aircraft. BWB is a conceptualized futuristic aircraft that has a potential to be used commercially. It offers advantages of aerodynamic performance and fuel economy. But our primary focus is on the flow analysis of the blended wing body and understanding its aerodynamic behavior. A planform for the blended wing body was conceptualized and a 3d model was built using CATIA. The NASA SC (2)-0610 reflex airfoil was used to provide the required aerodynamic shape and design. The Flow analysis was done for a subsonic regime using ANSYS 16.0 and a flow visualization test was conducted at the Open circuit Wind Tunnel at Indian Institute of Science. The study was done in order to understand how the aerodynamics of this unique body behaves under subsonic flow.
Keywords: Blended Wing Body (BWB), Aerodynamics, TBCC, Fabrication, Mach number, Domain, Meshing, Tuft flow visualization, Open circuit wind tunnel, Contour Plot.

I. INTRODUCTION

The project begins with the literature survey on the Blended Wing Body aircraft, where only fewer articles and papers have been published. The aircraft has a no clear dividing lines between the wings and the main body. The design blends the wings and fuselage smoothly with no distinct fuselage. The BWB also known as tailless aircraft as it does not require flaps or a tail plane for pitch control which leads to drastic reduction in the noise signature. It also emits fewer pollutants due to reduced fuel burn and higher propulsive efficiency. The BWB form minimizes the total wetted area - the surface area of the aircraft skin, thus reducing skin drag to a minimum. It also creates a thickening of the wing root area, allowing a more efficient structure and reduced weight compared to a conventional craft. In order to increase the aerodynamics in terms of design and create a flusher propulsion system, these blended wing bodies can use Turbine based combustion cycle propulsion. TBCC engines work similar to turbojet engines at lower mach numbers and perform as scramjet/ramjets when moving at higher mach numbers. It thus allows the blended wing body to travel through almost all flow regimes. As the aircraft speeds increases the air interacting with the aircraft surface increases in the relative manner. Let the speed of air gradually increase and free stream velocity close to Mach 0.7. The surface of the aircraft achieves the Critical Mach Number i.e. M=1. Now the behavior of the flows starts changing gradually.

As the free stream speed of air increases, the Mach number exceeds 1 at both leading edge and trailing edge and generates the shock. When free stream speed equals to 0.7, the Mach reaches 1 at the surface of the airfoil, called Critical Mach. Above the critical Mach number, the expanding normal shock wave travels towards the trailing edges and becomes weak oblique shock wave. The normal shock is generated in front of the object and its propagation towards the trailing edges depends upon the structure of the objects. When an aircraft goes beyond the speed of the sound, the pressure difference around the aircraft surfaces is a major factor to be considered. The high pressure is built in front of the aircraft which leads to higher impact forces. This built pressure is called a shock wave, and it propagates towards trailing edges and outwards forming cone like structure, is called Mach Cone. At speed over Mach 3, the shock wave is seen in the Conic form and all the flow is in supersonic level, but the speed between the shock wave and the aircraft will be in a subsonic level due to the stagnation of the flow ahead of aircraft nose. The speed of flow around the shock wave will be drastically reduced wherein the temperature, pressure and the density will increase. Increased in the temperature and the pressure leads to the ionization and dissociation of the gas molecules behind the shock wave. And such flow is called Hypersonic.

Airflow or air flow is the motion of air from one place to another. The airflow depends upon the pressure gradients. Air behaves like fluid or charged particle that flow from higher pressure to lower pressure. The atmospheric air relates to altitude, density, composition and temperatures. The measurement of the airflow is done in amount of air per unit of time that flows through certain vicinity. And the contours of the airflow over the aircraft gives us the patterns and which shows how the flow is behaving around the aircraft body. Aerodynamically the maximum drag generated in convention aircraft is fuselage. It generates almost 90% of the total drag induced by the whole aircraft. The fuselage is responsible for maximum inertial load as it provides the housing for cargo and passengers and almost negligible amount of the lift generation. The wings becoming the major source of lift generation. Additionally, wing and fuselage joined portion also leads to Induced and wave drag. On the other hand, the Blended Wing Body aircraft's wings and body is smoothly blended inwards without any drastic change in the cross-sectional area. This allows the airflow over the surface to be smooth and with minimal drag formation.

II. OBJECTIVES

To study and compare the different kinds of airfoils that are most suitable for a commercial blended wing aircraft. Design a CATIA model of the BWB using the selected airfoil. To study the BWB in detail and to understand its differences with respect to conventional fixed wing aircrafts. To conceptualize, design and analyze the BWB. To fabricate the designed model and carry out wind tunnel experiment at subsonic level .To tally the theoretical and experimental observations and plot the velocity and pressure contours.

III. METHODOLOGY

A. Problem Description

The BWB aircraft prototype is designed in reduced scale ratio of 1:50 of the original scale. The methodology begins with designing of BWB, its analysis, fabrication and visualization. The study is carried out in the subsonic flow, Mach number being less than 0.3.

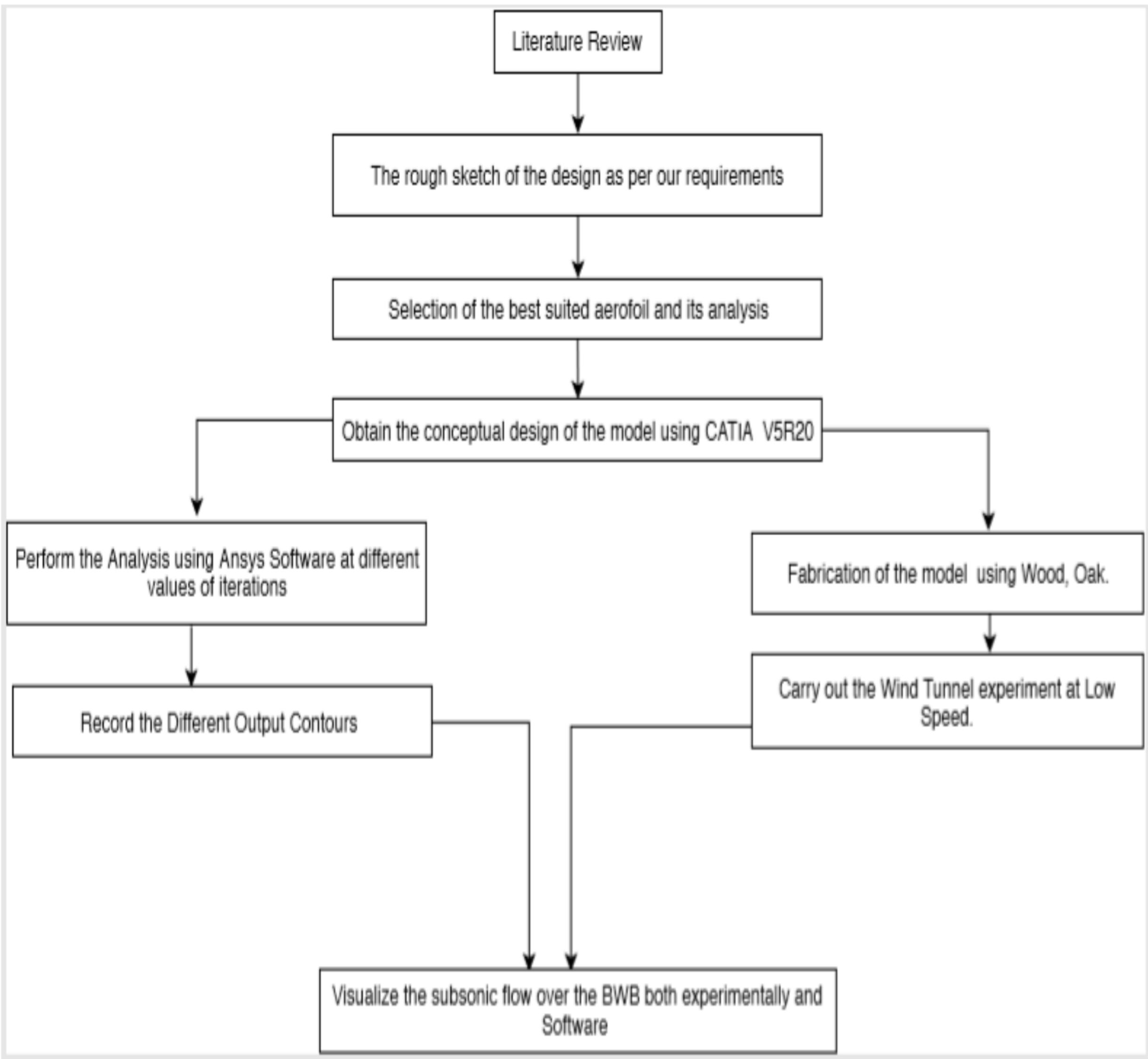

Fig 1: Methodology flow chart

B. Airfoil Selection

The selection of the airfoil is the crucial part, as we must be clear about our designing aspects and requirement. After the trial and error method, the NASA series reflex airfoil was selected. Since the model is Tail-less configuration, it is found important that it uses a reflex airfoil because it counter balances the moment produced by wing and body of aircraft. The design is based on the space available in the Wind Tunnel Test Section.

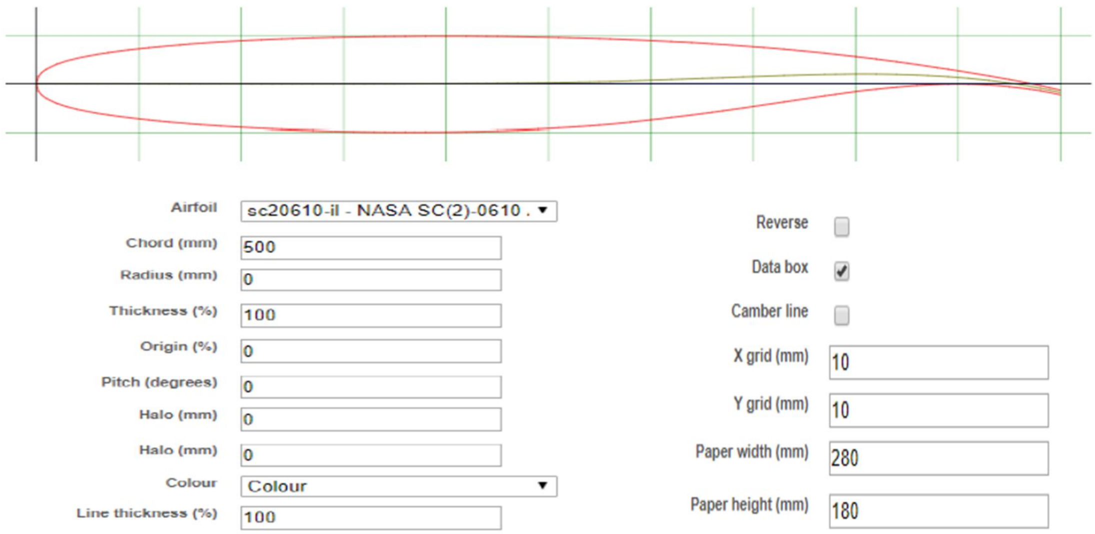

Fig 2: Nasa SC (2)-0610 reflex airfoil

Testing of the Airfoil selected is important as it defines aerodynamic stability and controllability. Due to tailless configuration, the moment of the airfoil should be negative to counter balance the moment produced by main body of aircraft.

The testing of the Airfoil is done using XFLR software. The stability control of the airfoil was tested and respective graphs were plotted.

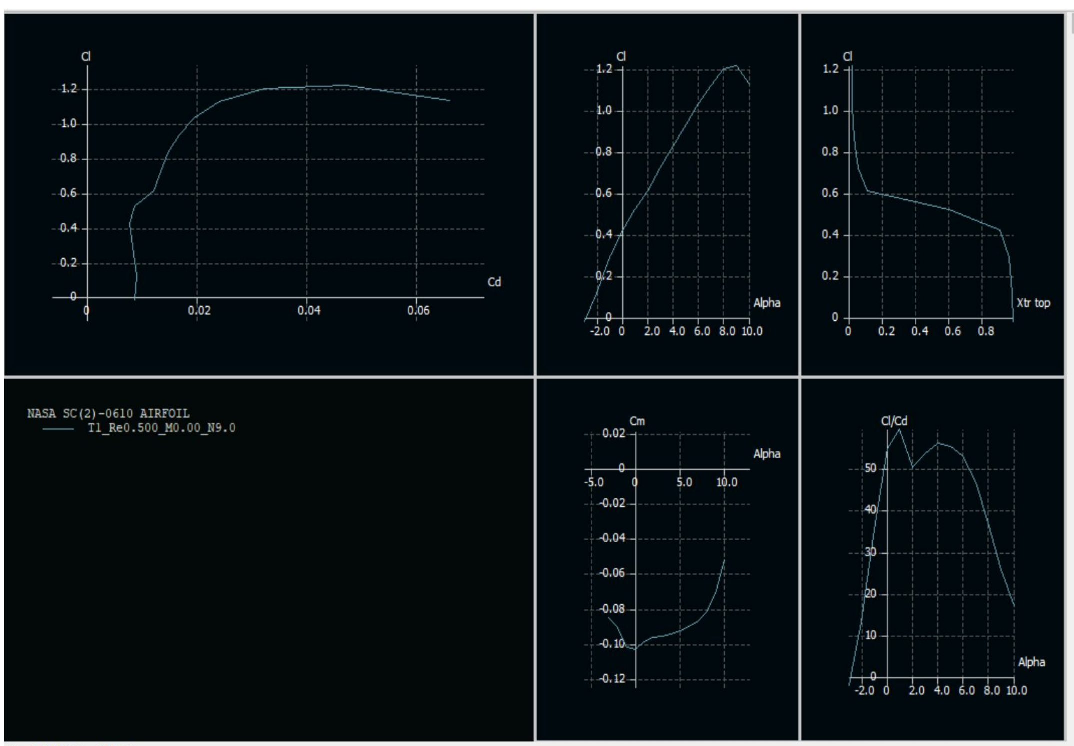

Fig 3: XFLR output of Airfoil

C. Model Design

The required model is designed using CATIA V5R20. The different chords of Airfoil are imported in the software and it is placed at the required coordinates and the surface is generated using surface enclosement tools. Designing of the 3D model was done using CATIA V5R20. Material assigned to the model was wood (oak). The estimated weight is 1.779 kg with dimensions of 500 mm * 600 mm.

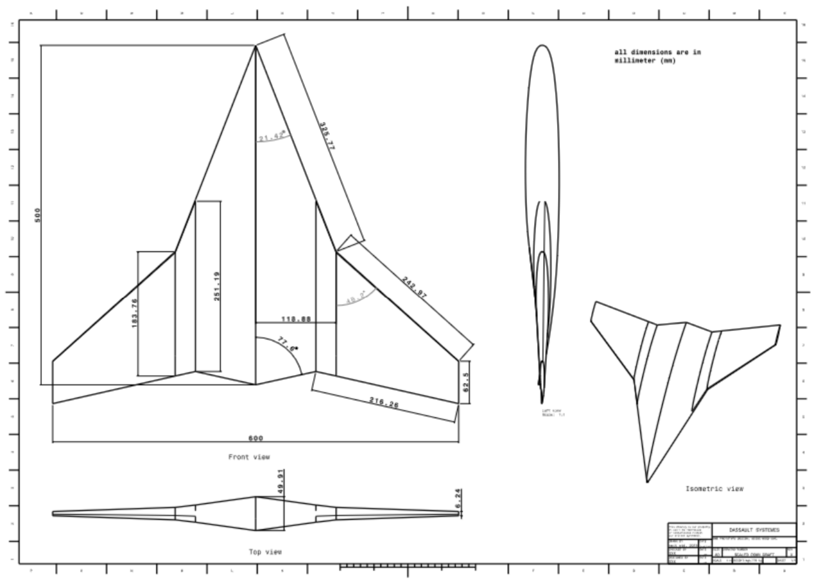

Fig 4: The Proposed CATIA dimensions and Draft

D. Meshing

Meshing is carried out using ANSYS Software. The quality of mesh should be finest to acquire the correct output. A Uniform flow domain of volume 1000 mm^3 was created. Named selections of Inlet velocity, outlet pressure and walls are done. Fine meshing of 0.6 mm element sizing and an unstructured mesh was generated.

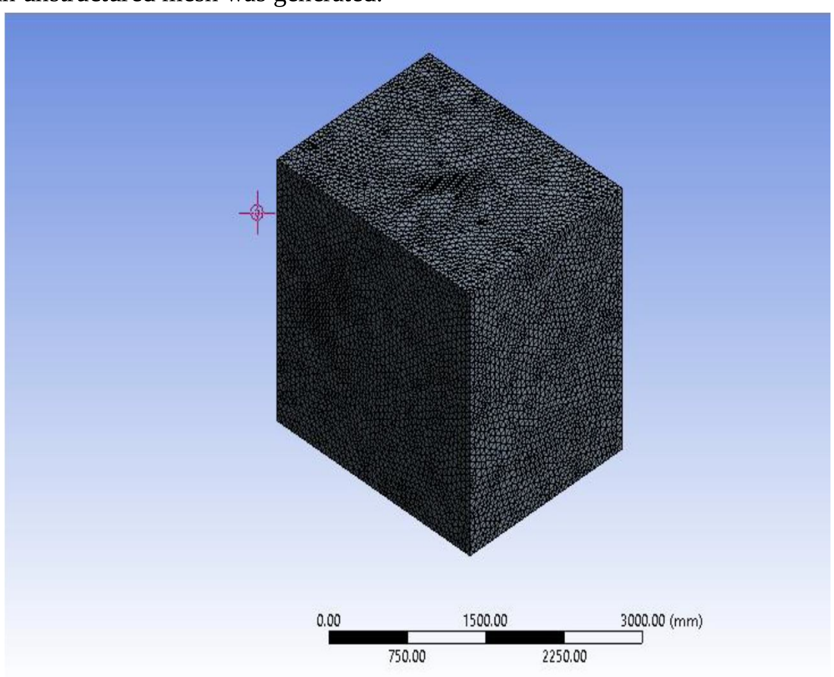

Fig 5: Mesh including domain

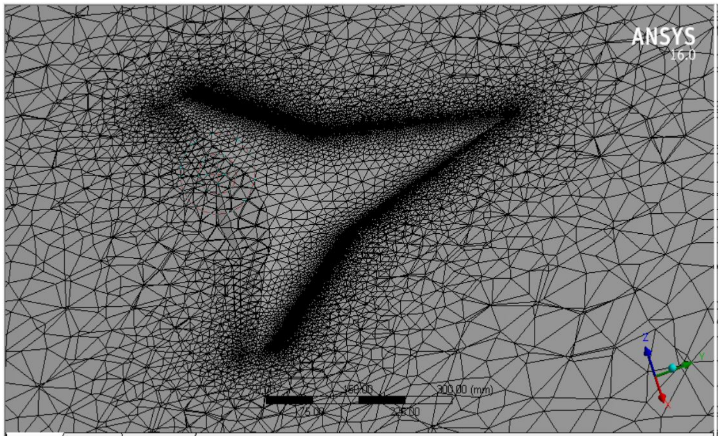

Fig 6: Cut section showing model mesh

E. Analysis

The Computational Fluid Dynamics (CFD) Analysis is carried out in ANSYS software, Fluent. Material assigned is AIR, with its density being 1.225 kg/m3. The turbulence model used was K-Epsilon, with standard wall functions, where k is the kinetic energy of Turbulence and Epsilon is the Turbulence dissipations. The inlet velocity was kept at 100 m/s for 200 iterations (which also happens to be the converging iteration), in order to simulate flow at Mach number 0.3. The Outlet Pressure was kept at 0.

F. Fabrication

Another addition to the analysis is the flow visualization and in order to do that it is necessary to fabricate and to demonstrate how exactly the BWB looks in real. The prototype dimension is of 500mm * 600 mm. The model was initially decided to be fabricated using the aluminum, since our maximum thickness at the centre line of the aircraft was 59 mm, it was a challenge to find Aluminum Plate of more than 60 mm thickness (including the tolerance dimensions).

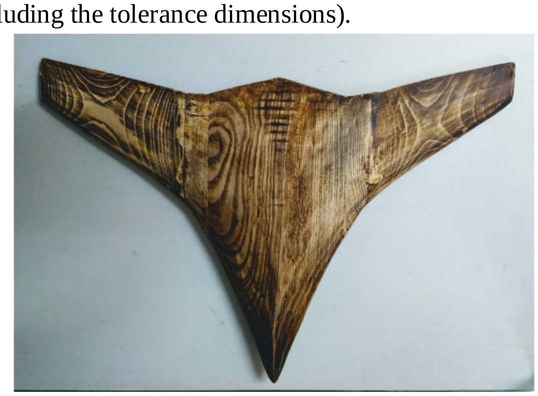

Fig 7: The original Prototype look

To fabricate the model out of aluminum, it would have been necessary to glue in each constituent plate. It needed 5 axis CNC (Computer Numerical Control) machine to cut the metal into require plate shapes. And also since aluminum itself is costly the overall cost would have come up to at least 4 times higher than the wood.

Oak, which happens to be a type of wood is cheaper, easier to fabricate and is strong enough to hold on against the pressure load inside the wind tunnel. Considering the Cost and Time Effectiveness, Oak proved to be the best option resulting in a net weight of 3.2 kg. The Following images show the original model look and the methods we applied to make it ready for the wind.

G. Wind tunnel Experiment

In order to visualize the behavior of airflow with the given 3D model of the Blended wing Body we had conduct an experiment in the Open Circuit Wind tunnel at Indian Institute of Science (IISc). But, before carrying wind tunnel experiment, there were few preliminary tasks to be completed. Our model needed a smooth surface finish, to keep skin friction as minimal as possible. We also needed stand and holder to mount the model inside the wind tunnel. In order to perform a tuft flow visualization experiment it was necessary to attach tufts/ simple light weight threads to the surface.

Fig 8: With Plaster of Paris

Fig 9: Black Oil Paint

So, in order to achieve smoother surface, Plaster of Paris was used. The layer of POP filled the small gaps and indentations on the wood model. Once the POP dried out, it had a higher chance to crack and surfaces become uneven. Thus, single layer of Primer was applied over dried POP, which also helps to hold the paint. Finally, the Black Oil Paint (Fig 9) was applied and dried.

We designed the holder that fits the stand available in IISc wind tunnel. The model is fitted into the Wind Tunnel and experiment was carried out at 15 m/s inlet velocity for various Angles of Attacks. The inlet speed was reduced to 15m/s because of the presence of other 3D models inside, which were being used for research by the Indian Navy. The main objective of conducting this experiment was to understand airflow patterns of the flow inside the test section around the BWB.

IV. RESULTS AND DISCUSSION

A. Flow Analysis results

The output obtained from ANSYS 16.0, FLUENT analysis has been obtained by post processing with ANSYS Post Processing. The following results represent the output for 200 iterations.

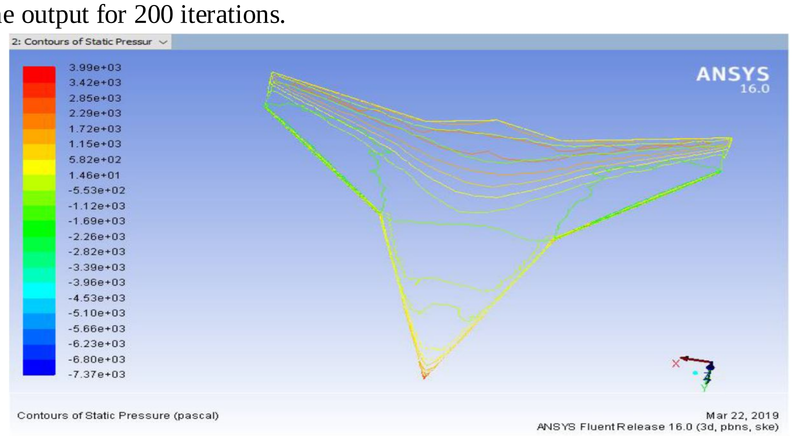

Fig 10: Static Pressure Contour

The static pressure distribution around the model is shown in fig 10. The tip of the model and the underneath of the trailing edges of the model experiences more pressure than the leading edges. The Dark Yellow Color shown represents high pressure region.

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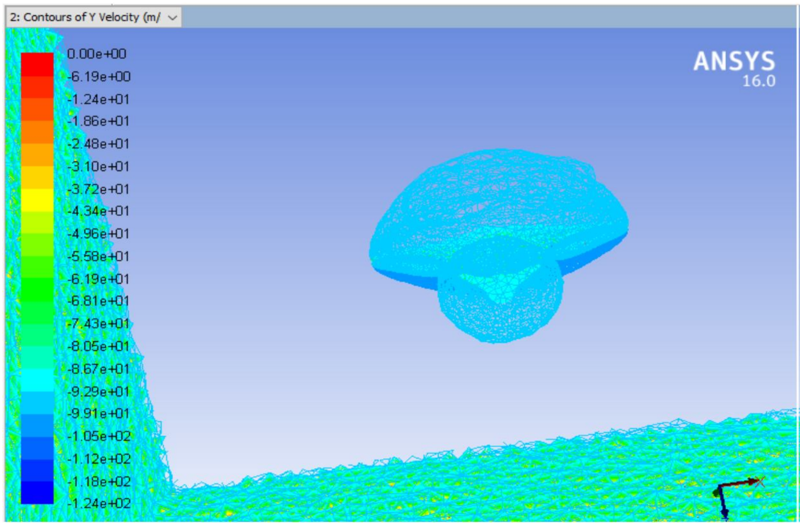

Fig 11: Y velocity Contour

The input velocity given is 100m/s in negative Y-axis. The Velocity over the surfaces drastically increases while the velocity underneath of the model is countered by higher pressure region. The dark blue region shows the lower velocity.

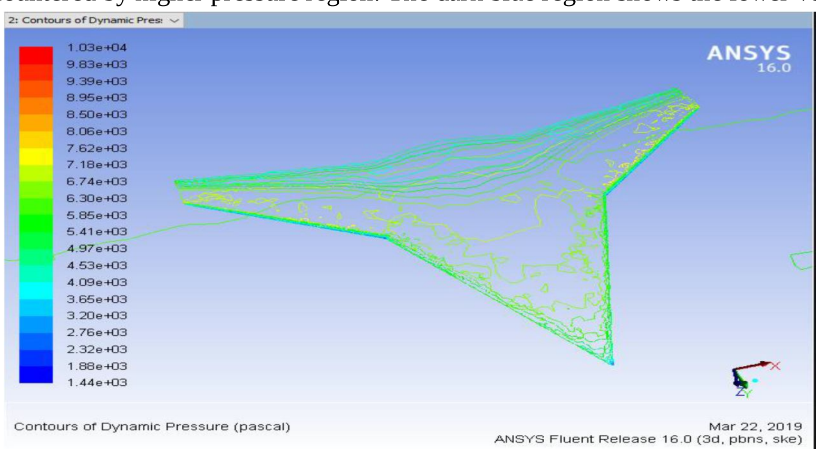

Fig 12: Dynamic Pressure Contour

The dynamic pressure over the model is lesser than the underneath the model. Due to the reflex shaped airfoil, the air over the airfoil has to travel at the greater speed which eventually leads to decrease in the pressure.

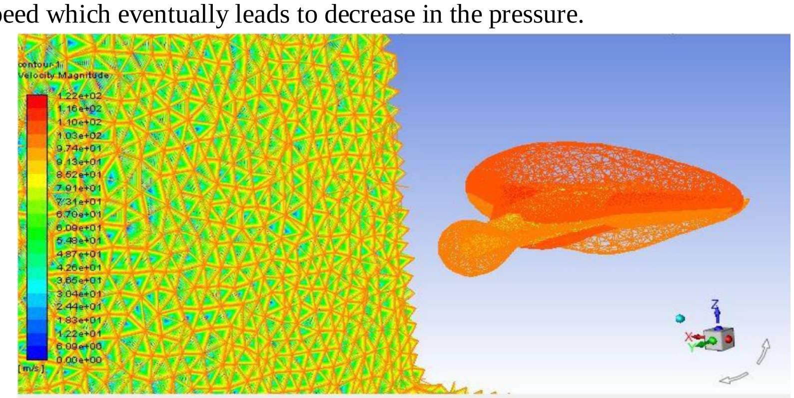

Fig 13: Velocity Magnitude Contours

The velocity magnitude around the model is shown in the figure 13. The Red region shows the higher velocity magnitude and yellow region shows the lower velocity magnitude.

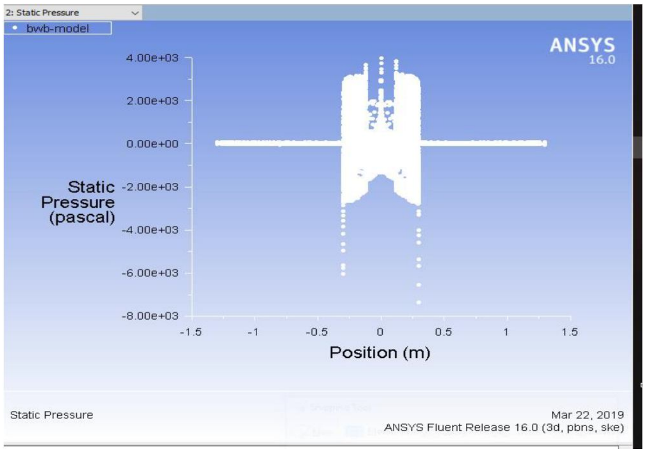

Fig 14: Static Pressure Vs Positions

The figure 14 shows the distribution of the pressure around the model in 2D form. The pressure distribution is symmetrical along the 0 position.

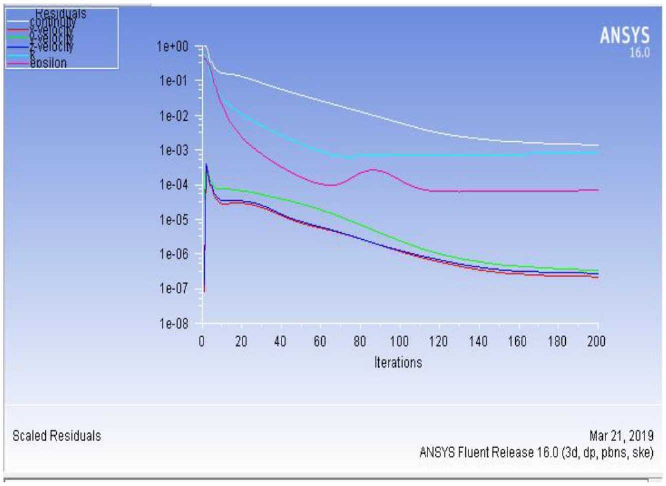

Fig 15: Residual Graph

The figure 15 shows the converging values of the Analysis. The converged value is lesser than the 10-5, which is well converged graph.

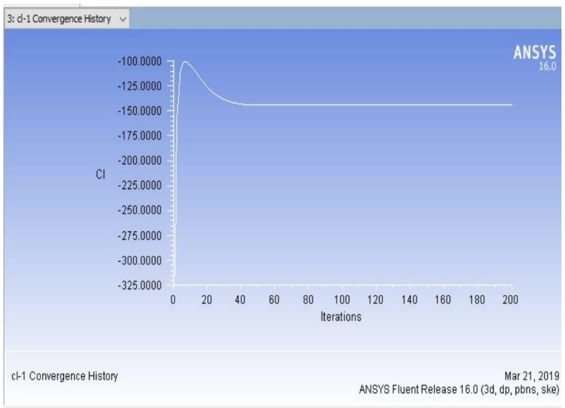

Fig 16: Cl Graph

The Cl graph of figure 16 at Zero Angle of Attack for 200 iteration is shown. The Cl graph is well converged, and the steady value is around 150 N.

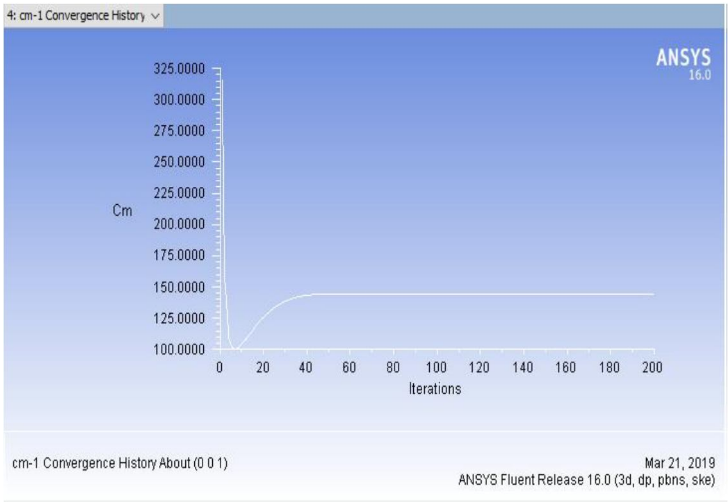

Fig 17: Moment Graph

The moment graph of figure 17 is well converged at zero angle of attack for 200 iterations, the steady converged value is 135 Nm.

B. Flow Visualization Observations

The wind tunnel experiment was conducted for a series of three different angles of attack.

Fig 18: Zero Degree Angle of attack

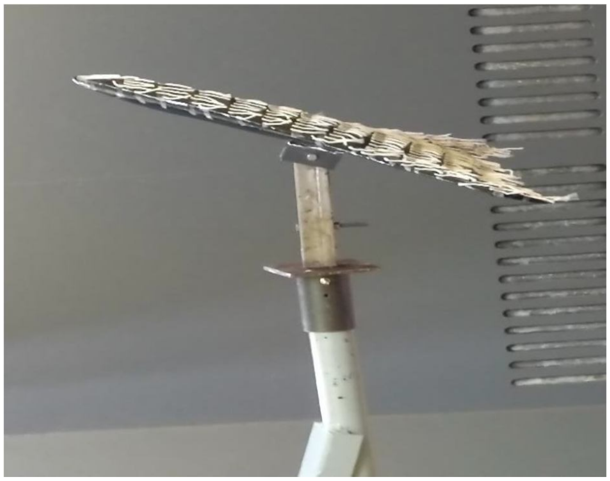

Fig 19: Positive 15 degree angle of Attack

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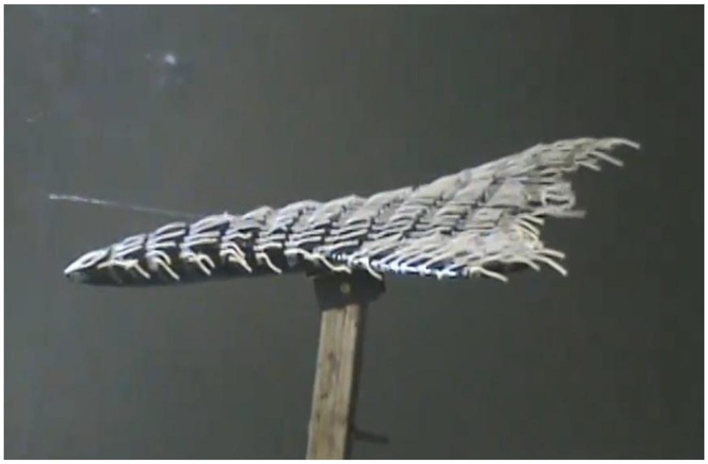

Fig 20: Negative 10 degree angle of attack

At zero angle of attack, the flow over the surface is laminar as expected. As the Angle of Attack increases, the pressure below the aircraft gradually increases and results in the lift generation. Even at the higher angle of attack (15 degree), the flow over the surface is laminar till the trailing edge. However it gradually leads to dissipation due to the laminar flow over the surface which encounters with the higher-pressure wind underneath model, as a result it could form vortices

This could lead to challenges especially when the model has mounted the engine at the rear end. The air underneath the model could come in direct contact with the engine nozzle or the exhaust. The flow over the surface gradually decreases and the flow underneath the surface increases. At a negative, angle of attack, the pressure over the upper surface is higher than the lower surface.

Similar, the high-pressure wind and low-pressure wind encounters at the end of trailing edges which could impose challenge for the real working aircraft as it comes with the engine mounted at upper or under the wings.

V. CONCLUSIONS

Blended wing body has proven to be the next big innovation in terms of design and performance. As observed during the flow visualization, the Blended wing body has really efficient aerodynamics. Coupled with integrated propulsion system, preferably electric or a Turbine based combined cycle, will reduce environmental hazards by great lengths. It will reduce travel time and might make air travel more economical. There is however lots of research still required in optimizing the shape, construction and increasing passenger comfort. Hence it is a BWB concept is recommended for UAVs and military and cargo operations.

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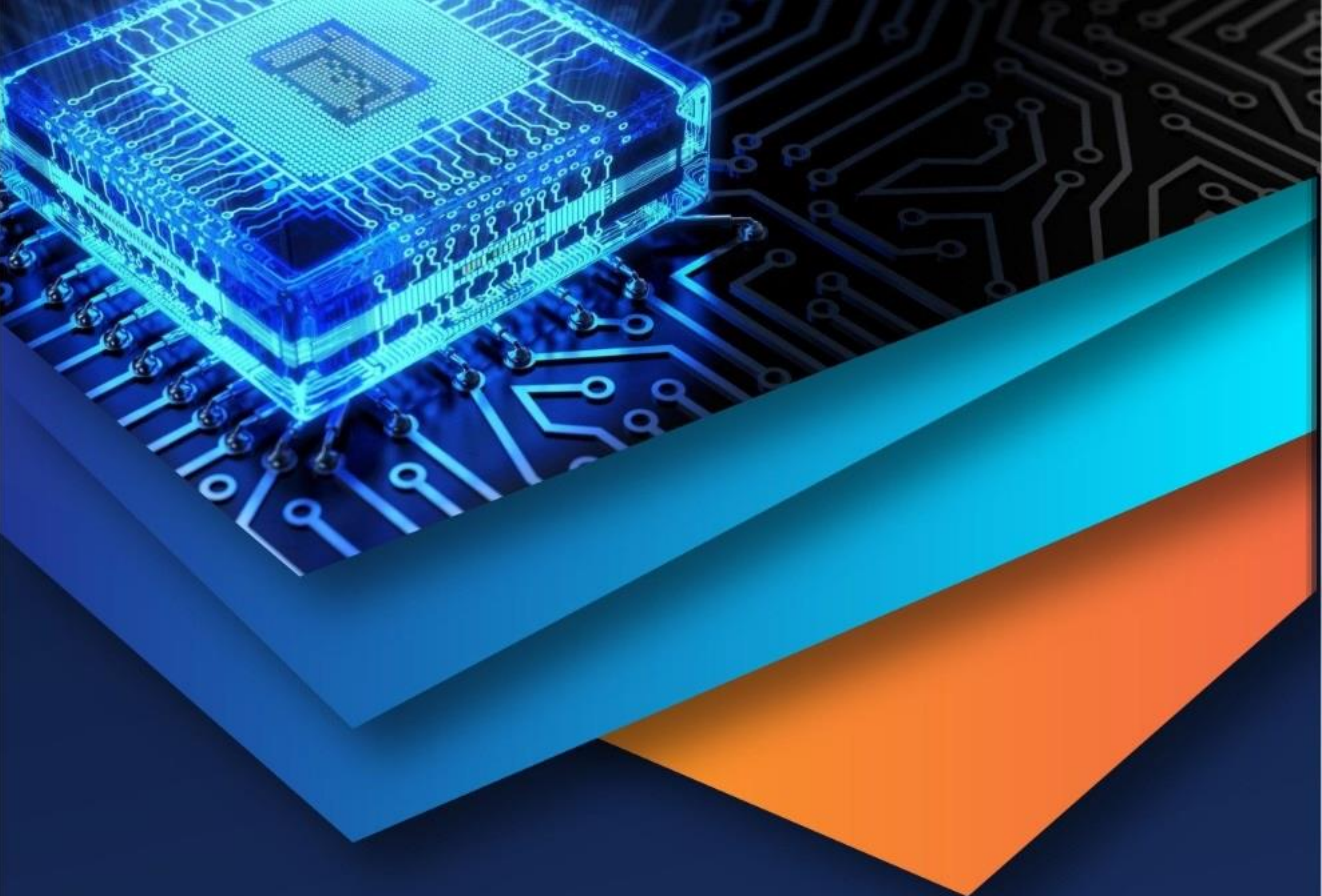

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