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Comparative Assessment of Drag & Lift Force on NACA 66(2)-015 Airfoil Model by Computational Fluid Dynamics and Experimental Method

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***Abstract*—In this paper modelling and simulation of an airfoil problem related to the CFD as well as wind tunnel experimentation has been studied briefly. The analysis of symmetric and cambered airfoil i.e. NACA 662_015 at different angle of attack (AOA) and for different approaching flow velocity, using wind tunnel setup for experimentation and ANSYS-Fluent for computational study is showcased. For simulation, 3D models were created in solid work and analysis was done in ANSYS-Fluent tool. The experiments were conducted in wind tunnel where lift and drag forces for various AOA are quantified. Coefficient of lift, drag and other characteristics are measured for 25 m/s, 30 m/s and 35m/s free stream velocity, and for each velocity case the AOA is varied from 0 degree to 14-degree with an interval of 2 degrees.. Also, the variations in aerodynamic forces for both symmetric and cambered airfoils were highlighted.**

Keywords*— *NACA, airfoil, ANSYS, Wind Tunnel

1. INTRODUCTION

Airflow over an airfoil generates the lift force and drag force to the airfoil. The drag force will be combinations of parasite drag, lift induced drag and wave drag. The shape, velocity and the surface finish decided the parasite drag contribution, and the angle of attack (AOA) for generating lift will also produce drag beyond a critical value of AOA, which is lift induced drag, and wave drag is due to the compression wave when the airfoil travels at transonic speed and above. The lift force is due to the pressure difference between upper and lower surface of airfoil which is because, the time taken by the approaching air molecules is different to reach the trailing edge from leading edge. The details of these forces are shown below in figure 1.

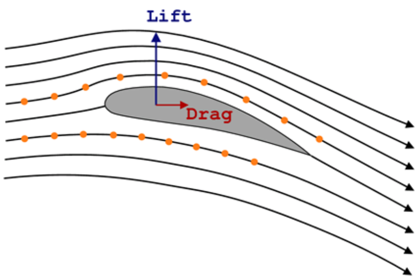

Fig 1: Aerodynamic Forces acting on airfoil

NACA experimented many airfoils of different series, and showcased the performances. Compared to the other series airfoils, 6-digit airfoil has the detailed information on correlations hence it is opted in this research work. In this thesis, the numerical as well as experimental work on symmetric and cambered NACA 66(2)-015 airfoils to understand the steady lift and drag force components for different approaching velocities. The experimental and computational research works were progressed simultaneously and compared the outcomes to check the validation as shown in figure 2.

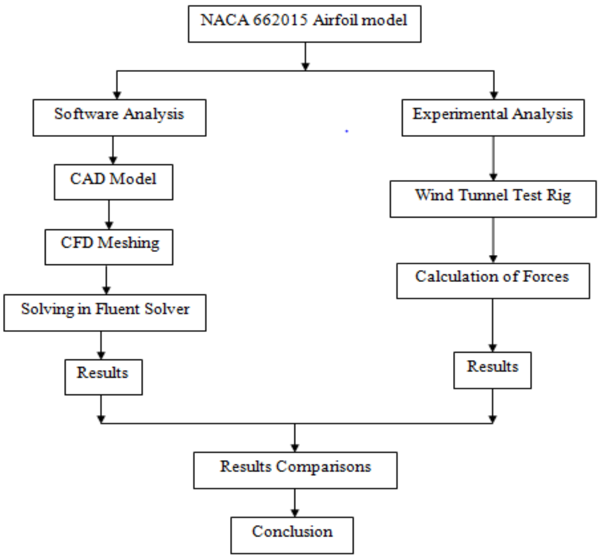

Fig 2: Research flow chart

2. NUMERICAL APPROACH

NACA airfoil geometric data is used in designing particular airfoil using Solid Works tool (version 14). The Figure 3.a and Figure 3.b shows the 3D model of symmetric and cambered airfoil respectively.

Further design, meshing the model using specific mesh type and quality is very essential to have converged results. The model is meshed using unstructured tetra element in ANSYS tool (R 15.0 version) in which the model consists of 81051 elements and 24379 nodes. The Fig 4.a & 4.b shows the meshed model of symmetric and cambered airfoil.

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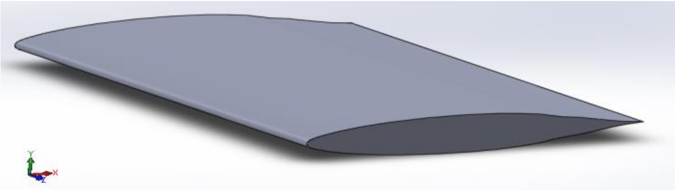

Fig 3.a : Symmetric airfoil

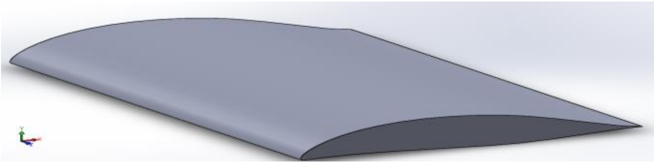

Fig 3.b : Cambered airfoil

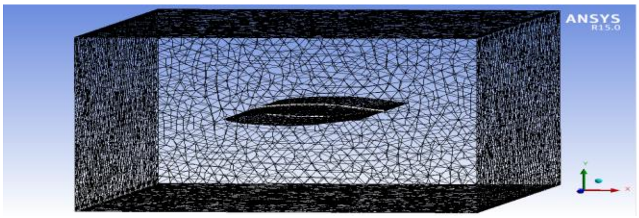

Fig 4.a : Meshed model of symmetric airfoil

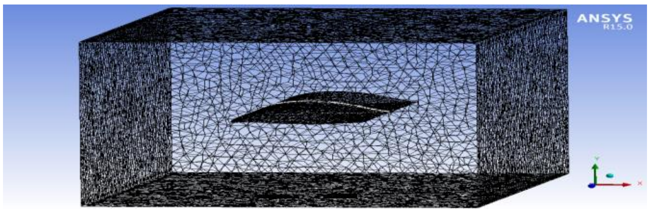

Fig 4.b : Meshed model of cambered airfoil

The turbulence model (k-ε model) is used in analysing the flow characteristics of this computational problem. To be specific, the second order upwind condition is considered.
The magnitudes of turbulence intensity and respective viscosity ratio are considered to be 0.00034 and 0.2.

A subsonic wind tunnel of test section size 0.3 X 0.3 X 1.2 cubic meter and a tunnel contraction ratio of 9 where flow speed of 20 to 40 m/s can be achieved are used. The pressure force on airfoil is measured using pressure tapping with a calibrated manometer setup. In total 16 pressure tapping were made on each type of aircraft and measured the pressure magnitudes for different angle of attack and flow velocities. The general equations of aerodynamic coefficients are used to find the aerodynamic forces using pressure data.

3. RESULTS AND DISCUSSION

The problem is evaluated for a velocity range of 25 m/s to 35 m/s with a step of 5 m/s, and for AOA range of 0 to 10 degrees with a step of 2 degrees.

3.1 Computational Approach

The pressure contours shown in figure 5.a to 5.d showcase the variation of the static pressure distribution over symmetric airfoil for different angle of attack for 30 m/s free stream velocity.

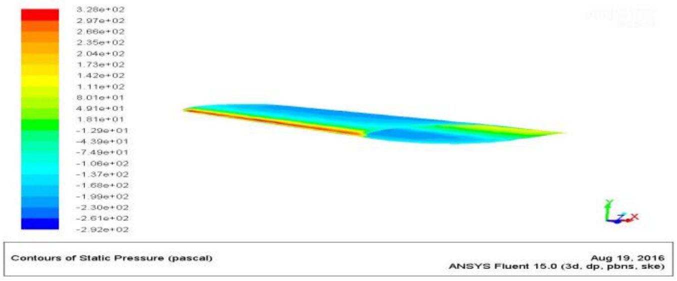

Fig 5.a: Static pressure for 0 degree AOA symmetric airfoil

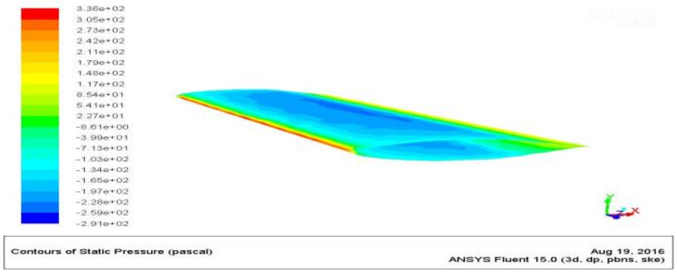

Fig 5.b: Static pressure for 4 degree AOA symmetric airfoil

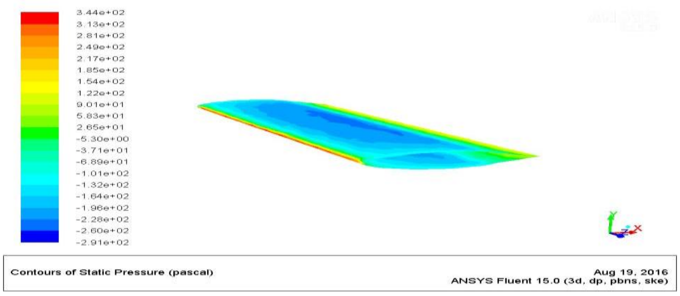

Fig 5.c: Static pressure for 6 degree AOA symmetric airfoil

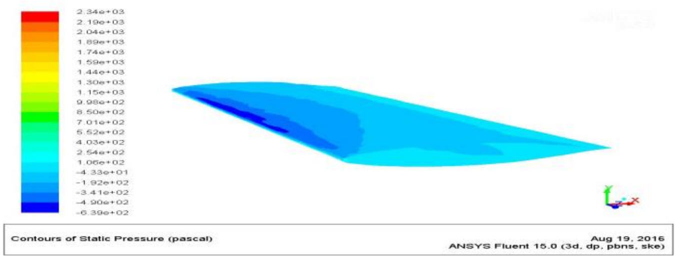

Fig 5.d: Static pressure for 8 degree AOA symmetric airfoil

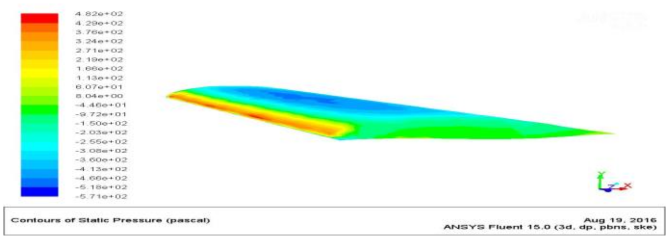

Fig 6.a: Static pressure for 0 degree AOA cambered airfoil

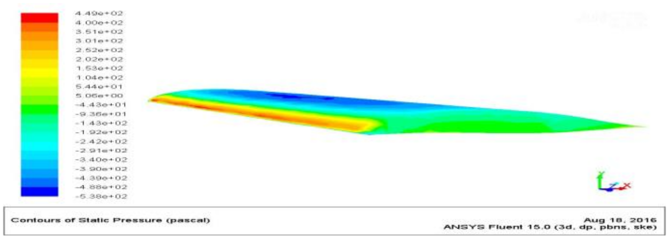

Fig 6.b: Static pressure for 4 degree AOA cambered airfoil

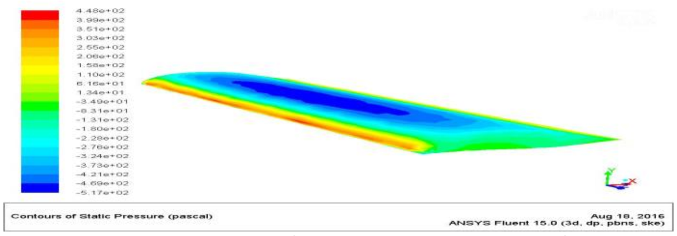

Fig 6.c: Static pressure for 8 degree AOA cambered airfoil

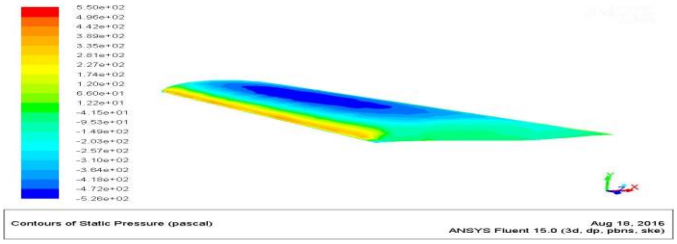

Fig 6.d: Static pressure for 10 degree AOA cambered airfoil

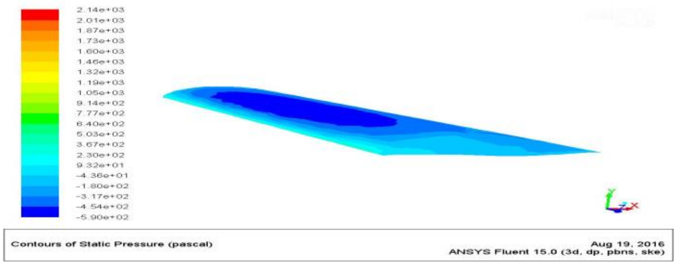

Fig 6.e: Static pressure for 12 degree AOA cambered airfoil

Analysing above graphs, it is clear that till 6 degree AOA there is high static pressure acting on leading edge but at 8 degree AOA there is negligible static pressure because of the boundary layer separation at leading edge due to turbulence. Hence the stalling angle for symmetric airfoil is 6 degree.
The contours shown in figure 6.a to 6.e showcase the variation of the static pressure for cambered airfoil for different angle of attack for 30 m/s free stream velocity.

The graphs in Figure-7.a & 7.b shows the change in magnitude of aerodynamic forces for 25 m/s, 30 m/s and 35 m/s velocities for symmetric airfoil. Here the magnitude of both lift and drag forces are directly proportional to the velocity because when the flow velocity increases the pressure on the upper surface decreases and opposite at bottom of the airfoil body.

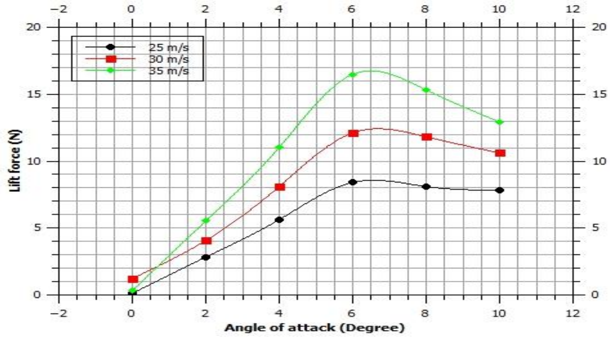

Fig 7.a: Lift vs AOA at various velocities for symmetric airfoil

Similar graphs as shown in figure 8.a & 8.b are plotted for cambered showing same characteristics and found that the magnitude of forces are more for cambered airfoil. The lift force and drag force are greater for cambered airfoil because of the improved stream lining of cambered airfoil due to which the velocity increases. Graphs for 30m/s and 35 m/s flow velocity showing same characteristics but the magnitude of forces are higher as the flow velocity increases.

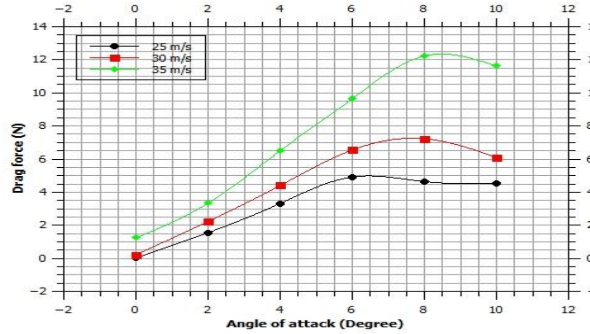

Fig 7.b: Drag vs AOA at various velocities for symmetric airfoil

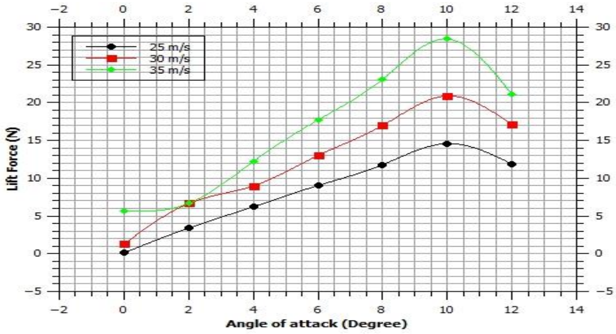

Fig 8.a: Lift vs AOA at various velocities for cambered airfoil

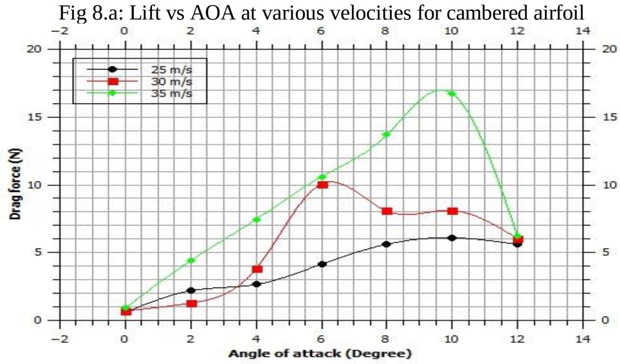

Fig 8.b: Drag vs AOA at various velocities for cambered airfoil

3.2 Experimental approach
The following graphs in figure 9.a & 9.b shows the change in magnitude of forces for 25m/s, 30m/s and 35m/s velocities for symmetric airfoil. Here the magnitude of both lift force and drag force are directly proportional to the velocity i.e. the lift and drag force increases with increase in the velocity.

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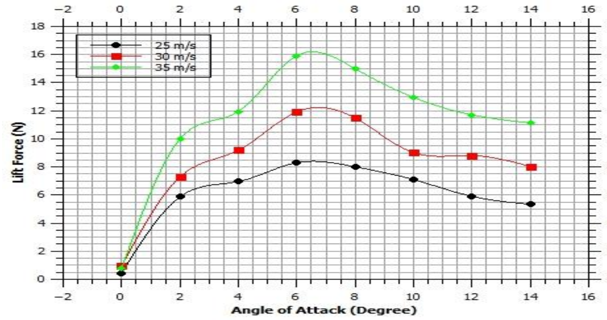

Fig 9.a: Lift vs AOA at various velocities for symmetric airfoil

It is because when the velocity increases the pressure on the upper surface decreases and reverses effect is happening at bottom of the airfoil body.

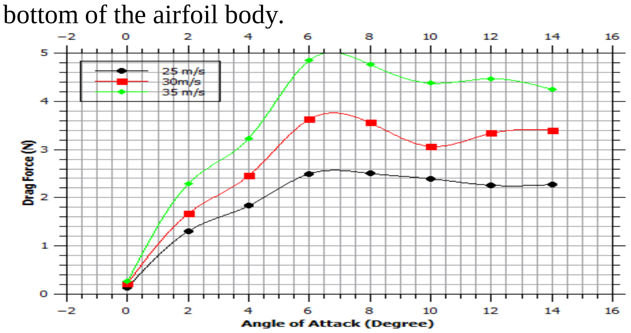

Fig 9.b: Drag vs AOA at various velocities for symmetric airfoil

Similarly same type of graphs are obtained for cambered airfoil as shown in figure 10.a & 10.b, showing same characteristics but the magnitude of forces are bit higher.

The graph 11.a & 11.b show the comparison of lift force and coefficient of lift (computational and Experimental method) with respect to angle of attack for 25m/s free stream velocity for symmetric as well as for cambered airfoils. Here initially the lift increase and for further increase in AOA the lift force reaches the maximum which is known as stalling angle and then decreases, this is because at the stalling angle the boundary layer starts separating at leading edge because of turbulence. Comparing the values of lift force and coefficient of lift at angle of stall for analysis and experimental method we get the percentage deviation of nearly 2%. Hence the lift and coefficient of lift calculated for symmetric and cambered airfoil by CFD simulation and experimentation using wind tunnel are in good correlation with each other.

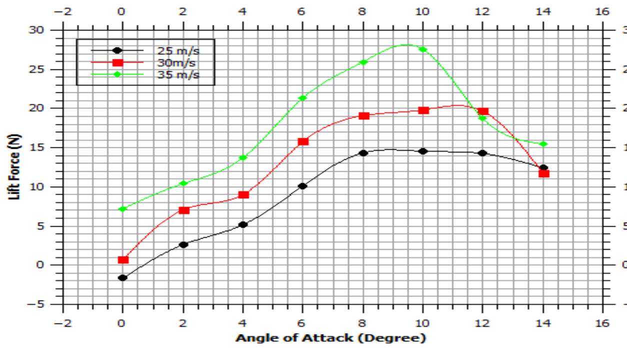

Fig 10.a: Lift vs AOA at various velocities for cambered airfoil

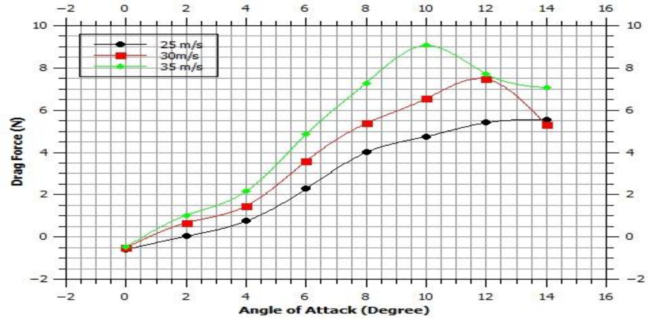

Fig 10.b: Drag vs AOA at various velocities cambered airfoil

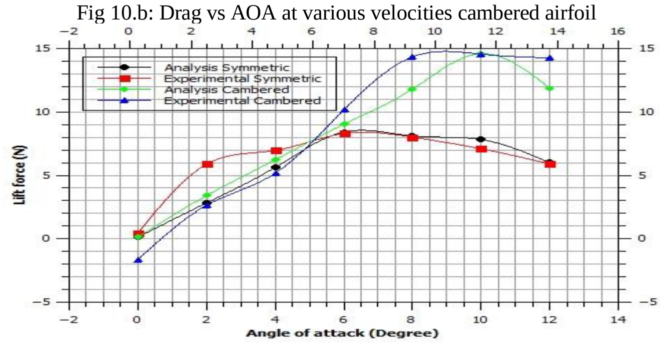

Fig 11.a: Comparison of lift for computational and Experimental method

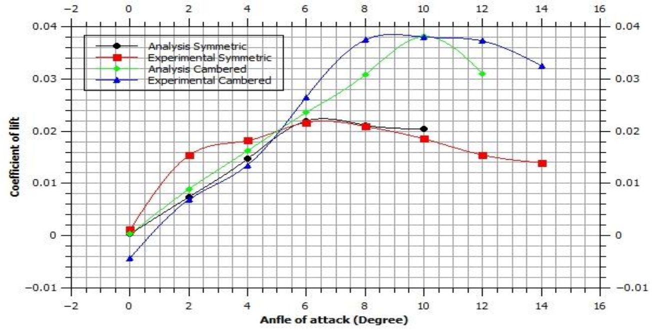

Fig 11.b: Comparison of coefficient of lift force for computational and Experimental method.

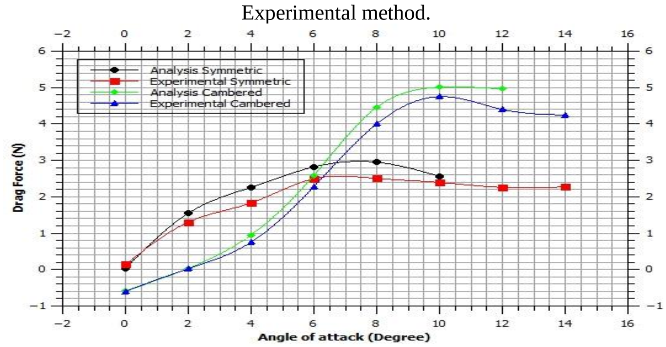

Fig 12.a: Comparison of drag force for computational and Experimental method

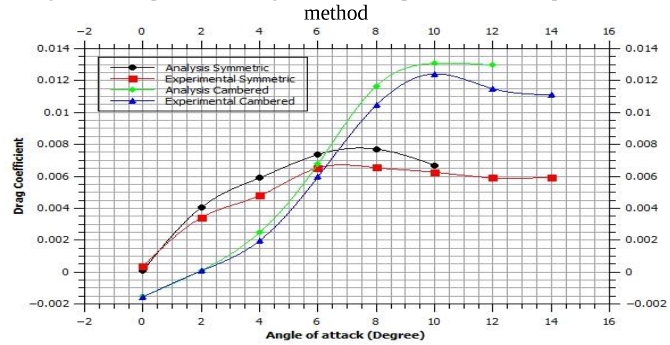

Fig 12.b: Comparison of drag coefficient for computational and Experimental method

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The above Fig- 12.a and 12.b show the comparison of drag force and drag coefficient (Analysis and Experimental method) with respect to angle of attack for 25m/s free stream velocity for symmetric as well as for cambered airfoils. The figures shows that as the angle increase the drag force and drag coefficient quickly rises because of increased frictional area and increased boundary layer thickness, at low angles the drag force varies with angle of attack is nearly constant because of the skin friction and stream lined flow. Comparing the values of drag force and drag coefficient at stall angle for analysis and experimental method we get the percentage deviation of nearly 8.5%. Hence the drag force and drag coefficient calculated for symmetric and cambered airfoil by CFD simulation and experimentation using wind tunnel are in good correlation with each other.

The sole purpose of this experiment was to compare the different parameters of NACA 66(2)-015 symmetric and cambered aerofoil and thus finding out which one is the most efficient between these two. The analysed parameters are compared for a velocity of 35 m/s as shown in table 1.

Table 1: Comparison between the two approaches for both the airfoils at 35 m/s flow velocity

Parameters	Symmetric CFD	Symmetric Expt.	Cambered CFD	Cambered Expt.
Stall Angle	6	6	10	10
Max. Lift (N)	17	16	28	26
Max. Drag (N)	13	05	17	9.5
Max. C_L	0.022	0.02	0.045	0.048
Max. C_D	0.007	0.06	0.015	0.010

4. CONCLUSIONS

In the present thesis the analysis is carried out on the NACA 66(2)-015 airfoil by employing CFD analysis and experimental method using wind tunnel to study the various characteristics of symmetric and cambered airfoils at various velocities and angle of attack.

The simulated and experimental analysis work is performed on the airfoil and it is observed that the lift force increases as angle of attack increases and reaches maximum and decreases for further increase in angle of attack.

Stalling was found to happen at an angle of attack of approximately 6 degree for symmetrical airfoil and 10 degree for cambered airfoil. At this angle of attack, flow separation begins to occur close to the leading edge. As a result, the separated regions on the top of the airfoil wing amplify in size and delay the wing's ability to create lift. At the crucial angle of attack, separated flow is so dominant that the further increases in angle of attack produce less lift.

Coefficient of lift and coefficient of drag are found for different angle of attack from the simulation and experimentation.

The lift and drag forces for cambered airfoil are greater than that of the symmetric airfoil operating at same working conditions. The magnitude of lift force and drag force increases for both the airfoils with increase in velocity of air.

The lift force and coefficient of lift calculated for symmetric and cambered airfoil by CFD simulation and experimentation using wind tunnel are in good correlation with each other with a percentage deviation of 2% hence we can say that analysis performed in the fluent are correct.

The drag force and drag coefficient calculated for symmetric and cambered airfoil by CFD simulation and experimentation using wind tunnel are in good correlation with each other with a percentage deviation of 8.5% hence we can say that analysis performed in the fluent are correct.

The cambered airfoil gives the better performance than that of symmetric airfoil.

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