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XFOIL analysis on Low Reynolds number airfoil

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Abstract:

The range of low Reynolds number airfoil is between 10^4 to 10^5.In this study the investigated airfoil is NACA2414.The aerodynamic performance of low Reynolds airfoil is less than 10^5 is important for various applications such as Unmanned Air Vehicles(UAV'S), Micro Air Vehicles(MAV'S) and "low-speed/high altitude aircrafts". Generally, airfoils with Reynolds numbers less than 106 cannot be assumed to have constant Lift(L) and Drag(D) characteristics . It includes XFOIL'S direct and inverse analysis capabilities. The lifting line theory, the vortex lattice method and the 3D-panel method can be used for wing design and analysis. The pressure distribution (c_P) and lift coefficient (c_L) are important parameters that characterize behavior of the airfoils. The basis of aerodynamic analysis during aircraft development is pressure distribution information.

Keywords: *low Reynolds number, XFOIL, Aerodynamic performance, Pressure distribution*.

Abbreviations: *c-chord length; (c_D)-drag coefficient; (c_L)-lift coefficient; D-drag;*

L- Lift; Re-Reynolds number; α-angle of attack (degree); L/D- lift to drag ratio.

Introduction:

Airfoil is such an aerodynamic shape and it generates aerodynamic forces. The air passes above and below the wing due to the momentum

wings upper surface decreases due to the energy conservation. Because of that the high air pressure moves toward lower air pressure. Air pushes the wing so that force known as lift force is generated.

Airfoils have Leading Edge(LE) and Trailing Edge(TE). The point on front of the airfoil is the Leading Edge, and the point behind the airfoil is the Trailing Edge. The distance between the LE and TE is known as the chord length.

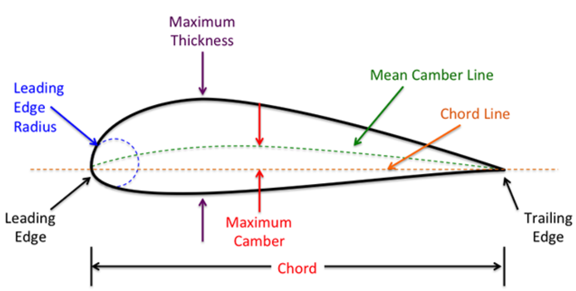

Fig1: Basic geometry of the airfoil

conservation, the speed of air particles on wings upper surface increases and also the pressure on the

An airfoil-shaped body moving through a fluid produces an aerodynamic force. "Lift" is the force perpendicular to the direction of motion, whereas "Drag" is parallel to the motion direction. The camber(C) and thickness(t) of an airfoil are two important parameters to describe its shape.

The NACA four digit airfoil define the profile by :

1) 1 digit describes the maximum camber as % of the chord.

2) 1 digit describes the distance of maximum camber from the airfoil leading edge in tenths of % of the chord.

3) 2 digits describes the maximum thickness of the airfoil as % of the chord.

1.1. Airfoil description:

The low Reynolds NACA2414 airfoil, is investigated in this study, maximum thickness 14%, maximum camber 2% and chord located at 0.40 chord

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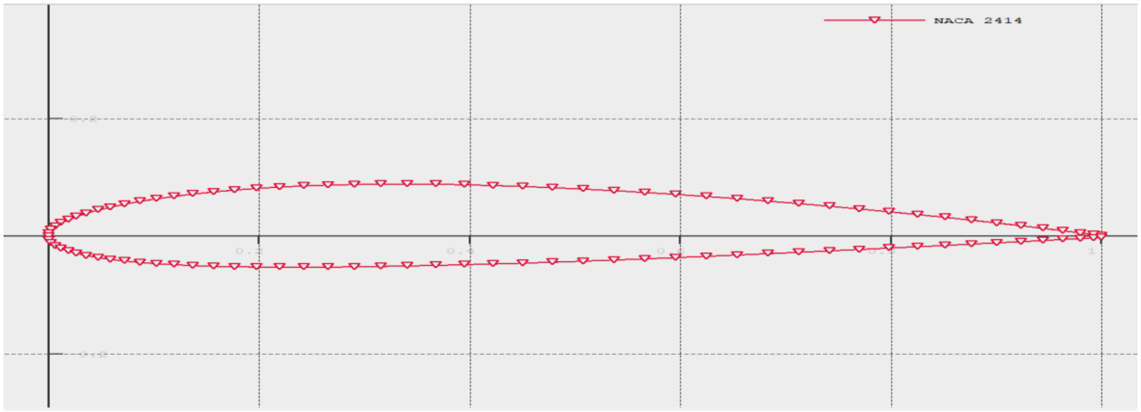


Fig2: The profile of NACA2414

1.2. Lift and drag:

The flow of air through the aircraft determines the amount of lift and drag provided to an aircraft from the ground. Lift provides the force to move the aircraft in an upward direction. Therefore, it is vertical while drag is the pull effect the tax on the aircraft along the horizontal direction. It is critical for an aircraft to have a higher lift coefficient than a lower drag coefficient. The attack of air at the LE of the airfoil determines lift and drag.

Methodology:

The XFOIL code combines a potential flow panel method and an integral boundary layer formulation for the analysis of the flow around airfoils. The code was developed to rapidly predict the airfoil performance at low Reynolds number.

The NACA2414 was selected from the NACA foil from the XFLR5. The aerodynamic characteristics of an airfoil were obtained by defining an analysis in XFLR5. In batch analysis the Reynolds number of the flow was setup as 6×10^4 and 8×10^4. The results were drawn as the lift coefficient (c_L) versus angle of attack (α), Coefficient of moment (c_m) versus angle of attack (α), (c_L / c_d) versus (α) and also Pressure distribution around the airfoil can be acquired in Batch Analysis.

Modelling and simulation:

The analysis is carried out in NACA2414 airfoil section.In figure 3a,3b,3c and 4a,4b,4c the comparison of the aerodynamic coefficients of NACA2414 in XFOIL and experimental results at different reynolds number are shown(6×10^4 and 8×10^4).

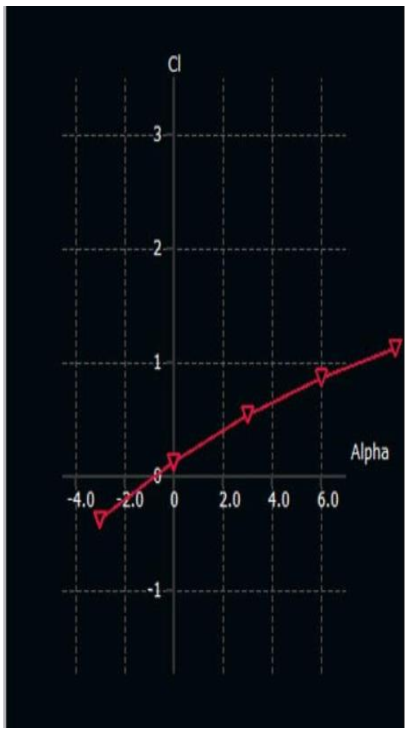


Fig:(3a) c_L vs α

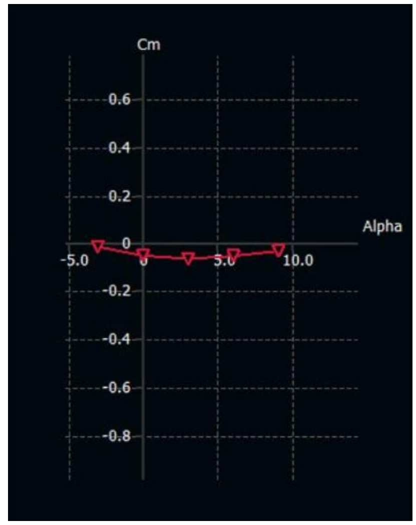


Fig:(3b) c_m vs α

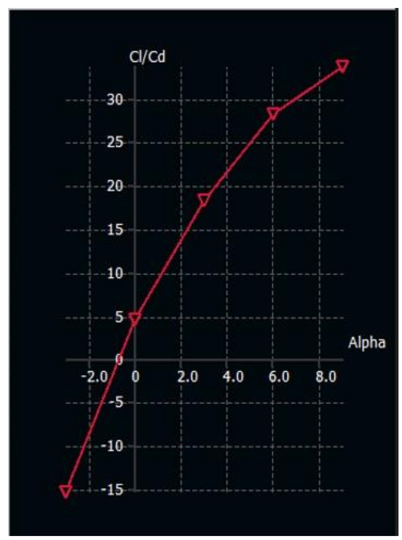


Fig:(3b) c_L/c_d vs α

From the analysis,As the angle of attack increases coefficient of lift (c_L)and coefficient of Drag (c_D) increases.As angle of attack increases coefficient of moment (c_m)decreases.The maximum lift coefficient c_{Lmax}=0.9 at $\alpha=6^0$as shown in fig 3a and 4a.Airfoil will stall at a lower angle of attack and achieve a maximum lift coefficient with laminar boundary layer.The peak suction of c_P directly corelated with c_L.The c_L

increases linearly.As shown in fig 3b and 4b the moment is negative,hence it is stable.

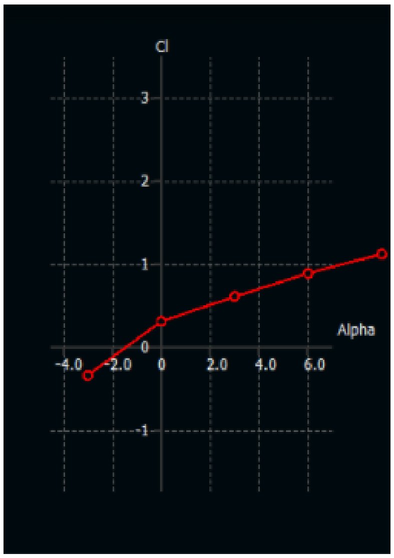


Fig: (4a) c_L vs α

Fig:(4b) c_M vs α

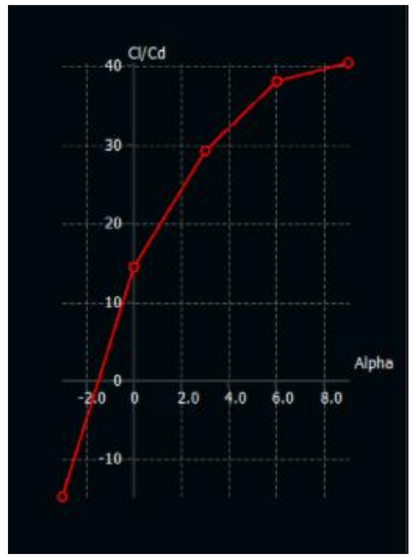
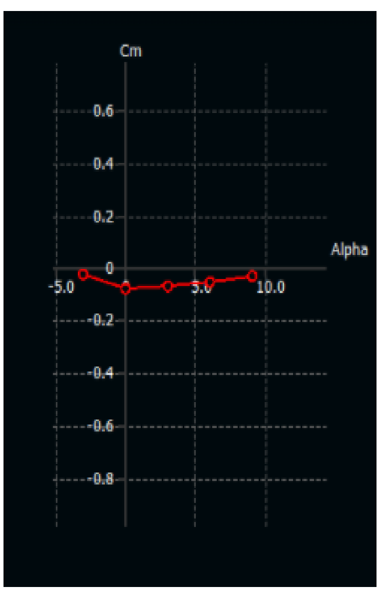


Fig:(4c) c_L/c_D vs α



Pressure coefficient (c_p):

The pressure coefficient (c_p) distribution is calculated in XFOIL direct analysis by defining direct foil analysis. The pressure coefficients (c_p) of the NACA2414 airfoil testing are displayed in fig:5 and fig:6 with the reynolds number 6×10^4 and 8×10^4.

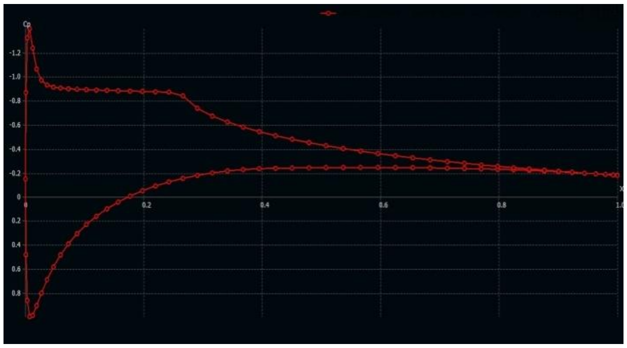


Fig5:c_P distribution of NACA2414 at Re-60000

The pressure distribution is high at the leading edge when compared to trailing edge.Because of high pressure at the leading edge the airfoil moves upwards,downwards at the trailing edge.Rise in c_P near leading edge during stall condition cause a strong negative movement.

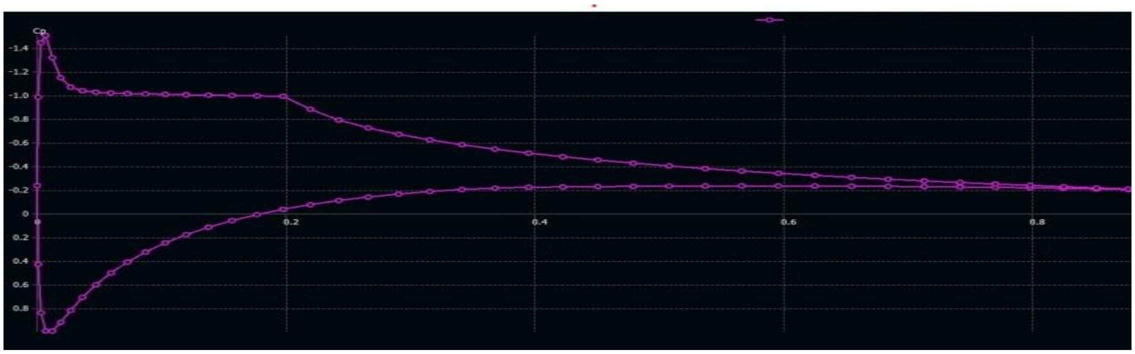
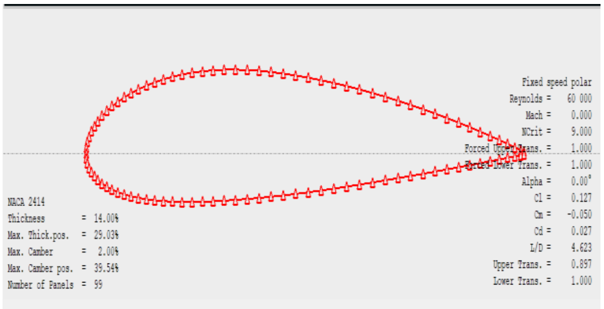


Fig6: c_P distribution of NACA2414 at Re-80000

The 1st Angle Of Attack (AOA) tested at 0^0 which should produce zero lift,because the area reduction of the stream tubes on both surface of the airfoil should be equal as shown in the (fig7) and (fig8). Since the airfoil was experiencing an increase in flow velocity, the pressure coefficient was below zero along much of the airfoil, but the increase was equally distributed across the airfoil.



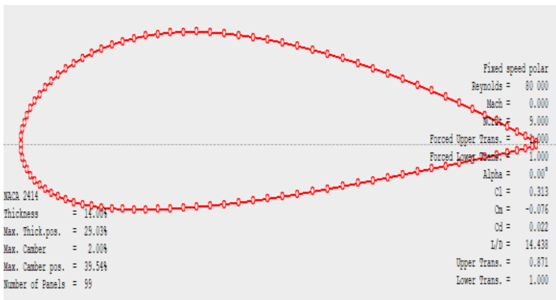


Fig7:At re-60000,α=0^0

Fig8:At re-80000,α=0^0

The coefficient of pressure data generated using XFOIL is plotted with the experimental data in fig 9.the pressure coefficients reached a minimum value of -3.1 and a maximum value 1.0. As chord length increased, the pressure coefficients converged quickly. In all locations, the C_p on the upper surface of the airfoil remained greater than -2. This depicts the concentration of lifting and the large adverse pessure gradient near the LE of the airfoil.

The modelling technique used by XFOIL,The vortex panel method,makes the inviscid assumption,so the XFOIL solution could not show large separation effects. The close agreement of the experimental data along the length of the airfoil indicates that there was no significant separation in the analysis. XFOIL, on the other hand, was programmed to predict transition separation bubbles, as shown in fig9.

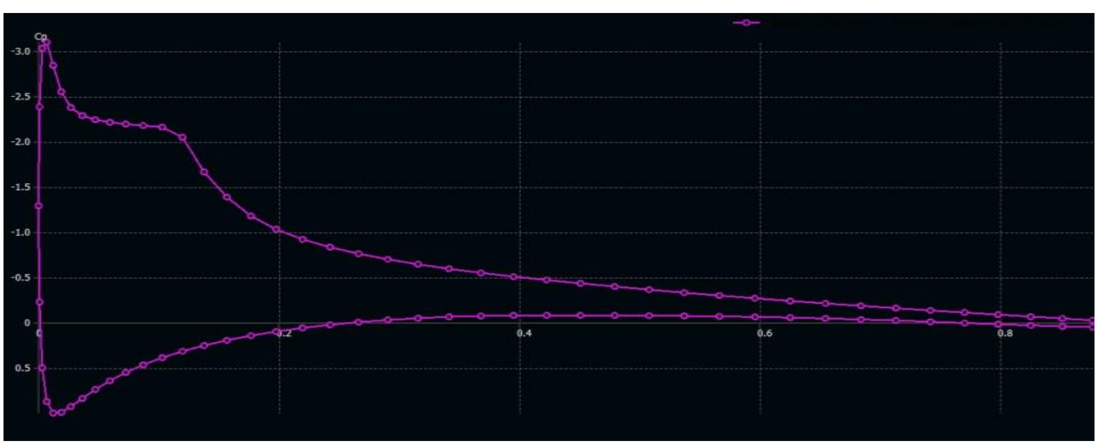


Fig9: separation Bubble

Conclusion:

Flow performance characteristics of NACA2414 has been computationally investigated at reynolds number 6×10^4 and 8×10^4.The commercial code fluent with the SST K-w transition and general public license XFOIL, was used for numerical analysis.The XFOIL analysis depicts good results.To predict accurate aerodynamic coefficient such as coefficient of lift (c_L),coefficient of moment(c_M) and coefficient of drag (c_D) values,coefficient of pressure (c_p) analysis revealed the concentration of the pressure on the airfoil at the leading edge.The primary conclusion of the lift coefficient (c_L) data is that

the airfoil stalled at alower angle of attack and achieved a lower maximum lift coefficient (C_{Lmax}) with a laminar boundary layer. It is clear that for conceptual design in engineering, the XFOIL tool can be used to predict the aerodynamic performance of airfoils at low Reynolds Numbers.

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