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CFD Modelling and Analysis of Clark Y Airfoil for Turbulent Flow

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Abstract: Airfoils have taken their rightful place as one of the most integral components in the field of aerodynamics. Every kind of airfoil has its own particular design and significant characteristics which must be studied and analysed before subjected to the implementation of an actual flight. Several aerodynamic effects concerning lift, drag, velocity and pressure were evaluated by subsonic wind tunnel testing and computational fluid dynamic method in order to determine the behaviour of Clark Y airfoil (11.7% smoothed). Furthermore, the difference of results achieved by the two methodologies of subsonic wind tunnel testing and computational fluid dynamics were compared. In this paper, an analysis was performed at an air velocity of 18.77 m/s and 0.05 Mach (turbulent conditions) to derive and study the sensitivity of meshing, coefficient of lift, coefficient of drag, lift to drag ratio, pressure, velocity and vector profile of Clark Y airfoil.

Keywords: Clark Y, Turbulent Flow, Subsonic Wind Tunnel, CFD Analysis.

1. Introduction

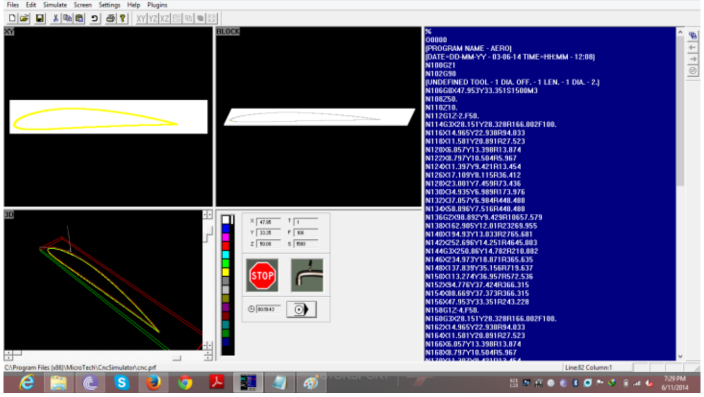
An airfoil is capable of producing an aerodynamic force while moving through a fluid [1]. The component of that aerodynamic force which is perpendicular to the direction of motion is known as lift while the component which is parallel to the direction of motion is known as drag [2]. Airfoil is designed in such a way that when it is moving through the air, the air splits as some of its portion moves above the airfoil while the remaining portion moves below the airfoil. While doing so, the air passing above the surface of the airfoil decreases the pressure of the air on the same surface. Due to high air pressure always moving towards low air pressure, a lift is produced since the air below the wing pushes upward [3]. In other words, the shape of the airfoil causes air to travel faster on the top as compared to the air speed and the air pressure beneath the wing. This reduces air pressure and creates lift [4]. However, it is not the airfoil alone that creates a lift. In the case of aircraft, lift occurs when the airfoil deflects an incoming air due to its angle of attack [5].

2. Methodology and Experimental Work

Clark Y is a general purpose that is used for its steady flow at low Reynolds numbers [7]. Furthermore, the lower surface of this airfoil is parallel to its chord line. Thus, enabling the inclometer to directly change its angle of attack. In other words, the Clark Y airfoil has high stability at low speeds and has discovered colossal support for the development of model airplane, on account of the flight execution that the segment offers at medium Reynolds number wind streams [6]. The Clark Y is engaging on account of its high camber and for its close flat lower surface, which helps in the precise development of wings on arrangements mounted on a level development board [9].

2.1 Fabrication of Airfoil

Clark Y airfoil was manufactured by CNC Machine. The code required to obtain its shape was generated by Master CAM and displayed on CNC Simulator.



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N154X88.669Y37.373R366.315
N156X47.953Y33.351R243.228
N158G1Z-4.F50.
N160G3X28.151Y28.328R166.002F100.
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N164X11.581Y20.891R27.523
N166X6.057Y13.398R13.874
N168X8.797Y10.504R5.967
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Fig 1: CNC Simulator for Clark Y Airfoil

The Clark Y airfoil structure was constructed by balsa wood and then laminated by thin balsa sheet.

Fig 2: Lamination of Clark Y Airfoil

2.2 Wind Tunnel Testing

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A subsonic wind tunnel was chosen for the analysis of Clark Y airfoil. Normally, wind tunnel testing consume a lot of energy and prove to be a costly process. In this case, the subsonic wind tunnel was utilized for experimentation and testing on Clark Y airfoil to compare its results with those of CFD analysis in order to determine whether the latter can prove to be a cost saving alternate.

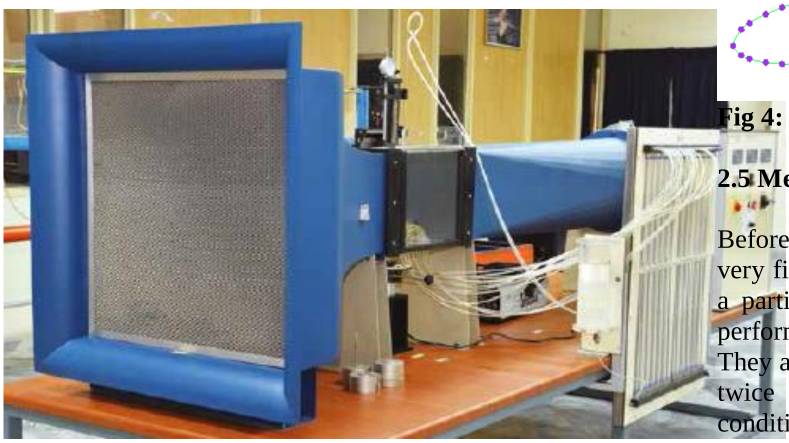

Fig 3: Subsonic Wind Tunnel

2.3 CFD Analysis

Analysis regarding coefficient of lift, coefficient of drag, lift to drag ratio, pressure, velocity and vector profile were performed with the aid of FLUENT solver. The Clark Y airfoil is characterized under the medium-speed operating conditions of turbulent flow with various parameters as shown in Table 1.

2.4 Input and Boundary Conditions

The following initial and boundary conditions were chosen for the CFD analysis of 2D Clark Y airfoil.

No.	Input	Value
1	Velocity of Flow	18.77 m/s
2	Mach Number	0.05 Mach
3	Operating Temperature	288.16 K
	Operating Pressure	101325 Pa.
4	Type of Flow	Turbulent
5	Regime	Subsonic
6	Density of Flow	1.225 kg/m^3
7	Kinematic Viscosity	1.4607 x 10^{-5} m^2/s
8	Angle of Attack	0° - 18°
9	Reynolds's number	3.2 x 10^5
10	Chord Length	0.254 m
11	Fluid	Air as ideal

Table 1: Operating Parameters

2.5 Generation of Points

In order to design a two-dimensional Clark Y airfoil, the data points necessary for execution were generated on Microsoft Excel. After this, the data was then saved in a notepad file. The data points were then imported in ICEM 15.0 so a 2D geometry of an airfoil could be automatically generated.

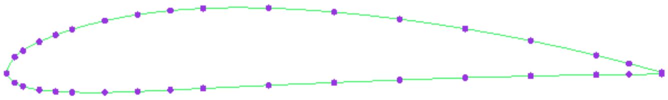

Fig 4: 2D Geometry of Clark Y Airfoil

2.5 Meshing of Clark Y Airfoil

Before any CFD analysis, grid generation or meshing is the very first step. Meshing is the division of elements or nodes of a particular geometry. Two different types of meshing were performed on the two-dimensional geometry of Clark Y airfoil. They are medium meshing and fine meshing. Fine meshing has twice the elements as compared to medium meshing. A condition occurs during meshing when results hardly show any difference by increasing the number of elements. Same was the case between the results shown by fine and medium meshing. The results of both of these types of meshing hardly showed any difference and the analysis was performed on medium meshing.

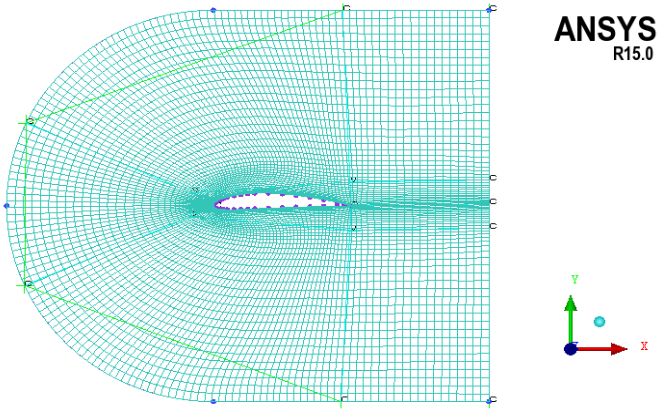

Fig 5: Medium Meshing on Clark Y Airfoil

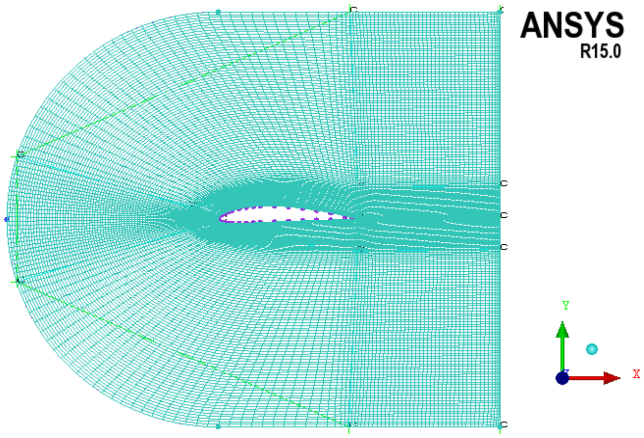

Fig 6: Fine Meshing on Clark Y Airfoil

3. Results

The study was successful in terms of plotting the graphs of Coefficient of lift at different angle of attacks, Coefficient of drag, pressure contours, velocity contours and vector contours. From the results, it is observed that when the angle of attack increases, then the static pressure begins to shift over the airfoil and the airfoil stalls. It is also evident from the results that as the angle of attack increases, then the air flow becomes unsteady [10]. This unsteady behavior is caused by the severe increase in the turbulent kinetic energy and the dissipation energy. The graph below exhibits the difference between the values of coefficient of lifts determined by both wind tunnel testing and CFD analysis. It shows a very slight difference and how coefficient of lift increases with the increase of angle of attack but it is observed that at some angle, it begins to move downwards and the angle at which coefficient of lift is decreasing is called stall angle and that point is called stalling point.

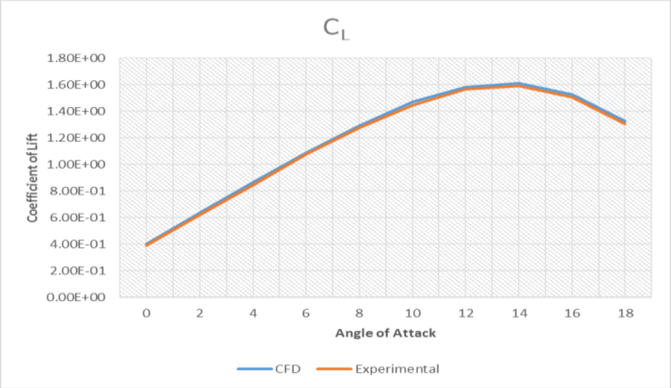

Fig 7: Comparison of Coefficient of Lifts at different Angle of Attacks (CFD vs. Wind Tunnel)

The following graph exhibits the difference between the values of coefficient of drags determined by both wind tunnel testing and CFD analysis. It shows a very slight difference and how coefficient of drag increases with the increase of angle of attack. It is to be noted that when the angle of attack is increasing, then the coefficient of drag also increases.

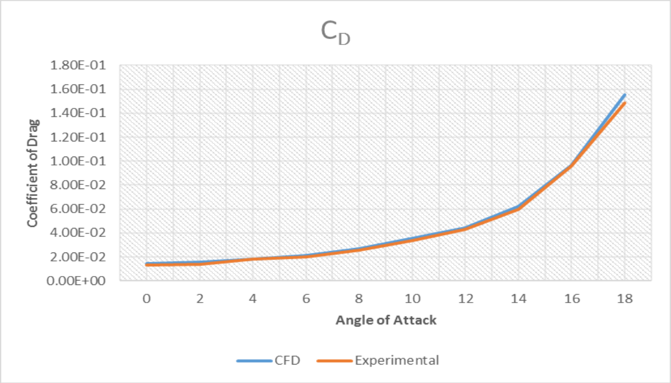

Fig 8: Comparison of Coefficient of Drags at different Angle of Attacks (CFD vs. Wind Tunnel)

The following shows a very slight difference how much extent the angle of attack effects the coefficients of lift and drag. Initially, it is observed that when the angle of attack increases, then the coefficient of lift is increasing much more as compared to coefficient of drag [8]. It is observed from the results that when the angle of attack becomes nearly equal to 14°, then value of coefficient of drag increases more as compared to the coefficient of lift. So we had to be limited till this angle because subsequently, stalling occurs.

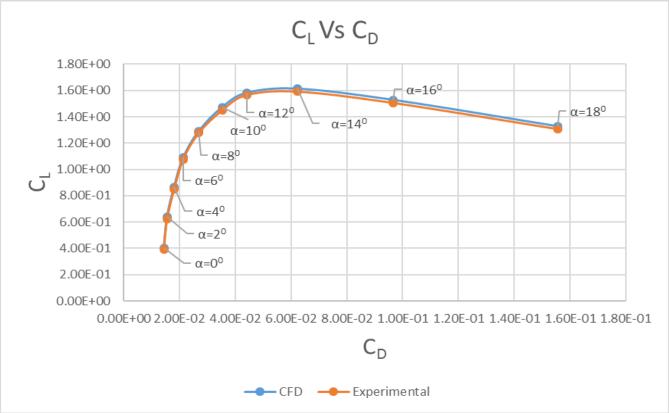

Fig 9: Comparison of Coefficient of Lifts vs. Coefficient of Drags (CFD vs. Wind Tunnel)

3.1 Pressure Contour Plot

By the CFD analysis performed on the two-dimensional Clark Y airfoil, the following pressure contour plot was obtained.

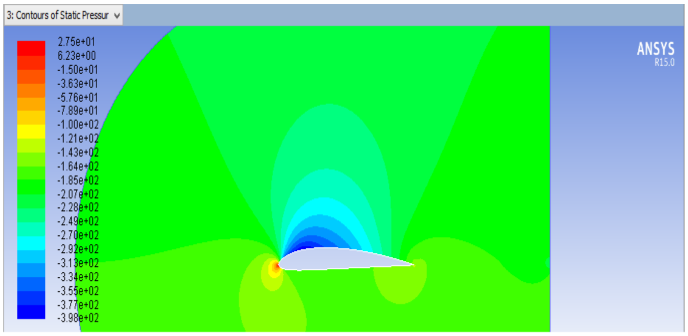

Fig 10: Pressure Contour Plot

From the pressure diagram, we can observe that the pressure contours at the leading edge is too much as compared to the trailing edge and the pressure contours at the upper surface of the airfoil is quite less as compared to the lower surface of the airfoil. This shows that the lift is produced when pressure contours are less than the upper surface. Due to this way, a lift can be achieved. It is to be noted that pressure contours at the boundary remain the same.

3.2 Velocity Contour Plot

From the CFD pressure diagram, the following velocity contour plot was obtained from the two-dimensional Clark Y airfoil.

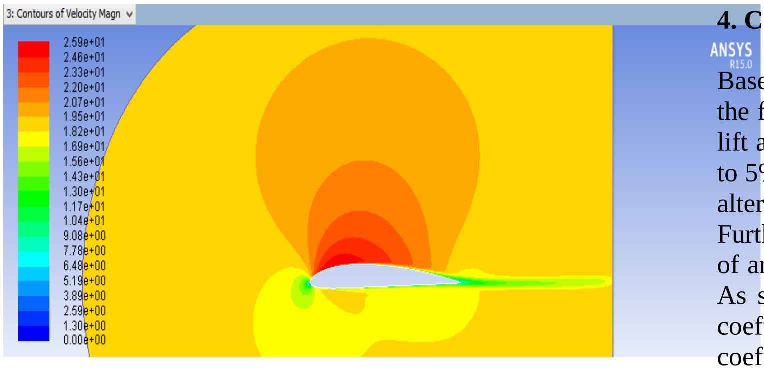

Fig 11: Velocity Contour Plot

From velocity diagram, we have observed that the velocity contours at the leading edge and trailing edge are, to some extent, different and the velocity contours at the upper surface of the airfoil is greater as compared to the lower surface of the airfoil. It shows that lift is produced when velocity contours are greater on upper surface. And at the boundary, the velocity contours remain the same. Furthermore, at the stagnation point, the velocity is zero.

3.3 Velocity Vector Contour Plot

From the CFD analysis, the following velocity vector contour plot was obtained for the two-dimensional Clark Y airfoil.

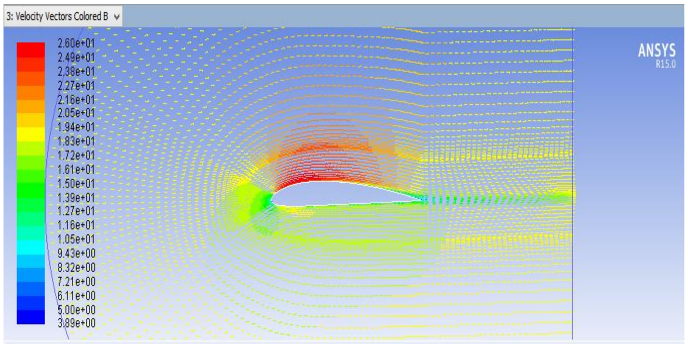

Fig 12: Velocity Vector Contours

It shows that how the velocity is separating over the airfoil and what is the behavior of air velocity at the boundary condition. It is also observed how vertices are formed at the trailing edge so, as far as our flow configuration is concerned, our flow is turbulent flow.

4. Conclusion

Based on the wind tunnel testing results and CFD analysis of the flow on Clark Y airfoil, differences between coefficients of lift and drag values at different angle of attacks range from 2% to 5%. It can be concluded that CFD analysis can act as a cheap alternate for the costly wind tunnel experimentation. Furthermore, the coefficient of lift increases with the increase of angle of attack as long as it does not reaches the stall angle. As soon as the angle of attack reaches the stalling point, the coefficient of lift begins to move downwards. As far as the coefficient of drag is concerned, it increases with the increase of angle of attack. As far as the lift is concerned, it is produced when pressure contours are less at the upper surface and when velocity contours are greater on the upper surface.

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References

i. *John. D Anderson Jr., "Fundamentals of Aerodynamics", McGraw Hill, 1991.*

ii. *Alex Sullivan Cleveland, F.A., "Aerodynamic forces acting on an airfoil" Education Series, 1989.*

iii. *Kundu, Ajoy Kumar. "Aircraft Design", Cambridge University Press, 2010.*

iv. *Raymer, Daniel P., "Aircraft Design - A Conceptual Approach", AIAA Education, 1989.*

v. *Kármán, Theodore Von. Aerodynamics, Cornell University Press, 1963.*

vi. *Houghton, E. L. "Aerodynamics for Engineering Students", Butterworth Heinemann, 2003.*

vii. *Marcman J. F. Virginia Polytechnic Institute, "Clark-Y airfoil performance at low Reynolds numbers", AIAA-84-0052.*

viii. *Howe, Dennis. "Aircraft Conceptual Design Synthesis", Professional Engineering Publishing, 2000.*

ix. *Fielding, John P. Introduction to Aircraft Design, Cambridge University Press, 1999.*

x. *Talay, Theodore A., "Introduction to Aerodynamics of Flight," NASA History Division, 2006.*