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# Bio-Inspired Study and Build-Out of New Airfoil for the Design of Basic Aircraft

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**Abstract—Build-out of airfoil for a basic aircraft design" deals with designing the aircraft through the selection of some similar type aircraft as prototypes for required basic parameters like range, maximum velocity, number of crew, etc. With the total data collection of the prototype aircrafts, Suitable required parameters are chosen by zeroth approximation of aircraft design required, Where the chosen mean value of prototype aircrafts are induced to obtain the zero approximate "modernized basic design of an aircraft". The bio-inspired airfoil concept deals with variation of distance between leading edge and maximum camber through the chord length of the basic reference airfoil, Inspired from the birds flight observation. Therefore the design evolves into different type of airfoil design. Hence each airfoil engaged with different parameters, characteristics and performance. On testing the above airfoils through CFD ANALYSIS and practical manner,(i.e.) with original models of those airfoil using wind tunnel. We study and compare the characteristics and performance parameters of the airfoils designed. The suitable design from the above airfoils will be used for the outer wing design of basic aircraft design, So that the characteristic's and performance parameters should improve.**

**Keywords—**Wind Tunnel Testing,CFD Analysis.

## I. INTRODUCTION

When it comes to being an aircraft manufacturer, today's leaders have more regulations than the Wright brothers did when they began their quest for flight. Before airplane manufacturers can even begin the process of building a plane for commercial use, all the parts must qualify for the minimum performance standard, known as Technical Standard Orders, or TSO authorization. Industry leaders in the commercial sector often work across the industry in other areas like government aircraft. With an industry leader, you can expect the most complete selection of aircraft, support, products and services.

Aircraft manufacture is a dynamic and cutting-edge field in which new technologies are created and implemented on a regular basis. As such, aircraft manufacturers' education and training encompasses a wide range of college and graduate degree programs, as well as additional training and certification for people employed by aircraft manufacturing companies.

Airplane manufacturers are continuously creating innovative designs, making greater use of new lightweight materials and increasing their focus on passenger comfort. The creative process of aircraft design is driven by the needs and opportunities of the future market. From these needs, covering the requirements from the entire air transport system specific targets is to be derived. Referring to today's products new designs are subsequently generated, aiming to meet the targets anticipated. Besides design aspects such as the a/c capacity and range, the development of new technologies is mandatory to minimize or even eliminate the width of the gap, thus ensuring the achievement of future market demands by new aircraft designs.

In this project, we look forward to design an airfoil for a basic business jet aircraft. Few prototypes of a 20 seater business jet aircraft are chosen and the average value of the parameters are taken into account for designing a new aircraft. Then we design an airfoil for this particular aircraft. This includes the shifting of maximum camber position and testing for its performance.

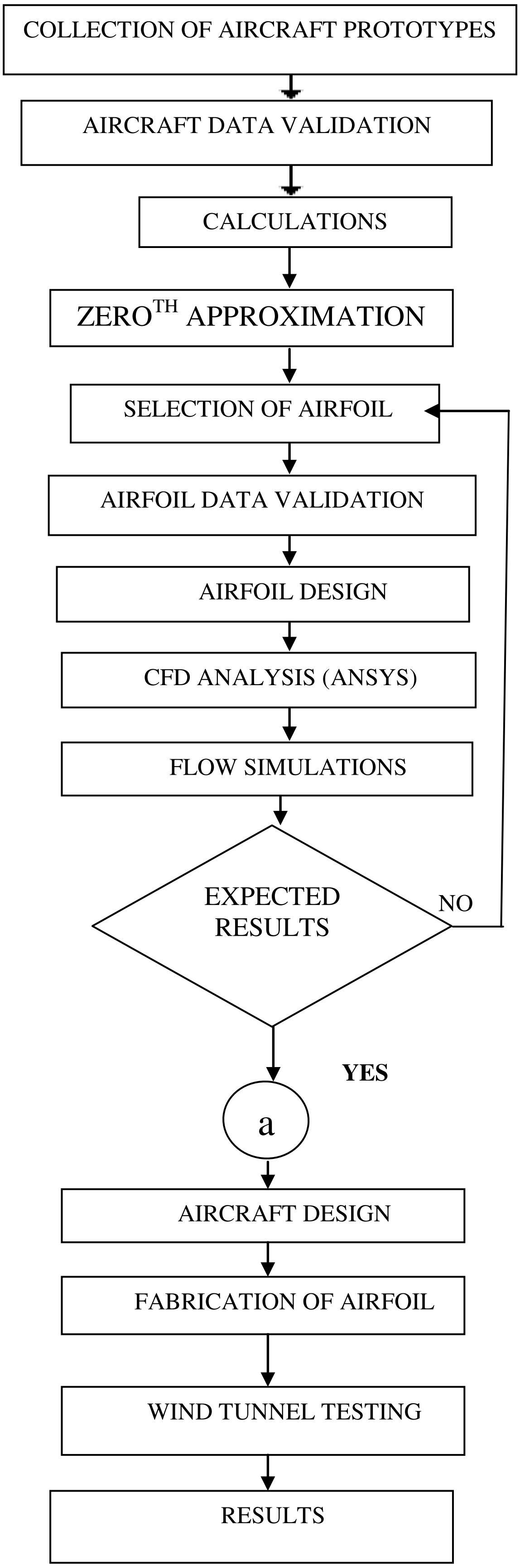
## II. LITERATURE SURVEY

Most of the airfoil database were collected from AIRFOIL TOOLS, Calculations were done using formulae from Aircraft Design Handbook and Textbooks referred. Some of the ideas obtained from the AEROSPACEWEB. The Aircraft designing and calculation are done by referring the text books given in reference section.

Mr.Arvind M "CFD Analysis of Static Pressure and Dynamic Pressure For Naca 4412" International Journal of Engineering Trends and Technology: Researched on NACA 4412 airfoil and analyzed its profile for consideration of an airplane wing. The NACA 4412 airfoil was analyzed using commercial code ANSYS 13.0 FLUENT. Fluctuations of static pressure and dynamic pressure are plotted in form of filled contour.

Karna S Patel, Saumil B patel, Ustav B Patel, Prof. Ankit P Ahuja UVPCE, Ganpet University: This paper highlights the CFD analysis over the airfoil in general and discusses the variations of CL, CD and CP by varying boundary conditions at different angle of attack.

## III. METHODOLOGY




## IV. AIRFOIL

Consider the wing of an airplane, as sketched in Figure. The cross-sectional shape obtained by the intersection of the wing with the perpendicular plane shown in Figure is called an airfoil.

Mean camber line: It is the locus of points halfway between the upper and lower surfaces as measured perpendicular to the mean camber line itself. The most forward and rearward points of the mean camber line are the leading and trailing edges, respectively.

Chord line: The straight line connecting the leading and trailing edges is the chord line of the airfoil, and the precise distance from the leading to the trailing edge measured along the chord line is simply designated the chord of the airfoil, given by the symbol c

The camber is the maximum distance between the mean camber line and the chord line, measured perpendicular to the chord line. The camber, the shape of the mean camber line, and to a lesser extent, the thickness distribution of the airfoil essentially controls the lift and moment characteristics of the airfoil.

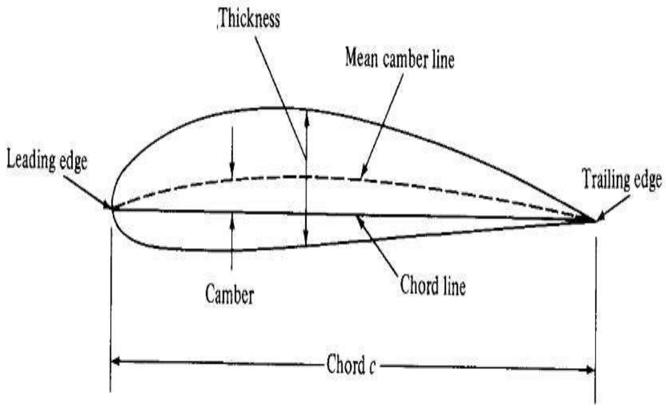



Fig 1. Airfoil Nomenclature

### *A. Aerodynamic Forces:*

The freestream velocity is the velocity of the air far upstream of the airfoil. The direction is defined as the relative wind. The angle between the relative wind and the chord line is the angle of attack a of the airfoil, there is an aerodynamic force created by the pressure and shear stress distributions over the wing surface. This resultant force is shown by the vector R in Figure 2. In turn, the aerodynamic force R can be resolved into two forces, parallel and perpendicular to the relative wind. The drag D is always defined as the component of the aerodynamic force parallel to the relative wind. The lift L is always defined as the component of the aerodynamic force perpendicular to the relative wind. In addition to lift and drag, the surface pressure and shear stress distributions also create a moment M which tends to rotate the wing.

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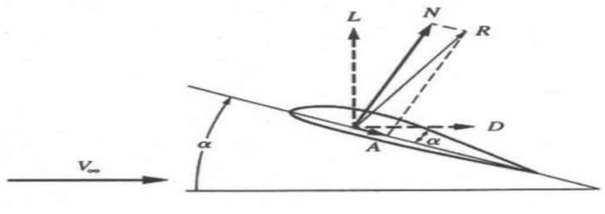


Fig 2. Aerodynamics Forces (Lift, Drag, Axial, Normal)

The diagram also introduces two new variables called N for normal force and A for axialforce. These two quantities are not measured with respect to the velocity, but with respect to the geometry of the airfoil itself Similar to lift and drag, normal force and axial force are defined as being perpendicular and parallel to the chord line, respectively.

We have already seen that lift and drag always keep the same orientation with respect to the velocity no matter what the angle of attack is. However, the orientation between these two forces and the chord line of the airfoil does change. The reverse is true for the normal and axial forces. As angle of attack changes, the normal and axial forces change orientation with respect to the velocity, but the two vectors always maintain the same orientation with respect to the body. The quantities lift, drag, normal force, and axial force are all related by simple trigonometry.

$$L = N\ \cos(\alpha) - A\ \sin(\alpha)$$
$$D = N\ \sin(\alpha) + A\ \cos(\alpha)$$

Lift Curve:

Let C1 be the coefficient of Lift. The variation of coefficient of Lift C1 with angle of attack α is as shown in the figure 3 .The experimental data indicate that c1 varies linearly with a over a large range of angle of attack. The slope of the linear portion of the lift curve is designated as a0 dc/da lift slope., when α = O, there is still a positive value of c1, that is, there is still some lift even when the airfoil is at zero angle of attack to the flow. This is due to the positive camber of the airfoil. All airfoils with such camber have to be pitched to some negative angle of attack before zero lift is obtained. The value of a when lift is zero is defined as the zero lift angle of attack αL=0 and is illustrated in Figure 3, where the lift curve for a cambered airfoil is compared with that for a symmetric (no camber) airfoil.

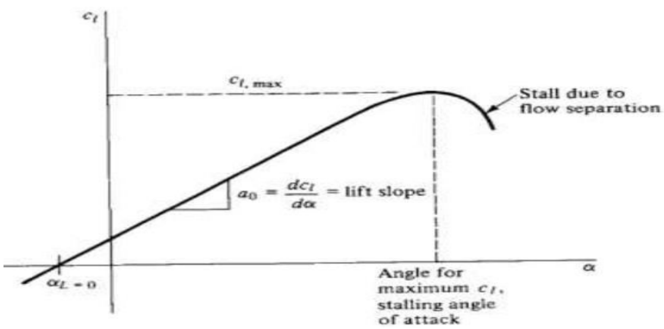


Fig. 3 Lift Curve

Note that the lift curve for a symmetric airfoil goes through the origin. At the other extreme for large values of α, the linearity of the lift curve breaks down. As α is increased beyond a certain value, c1 peaks at some maximum value, Ct max and then drops precipitously as further increased. In this situation, where the lift is rapidly decreasing at high a, the airfoil is stalled.

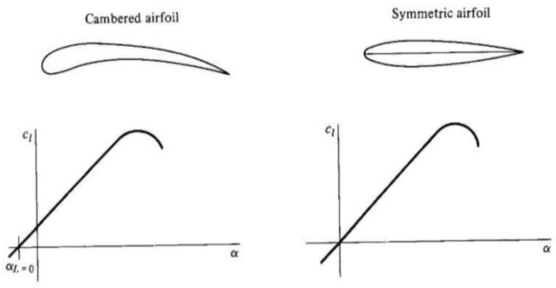


Fig 4 Comparison Between Cambered and Symmetric Curve

*B. Selection of Airfoil.*

Any section of the wing cut by a plane parallel to the aircraft xz plane is called an airfoil. It is usually looks like a positive cambered section that the thicker part is in front of the airfoil. An airfoil-shaped body moved through the air will vary the static pressure on the top surface and on the bottom surface of the airfoil. If the mean camber line in a straight line, the airfoil is referred to as symmetric airfoil, otherwise it is called cambered airfoil. The camber is usually positive. In a positive cambered airfoil, the upper surface static pressure in less than ambient pressure, while the lower surface static pressure is higher than ambient pressure.

There are some selection criteria for selecting a airfoil for a passenger aircraft

- The airfoil with the highest maximum lift coefficient
- The airfoil with the proper ideal or design lift coefficient ( dlC or ilC ).
- The airfoil with the lowest minimum drag coefficient.
- The airfoil with the highest lift-to-drag ratio ((Cl/Cd)max).
- The airfoil with the lowest (closest to zero; negative or positive) pitching moment coefficient (Cm).
- The proper stall quality in the stall region (the variation must be gentle, not sharp).
- The airfoil must be structurally reinforceable. The airfoil should not that much thin that spars cannot be placed inside.
- The airfoil must be such that the cross section is manufacturable.
- The cost requirements must be considered.
- Other design requirements must be considered. For instance, if the fuel tank has been designated to be places inside the wing inboard section, the airfoil must allow the sufficient space for this purpose.

- If more than one airfoil is considered for a wing, the integration of two airfoils in one wing must be observed.

*C. Selected Airfoil.*

The selected airfoil is GOE 617 (Gottingen 617 airfoil)

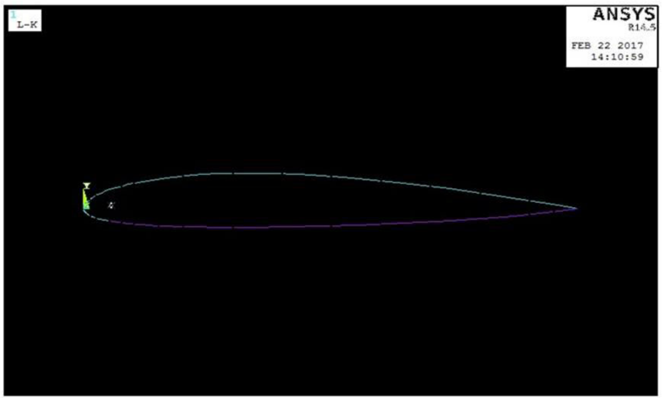


Fig 5 Gottingen 617 Airfoil

This series of airfoil was created in Gottingen university in Germany in early days of aviation. Most of them were created in 1920s and 1930s and some may date back into atleast 1910s. In any event the number associated with each airfoil appears has nothing to do with geometry or performance, its just the series of the airfoil as these airfoils evolved into different shapes to increase the performance.

GOE 617 Airfoil Co-Ordinates

| | | | |
|---|---|---|---|
| 0.0000 | 0.0000 | 0.0125 | -0.0165 |
| 0.0125 | 0.0235 | 0.025 | -0.023 |
| 0.0250 | 0.0345 | 0.05 | -0.0305 |
| 0.0500 | 0.0485 | 0.075 | -0.0345 |
| 0.0750 | 0.0580 | 0.1 | -0.038 |
| 0.1000 | 0.0655 | 0.15 | -0.0425 |
| 0.0150 | 0.0760 | 0.2 | -0.0445 |
| 0.0200 | 0.0840 | 0.3 | -0.0475 |
| 0.0300 | 0.0910 | 0.4 | -0.0465 |
| 0.0400 | 0.0900 | 0.5 | -0.0435 |
| 0.0500 | 0.0830 | 0.6 | -0.0390 |
| 0.0600 | 0.0720 | 0.7 | -0.0330 |
| 0.0700 | 0.0580 | 0.8 | -0.0250 |
| 0.0800 | 0.0405 | 0.9 | -0.0140 |
| 0.0900 | 0.0210 | 0.95 | -0.0075 |
| 0.0950 | 0.0110 | | |
| 0.0100 | 0.0000 | | |

Airfoil Co-Ordinates for Max-Cam at 10% Chord

| | | | |
|---|---|---|---|
| 0.000 | 0.000 | 0.0125 | -0.0165 |
| 0.025 | 0.06 | 0.025 | -0.023 |
| 0.05 | 0.0655 | 0.05 | -0.0305 |
| 0.1 | 0.091 | 0.075 | -0.0345 |
| 0.2 | 0.09 | 0.1 | -0.038 |
| 0.3 | 0.86 | 0.15 | -0.0425 |
| 0.4 | 0.077 | 0.2 | -0.0445 |
| 0.5 | 0.068 | 0.3 | -0.0475 |
| 0.6 | 0.059 | 0.4 | -0.0465 |
| 0.7 | 0.048 | 0.5 | -0.0435 |
| 0.8 | 0.035 | 0.6 | -0.0390 |
| 0.9 | 0.021 | 0.7 | -0.0330 |
| 0.95 | 0.011 | 0.8 | -0.0250 |
| 1.0 | 0.0 | 0.9 | -0.0140 |
| | | 0.95 | -0.0075 |

Airfoil Co-Ordinates for Max-Cam at 40% Chord

| | | | |
|---|---|---|---|
| 0.0 | 0.0 | 0.0125 | -0.0165 |
| 0.025 | 0.0345 | 0.025 | -0.023 |
| 0.05 | 0.0485 | 0.05 | -0.0305 |
| 0.1 | 0.065 | 0.075 | -0.0345 |
| 0.2 | 0.082 | 0.1 | -0.038 |
| 0.3 | 0.089 | 0.15 | -0.0425 |
| 0.4 | 0.091 | 0.2 | -0.0445 |
| 0.5 | 0.085 | 0.3 | -0.0475 |
| 0.6 | 0.075 | 0.4 | -0.0465 |
| 0.7 | 0.058 | 0.5 | -0.0435 |
| 0.8 | 0.04 | 0.6 | -0.0390 |
| 0.9 | 0.021 | 0.7 | -0.0330 |
| 0.95 | 0.01 | 0.8 | -0.0250 |
| 1.0 | 0.0 | 0.9 | -0.0140 |
| | | 0.95 | -0.0075 |

Airfoil Co-Ordinates for Max-Cam At 50% Chord

| | |
|---|---|
| 0.0 | 0.0 |
| 0.025 | 0.0345 |
| 0.05 | 0.0485 |
| 0.1 | 0.065 |
| 0.2 | 0.082 |
| 0.3 | 0.089 |
| 0.4 | 0.090 |
| 0.5 | 0.085 |
| 0.6 | 0.08 |
| 0.7 | 0.06 |
| 0.8 | 0.04 |
| 0.9 | 0.021 |
| 0.95 | 0.01 |
| 1.0 | 0.0 |

| | |
|---|---|
| 0.0125 | -0.0165 |
| 0.025 | -0.023 |
| 0.05 | -0.0305 |
| 0.075 | -0.0345 |
| 0.1 | -0.038 |
| 0.15 | -0.0425 |
| 0.2 | -0.0445 |
| 0.3 | -0.0475 |
| 0.4 | -0.0465 |
| 0.5 | -0.0435 |
| 0.6 | -0.0390 |
| 0.7 | -0.0330 |
| 0.8 | -0.0250 |
| 0.9 | -0.0140 |
| 0.95 | -0.0075 |

According to the airfoil co-ordinates mentioned above for maximum camber at different percentage along its chord length, the airfoils are designed and analyzed in ANSYS software as follows.

ANSYS publishes engineering analysis across a range of disciplines including fluid element analysis, structural analysis, computational fluid dynamics, explicit and implicit methods and heat transfer.

ANSYS Fluent, CFD, CFX and related software are computational fluid dynamics software tools used by engineers for design and analysis. These tools can simulate fluid flows in a virtual environment – for example, the fluid dynamics of ship hulls, gas turbine engines (including compressor, combustion chamber, turbines and after burners); aircraft aerodynamics; pumps, fans, HVAC systems, mixing vessels, hydro cyclones, vacuum cleaners, etc.

*D. Airfoil Design*

The modification of the airfoil design is done by shifting the maximum camber along the chord line. Hence the airfoil evolves into different shapes, on which the characteristics and performance will be analyzed and studied.

GOE 617 Max-camber at 30% of chord

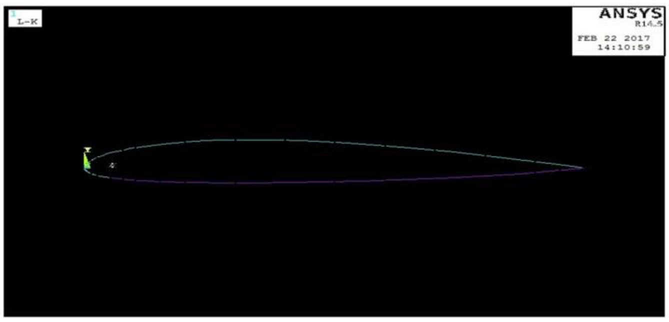


Fig 6 .GOE 617 Airfoil Design

GOE 617 Max-Camber at 10% of Chord

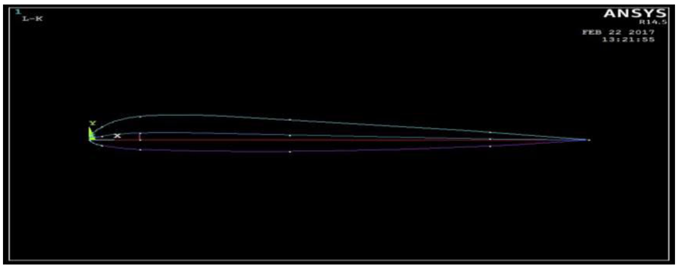


Fig 7. GOE 617 Airfoil Design for Max-Camber At 10% of Chord

GOE 617 Max-Camber At 40% of Chord

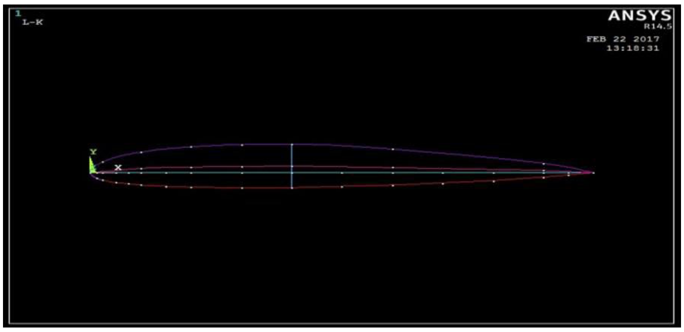


Fig 8 GOE 617 Airfoil Design For Max-Camber At 40% of Chord

*E. CFD Analysis of Airfoils*

Designed airfoils are analyzed using ANSYS software for different parameters like Velocity and Pressure. This shows the advantages and disadvantages of the developed airfoils. Maximum camber at 30% distance along its chord is the reference airfoil. i.e, original GOE 617.

Airfoils with maximum camber at 30% of chord

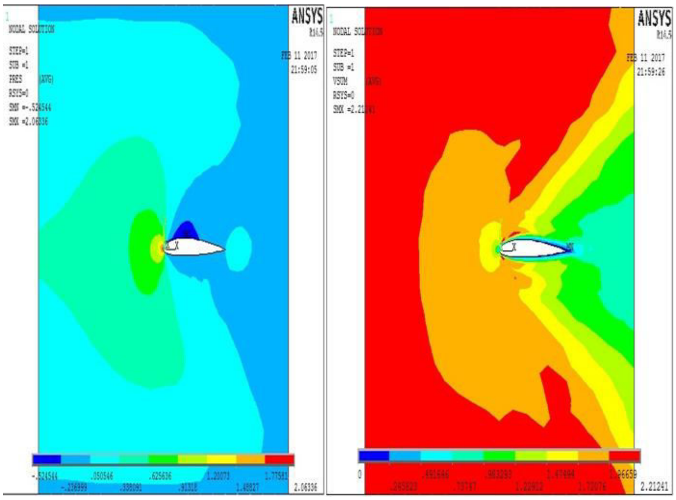


Fig 9. Pressure and Velocity Distribution At 30% of Chord

The pressure distribution and velocity distribution for different maximum camber distance along its chord is as follows.

Airfoils with Maximum Camber at 10% of Chord

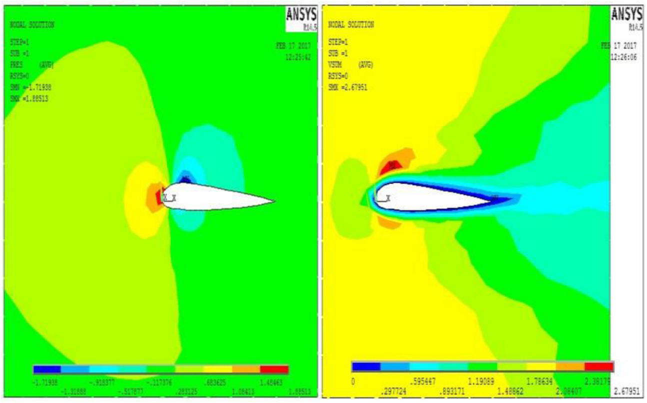

Fig 10.. Pressure and Velocity Distribution At 10% of Chord

Airfoils with Maximum Camber At 40% of Chord

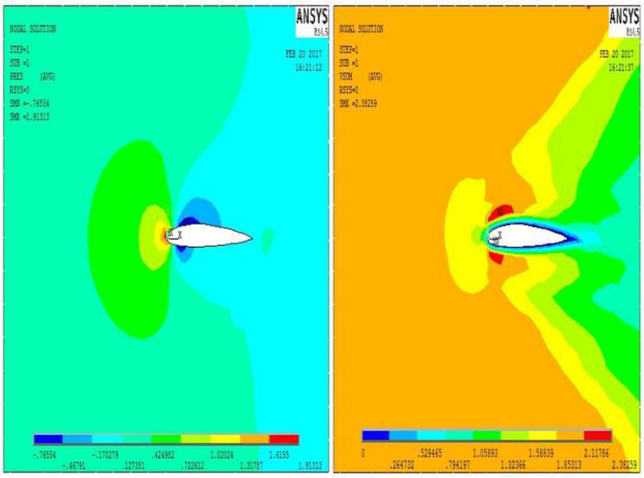

Fig 11. Pressure and Velocity Distribution at 40% of Chord

Airfoils with Maximum Camber at 50% of Chord

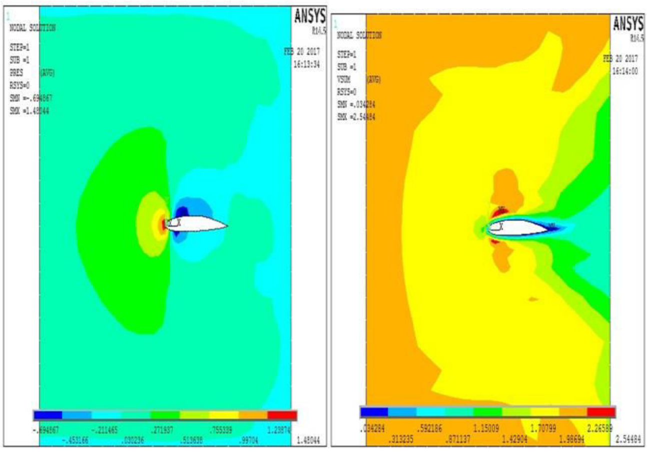

Fig12. Pressure and Velocity Distribution At 50% of Chord

From the analysis of the above airfoils, we come to know about the pressure flow distribution and velocity flow distribution of the airfoils. Airfoils with maximum camber 40% along its chord has better pressure flow and velocity flow performance and advantages comparatively to the original GOE 617 airfoil where the maximum camber is at 30% of its chord. Therefore these airfoils are selected for fabrication and testing in wind tunnel to visualize its actual performance aerodynamically.

## V. AIRCRAFT DESIGN

The suitable design from the above airfoils is GOE 617 of which maximum camber is at 40% along its chord length, Which will be used for the outer wing design and tail parts design like horizontal stabilizer and vertical stabilizer of basic aircraft design, So that the characteristic's and performance parameters are improved. The basic aircraft design is developed using CATIA software according to the calculated values and selected airfoil designed as shown in figure below.

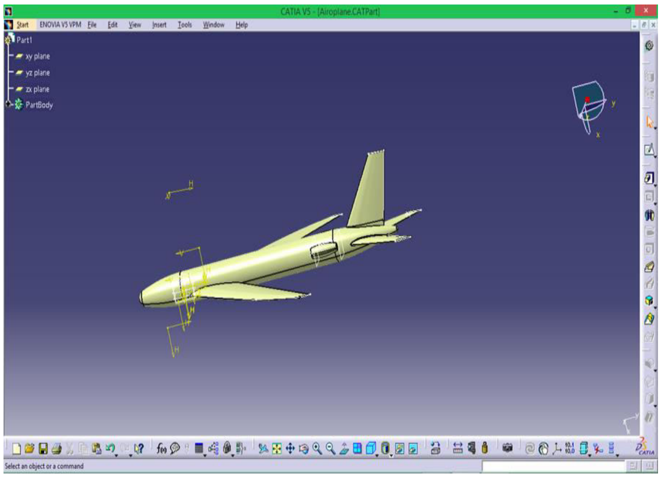

Fig13. Aircraft Design

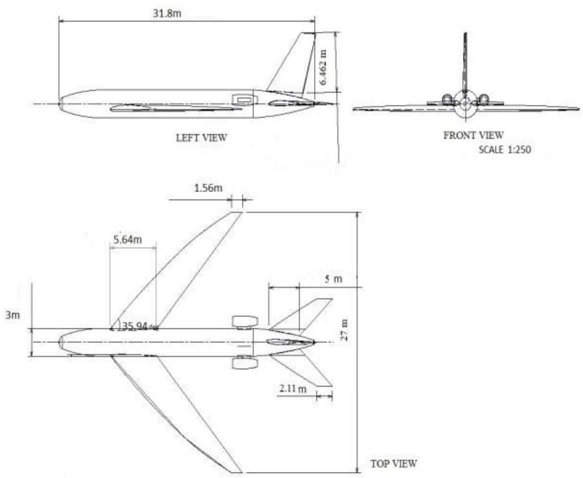


Fig14. 2D View of Aircraft Design

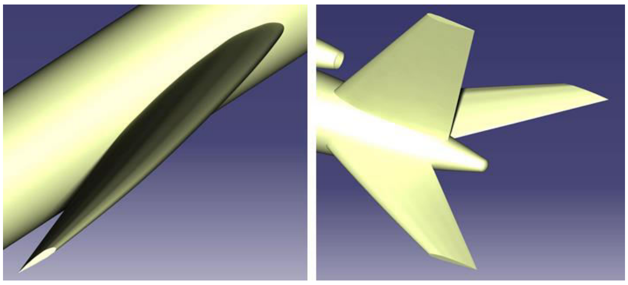

Fig 15. Wing and Tail Design

## VI. FABRICATION AND WIND TUNNEL SETUP

The airfoils were fabricated by using the 3-D view of airfoil designed with the actual dimensions using solid edge software, which is suitable for the wind tunnel that we use for testing. The airfoils dimensions are as follows:

- Span = 57.5 cm = 575 mm
- Chord length = 40 cm = 400 mm
- Maximum thickness = 5.54 cm = 55.4 mm
- Test section dimensions = 600 mm x 600 mm x 2000 mm

Fig 16. Fabricated Airfoil

### A. *Specifications of wind tunnel:*

- Type of tunnel: Low speed (subsonic), open circuit, suction type.
- Test Section: 600mm × 600mm cross section
- Airspeed: up to 50 m/sec
- Contraction ratio: 11:1
- Drive: axial flow fan driven by DC motor with Thyristore speed controller
- Overall Size: 9m (L) × 2.2m (B) × 2.5m (H)
- Power Requirement: AC 3ph 440 volts, 70 Amps.

Co-efficient of pressure: $C_p = ( P_i – P_{inf} ) / ( P_o – P_{inf} ) = ( H_i – H_{inf} ) / ( H_o – H_{inf} )$

Normal co-efficient: $C_n = ( C_{pl} - C_{pu} ) \times d ( X / C )$

Lift coefficient: $C_l = C_n \times COS\ \alpha$

Drag coefficient: $C_d = C_n \times SIN\ \alpha$

Where

- $P_i$ is the local static pressure values measured around airfoil
- $p_{inf}$ is the free stream static pressure measured by pitot tube
- $p_o$ is free stream total pressure measured by pitot static probe
- h is manometer liquid column height

## VII. RESULTS AND DISCUSSIONS

| MC at % c / Coefficients | Max cam. at 10% c | Max cam. at 30% c | Max cam. at 40% c |
|---|---|---|---|
| $C_n$ | 0.064 | 0.04 | 0.04 |
| $C_l$ | -0.063 | 0.04 | 0.04 |
| $C_d$ | $5.57 \times 10^{-3}$ | $4.314 \times 10^{-3}$ | $2.96 \times 10^{-3}$ |

Table1: Values of Coefficient of Designed Airfoils

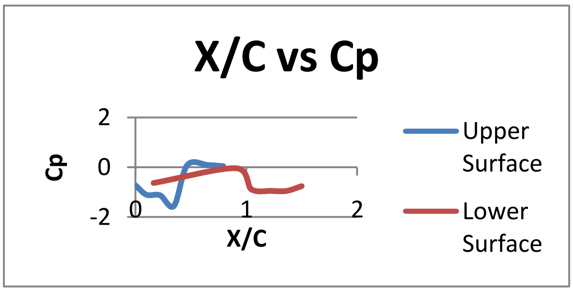


Fig17. $C_p$ Varying with X/C for Airfoil at 5° AOA of MC At 10% Chord

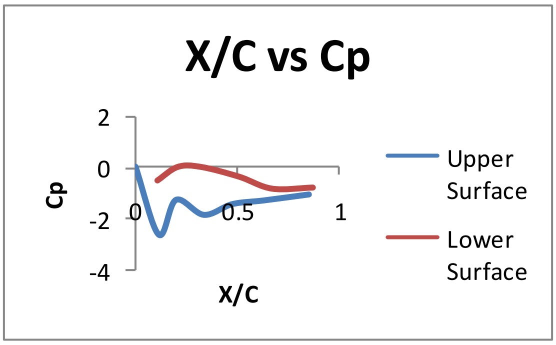


Fig18. $C_p$ Varying with X/C for Airfoil At 5° AOA of MC at 30% Chord

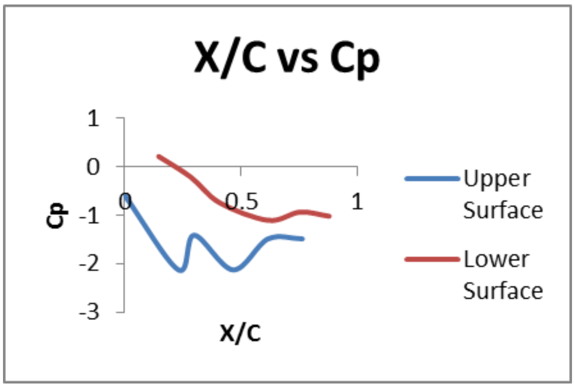


Fig19. $C_p$ Varying with X/C for Airfoil at $5^o$ AOA of MC at 40% Chord

## VIII. CONCLUSION

From the analysis of the above airfoils, we come to know about the performance of the airfoils. Airfoils with maximum camber 40% along its chord has better performance and advantages comparably. From the wind tunnel test, the Lift coefficient $C_L$ of the airfoil with maximum camber at 40% of chord is found to be similar to the existing airfoil, but the advantage is that the Drag coefficient is found to be less. Also, the Pressure distribution and Velocity distribution of the airfoil with maximum camber at 40% of chord is found to be better than the other airfoils. The boundary flow condition of the airfoil with maximum camber at 40% of chord gives less flow separation compared to other airfoils.

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