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Comparison of Aerodynamic Characteristics of NACA 0012 and NACA 2412 Airfoil

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Abstract:** A comparison between NACA 0012 and NACA 2412 has been made by comparing the lift co- efficient, drag co-efficient, pressure contour and velocity contour at various angles of attack. The process has been done taking steady state flow around NACA-0012 and NACA-2412 airfoil using 1m chord length and a velocity of 88.65m/s. The main aim is to understand the aerodynamic characteristics of both the airfoils at different angles of attack and draw a conclusion on which performs better under the same conditions. Modelling and numerical analysis has been carried out by using commercially available CFD software, which is a convenient method of analysis since computational methods are more preferred to experimental methods due to low expenses involved. The numerical results demonstrated are compatible with those of the theory. This confirms the validity of using Computational Fluid Dynamics (CFD) as a reliable alternative to experimental procedures.
***Keywords:** Symmetric airfoil, asymmetric airfoil, lift co-efficient, drag co-efficient, pressure contour, velocity contour*

I. INTRODUCTION

An airfoil is an aerodynamic profile that is designed to minimize drag and simultaneously produce lift. An airfoil makes up the cross-section of a wing that separates the streamlines into two paths when it strikes the leading edge of the wing. The general theory of lift is very complex and involves numerous phenomena. However, the main concept of lift generation will be explained through a few fundamental theories in this paper. The airflow that approaches the leading edge of the airfoil is divided into two paths: one that flows past the upper surface and the other that flows beneath the lower surface. The air tends to follow the adjacent curved surface as a consequence of Coanda Effect.

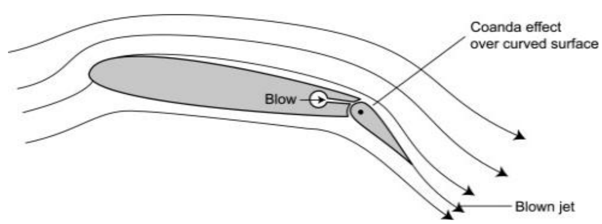

Fig. 1 Coanda Effect [15]

As seen from the diagram, the streamlines tend to follow the curvature of the airfoil. Overall, the air is deflected downwards because of the shape of the airfoil. When the aircraft is accelerating at a high velocity, the airflow is accelerated downward as an overall consequence of Coanda effect. From Newton's Second Law, a resultant forced is coupled by acceleration in the same direction. So a net downward force is exerted on the air exiting the trailing edge. As a result, an equal and opposite reaction forced called lift is produced in accordance with Newton's Third Law.

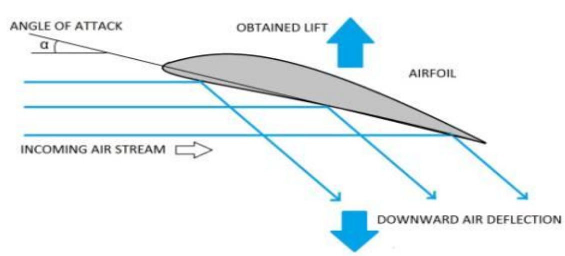

Fig. 2 Newtons Third law [16]

We have focused on the characteristics of NACA 0012 and 2412 airfoil, which are used in a wide variety of aircrafts. The NACA airfoils are airfoil shapes for an aircraft's wings developed by the National Advisory Committee for Aeronautics. The shape of the NACA airfoils is described using a series of digits. The parameters in the numerical code can be entered into equations to precisely generate the cross-section of the wing and calculate its properties. NACA 2412 describes an airfoil that has a maximum camber of 2% located at a distance of 40% from the leading edge, having a maximum thickness of 12%, where all the percentages are given in terms of chord length. NACA 0012 represents a symmetrical airfoil, having a maximum thickness equivalent to 12% of the chord length. NACA 2412 is a cambered airfoil. Due to having camber, the upper and lower surface area are not the same. So when the air is deflected, the mass flow rate of air over and under the airfoil will not be the same. Therefore, a variation of force is generated on both surfaces, resulting in the creation of lift. The geometry of NACA 0012 is such that it is incapable of generating lift when directed at a positive angle of attack relative to free stream air.

The flow characteristic of both these airfoils is determined by analyzing the velocity profile and pressure profile at various angles of attacks and plotting a curve of lift vs. angle of attack, thus facilitating a performance analysis of the airfoils at different orientations. This is carried out using Computational Fluid Dynamics (CFD) Software Ansys. CFD is an important tool used in predicting fluid flow through mathematical modelling and analysis. ANSYS is a software that enables the solution of problems related to aerodynamics, turbulence, fluid dynamics and structural analysis by using numerical analysis.

Karim Oukassou conducted an experiment to compare the power, lift and drag co-efficient of of NACA 0012 and NACA 2412.[1] Tousif Ahmed carried out a computational study of flow around a NACA 0012 Wing.[2] M. Yılmaz carried out a comparative CFD analysis of NACA 0012 and NACA 4412 airfoils.[3] Rubel R. I. compared the aerodynamic characteristics of NACA 0015 and NACA 4415 airfoil blades.[4] Er. Shivam Saxena analyzed NACA 2412 airfoil at different angles of attack and Reynolds Number.[5] Another computational analysis was carried out by S.P. Venkatesan for a dimple airfoil NACA 2412 at various angles of attack.[6] The Spalart allmaras model is used for computational analysis since it produces results closest to the theoretical value. k-ε and k-ωSST are used for the investigation of internal flow This type of model is had been found in the experimental analysis [7]-[14].

II. THEORY

The two main forces acting on an aircraft during its flight are lift and drag forces. Lift is a mechanical aerodynamic force that acts through the centre of pressure of an object and is perpendicular to the direction of free steam velocity. Drag is a mechanical force that is produced when a solid object comes into contact with a fluid. It can be classified into two main types: induced drag and parasite drag. Parasite drag can be further subdivided into form drag (or pressure drag) and skin friction drag. Induced drag is the drag due to lift, created by vortices at the tip of an aircraft's wing. It increases with increasing angle of attack. Parasite drag is the mathematical sum of form drag and skin friction drag. Form drag is created by the parts of an aircraft that are not responsible in generating lift, such as the nacelles, fuselage and landing gear. Skin friction drag arises due to friction between a fluid and a solid object moving through it.

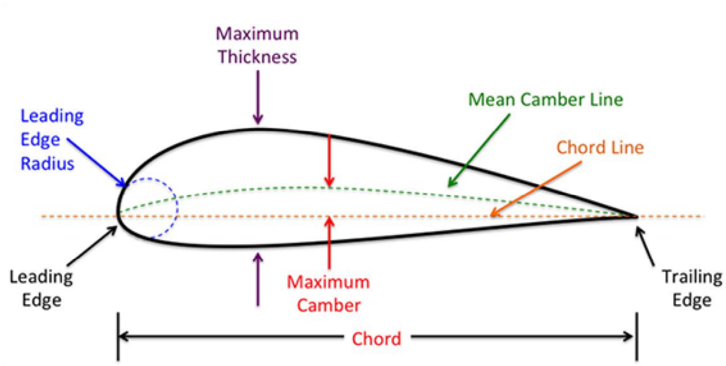

Fig. 3 Airfoil Nomenclature [17]

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Free-stream velocity is the velocity of the air far upstream the aircraft. The distance between the leading edge and trailing edge of an airfoil makes up the chord line. Angle of attack is the angle between the free stream velocity and chord length. The mean camber line is the locus of the points mid-way between the upper and lower surface of an airfoil. The maximum distance between the mean camber line and the chord line, perpendicular to the chord line is called camber. The distance between the upper and lower surface perpendicular to the chord line is the thickness.

A wing is simply an extrusion of an airfoil. Studying the pressure and velocity distribution throughout an airfoil facilitates a better understanding of how lift and drag forces in a wing are generated. The pressure and velocity profile are the pressure and velocity distribution over the entire contact area. In this case, the contact area is the wing surface.

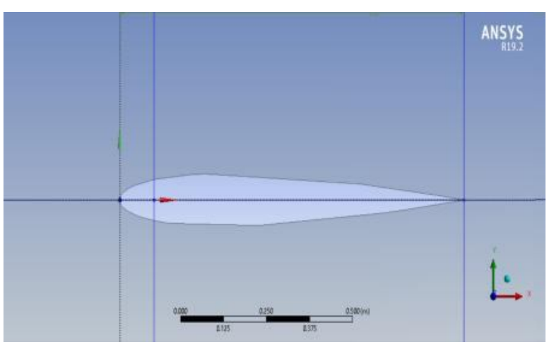
III. METHODOLOGY

Flow Specification and Computational Conditions:

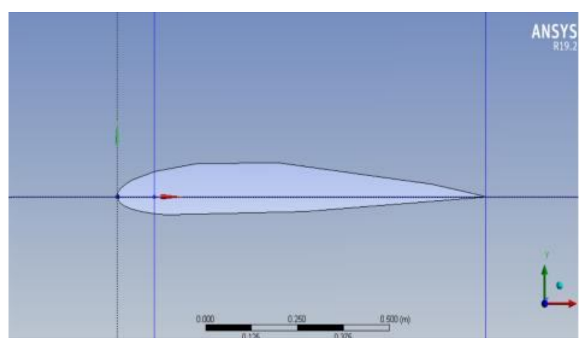
Computational Conditions	Range and Model
Fluid Type	Air
Velocity of Fluid	88.65m/s
Operation Pressure	101325Pa
Viscosity	1.81e-05kg/m^3
Density of Fluid	1.225kg/m^3
Model	Spalart allmaras model
Chord Length	1m
Operating Temperature	288.16K
Specific Heat Ratio	1.4
Reynolds Number	6000000
Mach Number	0.258
Surface Shear	No slip
Wall Motion	Stationary Wall
Gauge Pressure	Zero Pascal
Outlet Backflow	Normal to Boundary
Management of Flow	Pressure velocity coupling coupled
Momentum	2nd order up wind scheme
Turbulent Viscosity Ratio for outlet and inlet	1

IV. GEOMETRY

The coordinates of NACA 0012 and NACA 2412 are imported and the geometry are created for Computational Fluid Dynamics (CFD) Simulation.



(a)



(b)

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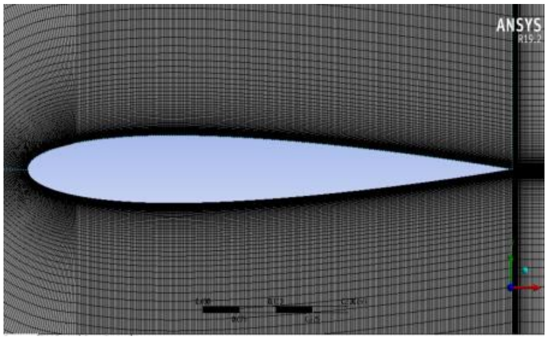
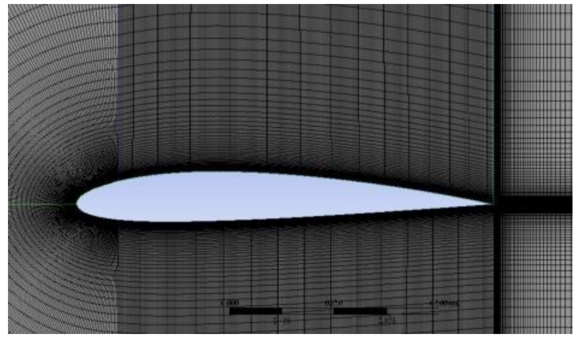


(c)



(d)

Fig. 4(a) Geometry of NACA 0012; (b) Geometry of NACA 2412; (c) Mesh Generation for NACA 0012; (d) Mesh Generation for NACA 2412

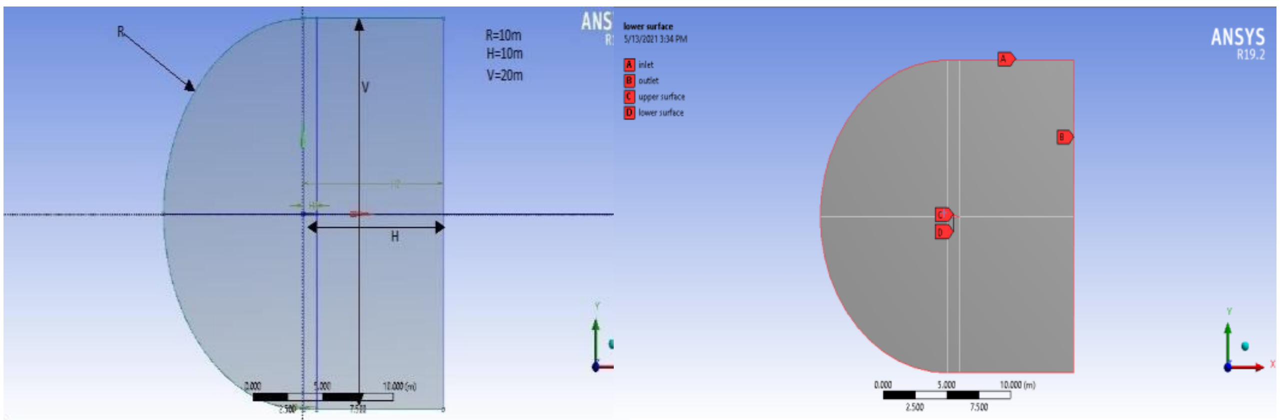
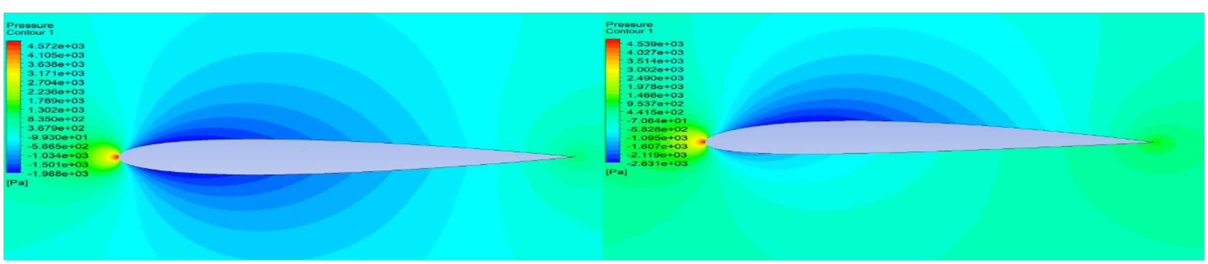
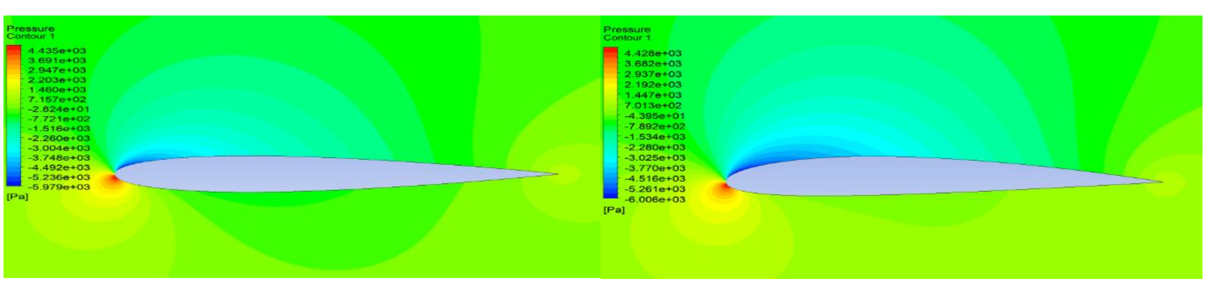


Fig. 5 Boundary Condition and Flow Domain

V. RESULTS AND DISCUSSION



(a) At 0^0 angle of attack



At 4^0 angle of attack

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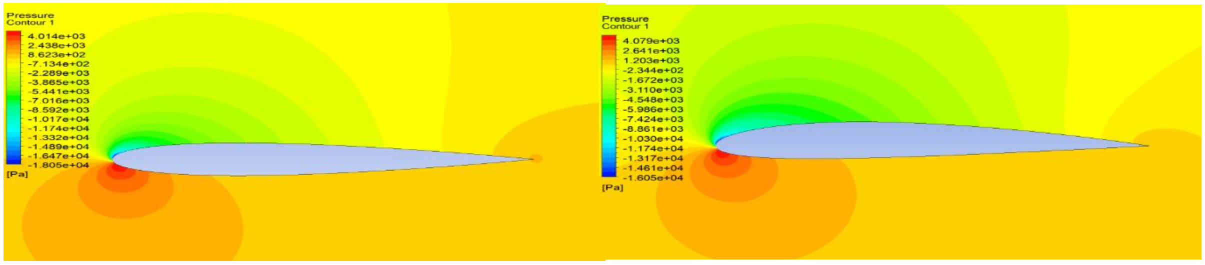
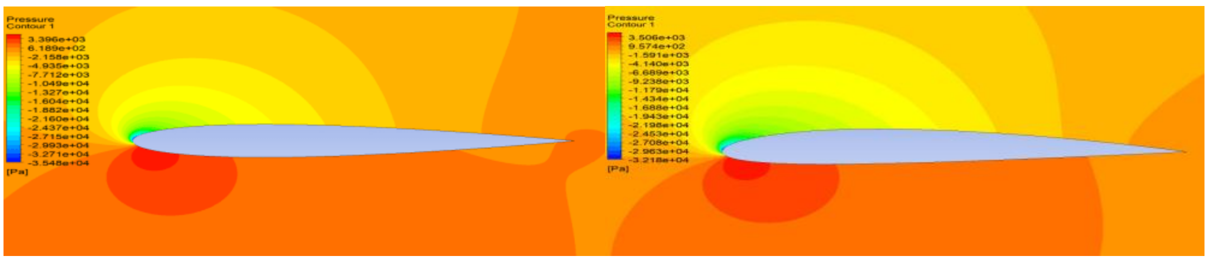
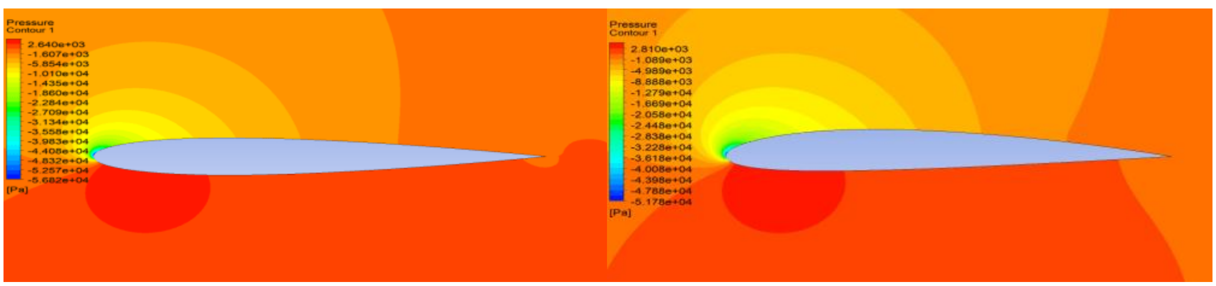


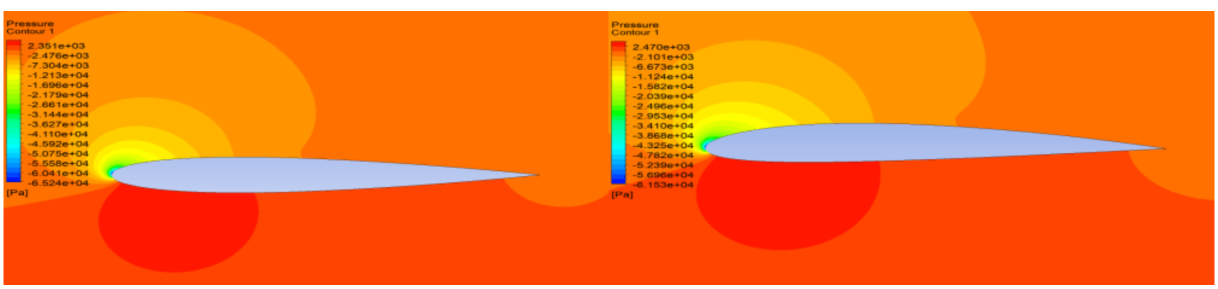
(c) At 8^0 angle of attack



(d) At 12^0 angle of attack

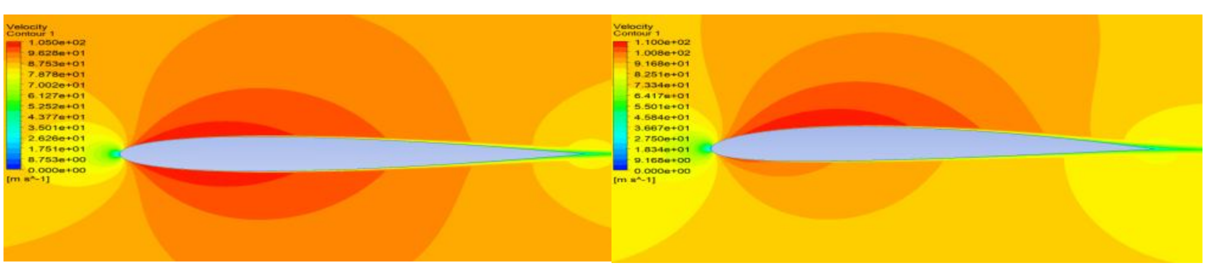


(e) At 16^0 angle of attack



f) At 20^0 angle of attack

Figure 6: Comparison pairs of pressure contours for NACA 0012 and NACA 2412 airfoils



(a) At 0^0 angle of attack

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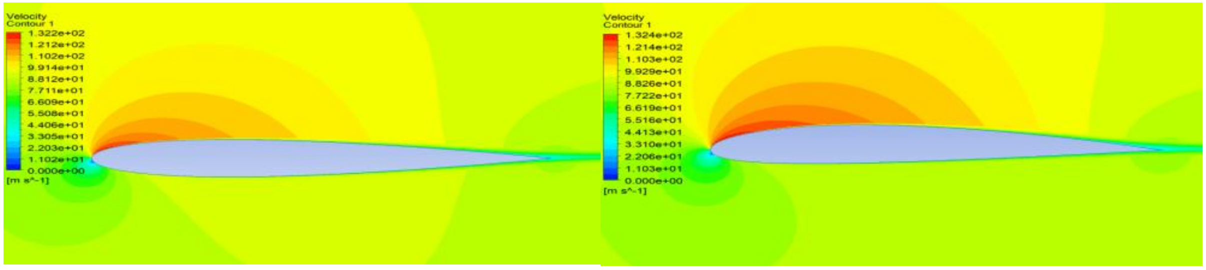
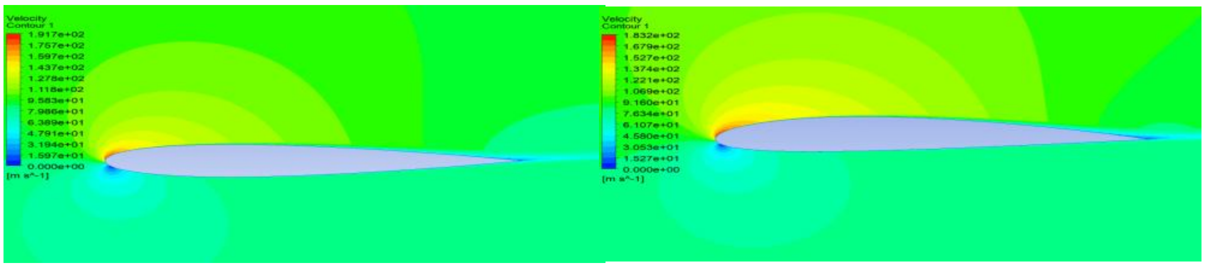
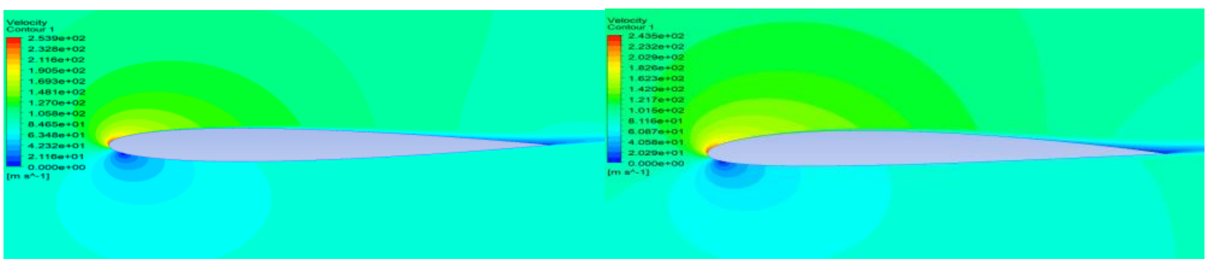


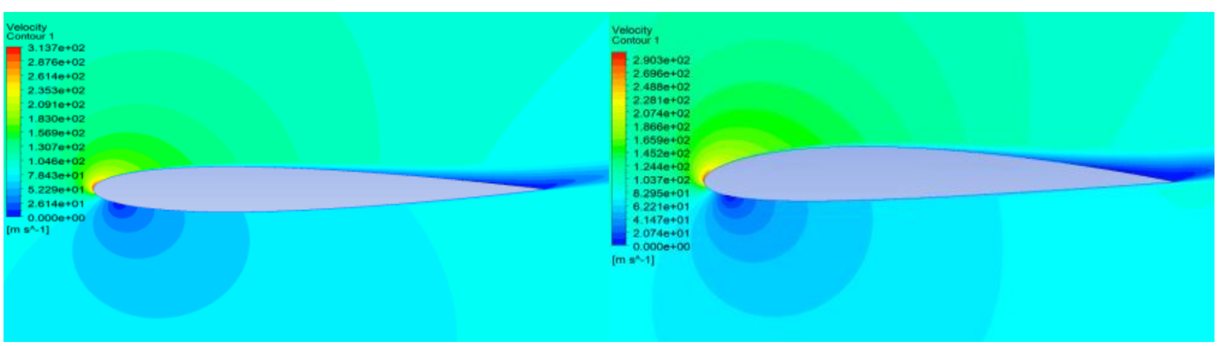
(b) At 4^o angle of attack



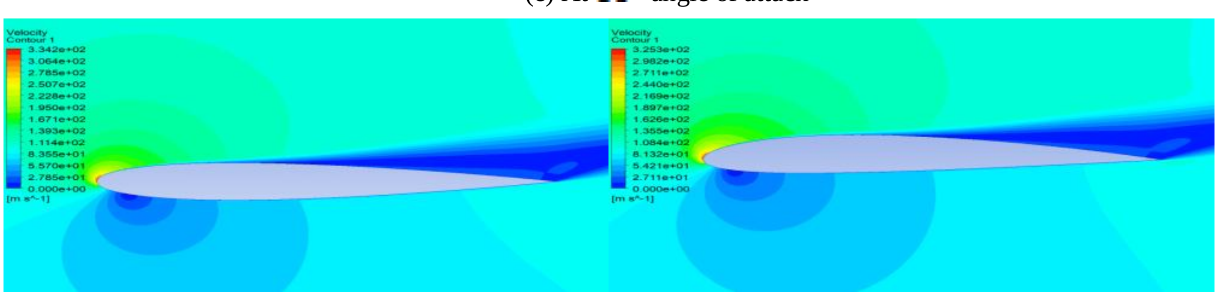
(c) At 8^o angle of attack



(d) At 12^o angle of attack

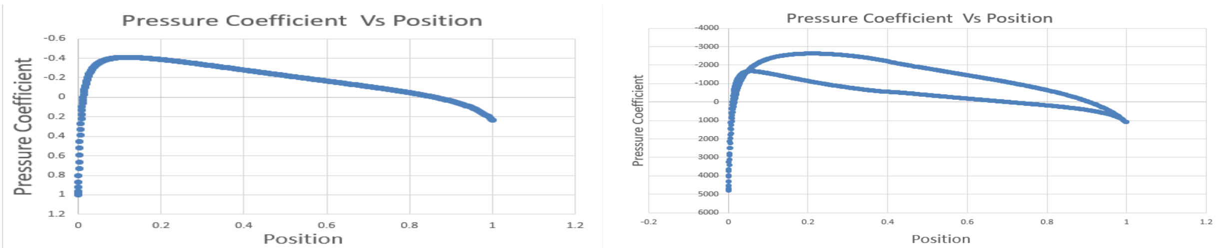


(e) At 16^o angle of attack

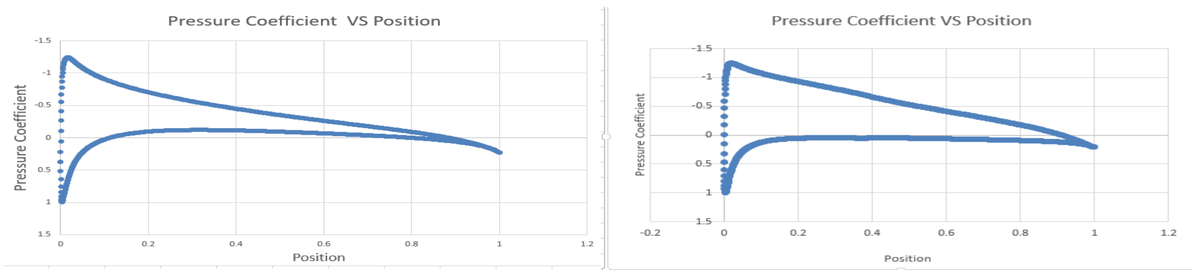


(f) At 20^0 angle of attack

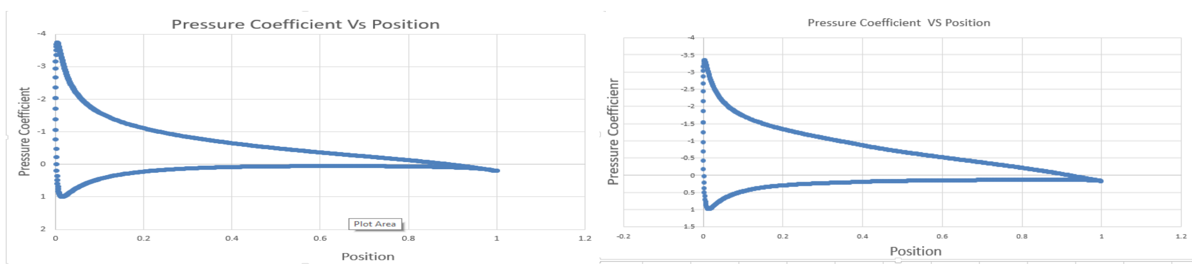
Figure 7: Comparison pairs of velocity contours for NACA 0012 and NACA 2412 airfoils



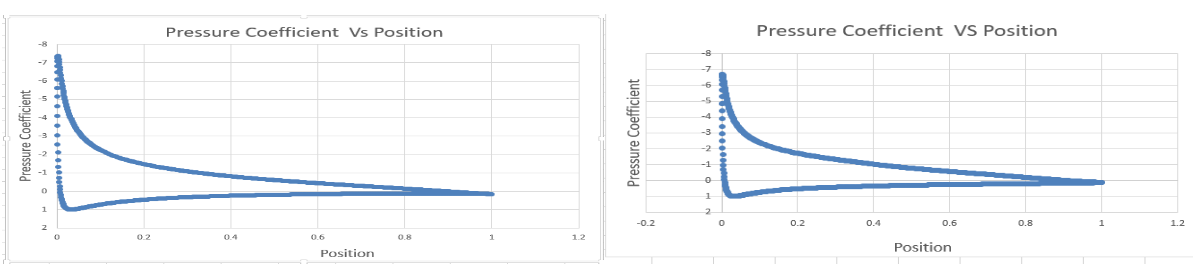
(a) At 0° angle of attack



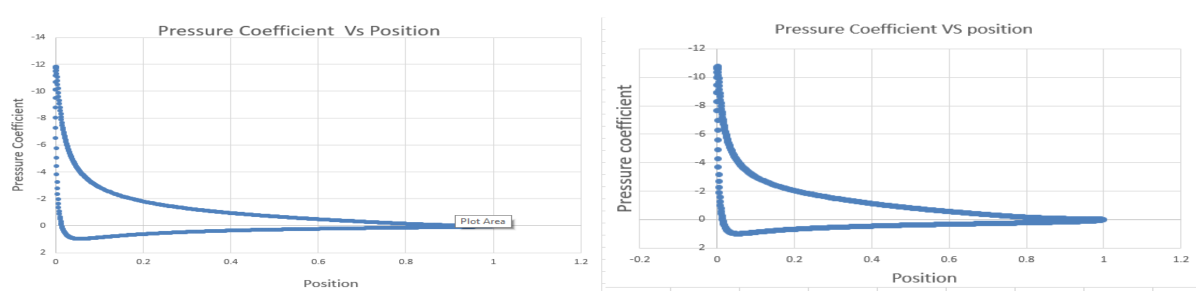
(b) At 4° angle of attack



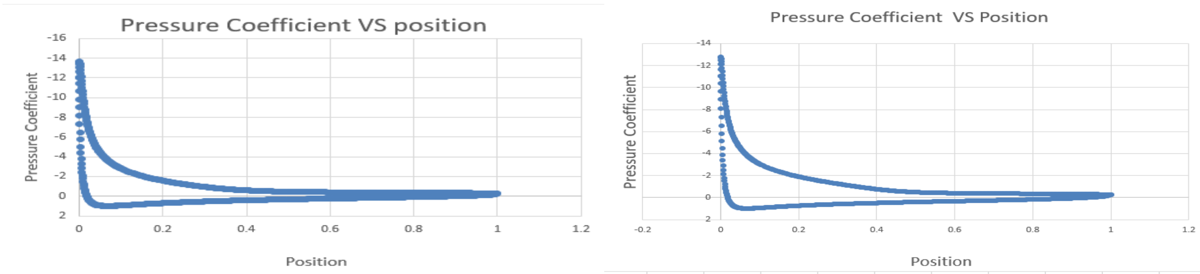
(c) At 8° angle of attack



(d) At 12° angle of attack



(e) At 16° angle of attack



(f) At 20^0 angle of attack

Figure 8: Comparison pairs of pressure co-efficient vs. position for NACA 0012 and NACA 2412 airfoils

From Fig 6(b) which shows NACA-0012 airfoil at 4-degree angle of attack, pressure is highest at the leading edge and less on the upper surface. It continues to rise as the airflow progresses towards the trailing edge.

At 16-degree angle of attack, pressure on both top and bottom surface of the airfoil increases. This is due to increase in angle of attack. Pressure distribution pattern remains the same, i.e., pressure at the upper surface is lower than that at the lower surface. Also, pressure increases as flow continues from the leading to trailing edge of the upper surface.

From the flow characteristic of NACA 2412 at 4 degree and 16-degree angle of attack. Pressure distribution pattern is the same, but the magnitudes of pressure on the upper and lower surface are very high compared to NACA 0012.

It can be concluded that the pressure increases on both surfaces of the airfoil with increasing angles of attack and the pressure is always higher on the lower surface. This phenomenon of pressure difference describes how lift is produced.

From the CFD diagrams of velocity contour, flow exits the trailing edge of the airfoil smoothly, since the flow is laminar. Velocity of NACA-0012 is higher at the upper surface and lower at the lower surface at 4 degrees angle of attack and the stagnation point is near the chord line at the leading edge. As AOA is increased, stagnation point moves further downstream on the lower surface. The greater the AOA, the earlier flow separation will occur and the width of the wake region increases. Similar velocity distribution pattern is observed for NACA-2412 airfoil. The width of the wake region is greater in NACA 2412 airfoil at both 12- and 16-degree angle of attack since flow separation occurs earlier. These differences are observed since NACA-2412 is cambered and NACA-0012 is symmetrical. As seen from fig. 8, the negative values in the Y axis represent the pressure coefficients at the upper surface and the positive values represent the pressure coefficients at the lower surface of the airfoils. This pressure difference contributes to the generation of lift in a wing. Hence, the pressure on the upper surface of the airfoil is lower than the lower surface. But as we go towards the trailing edge, pressure increases in the upper surface area and decreases at the lower surface.

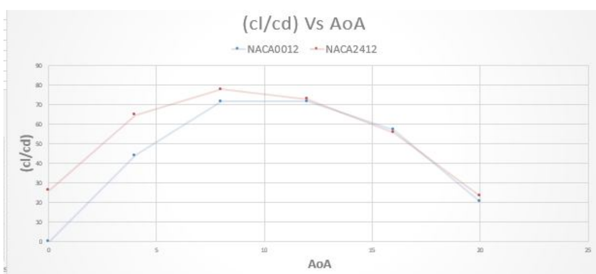


Fig. 9 cl/cd vs. Angle of Attack

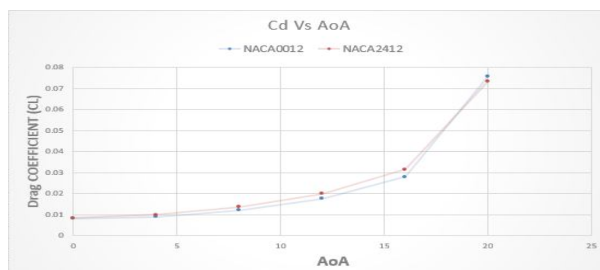


Fig. 10 cd vs. Angle of Attack

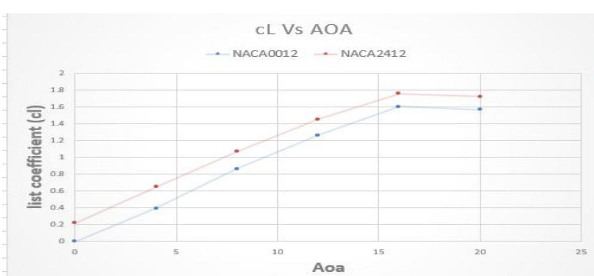


Fig. 11 cl vs. Angle of Attack

From the graph of cl/cd vs. angle of attack, it is seen that for NACA 2412 airfoil, the maximum value of Cl vs. Cd occurs at an angle of attack 8 degrees, after which it continues to decrease. For NACA 0012 airfoil, the maximum value of Cl vs. Cd occurs at an angle of attack 12 degrees before it starts to decrease. With increasing angle of attack, the width of the wake region increases. Hence, the drag increases as well and it does so at a higher rate than lift, thus the ratio falls after a maximum value.

From the graph of fig. 10, which shows the variation of lift co-efficient vs. angle of attack, it is observed that lift coefficient increases with increasing angle of attack. However, the lift coefficient of NACA 2412 is always greater than the lift coefficient of NACA 0012 since it a cambered airfoil. Hence, it can be concluded that NACA 2412 can produce larger lift that NACA 0012 given the same angle of attack. Due to the geometry of the airfoil, downwash in NACA 2412 is greater. Consequently, the lift produced by 2412 airfoil is greater as well.

Fig. 11 shows the relation of drag co-efficient with variation in angle of attack. It is seen that drag increases with increasing angle of attack for both the airfoils. This is because the width of the wake region increases at higher angle of attacks. The greater the wake region, the higher the drag. For NACA 2412, the drag produced is greater at all angle of attacks. Boundary layer separation occurs earlier in NACA 2412 airfoil, so the wake region is wider and thus, drag generated is also higher.

VI. CONCLUSION

The aerodynamic characteristics of NACA 0012 and NACA 2412 had been compared by means of Computational Fluid Dynamics (CFD) numerical analysis method. From the results obtained, it had been observed that the pressure is higher on the lower surface and lower on the upper surface. This pressure difference is necessary for the generation of lift. Also, the velocity is lower on the lower surface of the airfoil. The lift co-efficient and drag co-efficient of NACA-2412 airfoil is higher due to the presence of camber in its geometry. K-Omega Model could be used instead, but the disadvantage would be that the boundary layer computations are very sensitive to the values of omega in the free stream. Hence, for the ease of computation, Spalart allmaras model had been used.

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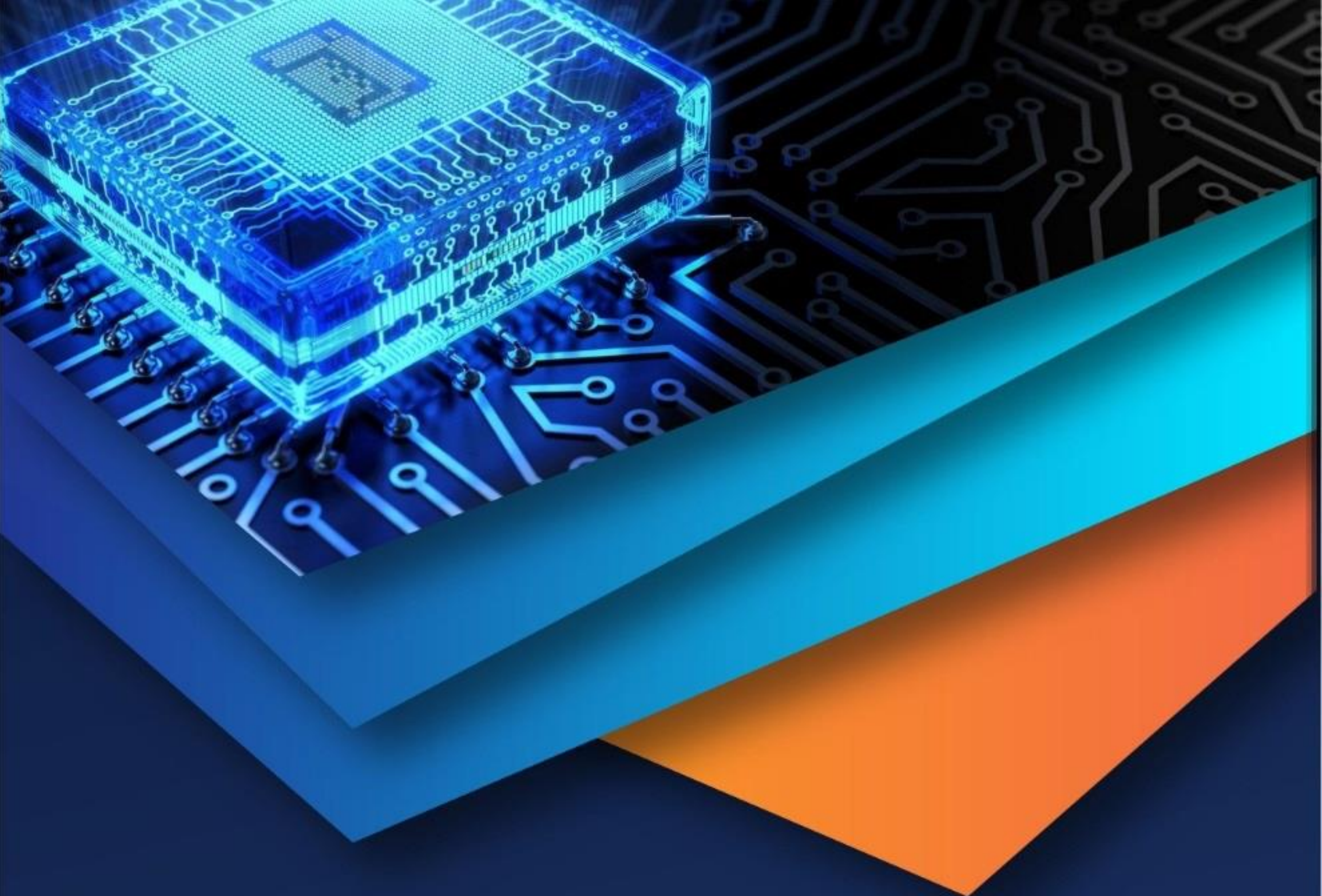

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