ANALYSIS OF NACA 5 SERIES AIRFOIL

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Abstract: Airfoil is basically a Surface which prepared both lift and drag. It is used in make turbomachinery like compressor and turbines. that airfoil plays an important role in turbomachinery due to airfoil shape and size other parameters like Cl and Cd also changed. In airfoil no of factors which include coefficient of lift, coefficient of drag, coefficient of momentum, angle of attack analysis. In this we are study Aboutanalysis and behaviours of 5 Digit Airfoil. which analysis the behaviour of airfoil by the change in Angle of Attack which get effect in Coefficient of life and coefficient of drag in the we also see the parameters like coefficient of moment also observed. Four variable Angle of attack. Coefficient of lift, Coefficient of Drag, Angle of attack and Reynolds no are considered for Study. For analysis the variables we use Reynolds no change and show the effects on all other variable. By this current Study we can show that how muchReynolds no are efficient on some specific Angle of attack. Dur to increases and decrease of Reynolds no, angle of attack shows some changes in Coefficient of lift and drag. The most important things re that due to analysis of airfoil we can clearly say that at some coefficient of lift and drag coefficient of moment also change. The graph and table of increase and decrease in different angle of attack at different angle of attack shows in this. And analysis on these we can say that we have some fix value at fix angle of attack at some specified Reynold no.

Keywords: Airfoil, turbomachinery, compressor and turbines, 5 Digit Airfoil, Angle of attack

I. INTRODUCTION

Airfoil is a surface like wing, tail of aircraft which create lift when moving throughout theair. Airfoil generate lift in the same direction as free stream airflow and the drag similar to airflow. In high speed aircraft airfoil are thin, with minimal drag and minimal lift. Low speedaircraft have thick airfoil with high lift and drag.

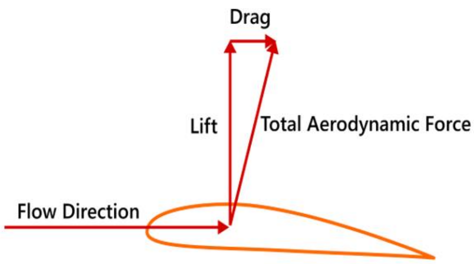


Fig. 1: Airfoil and forces

Types of Airfoils

There are 2 types of airfoils:

Symmetric Airfoils: It is the type of airfoil in which there are zero lift at zero AOA. It has same upper and lower surface which means it has one camber and one chord line.In this due to equal upper and lower surface the chord line and camber line are overlap each other.

Cambered Airfoil: It is the type of airfoil in which there are some lift at zero AOA also. It has different size of upper and lower surface which means it has more than onecamber and chord line.

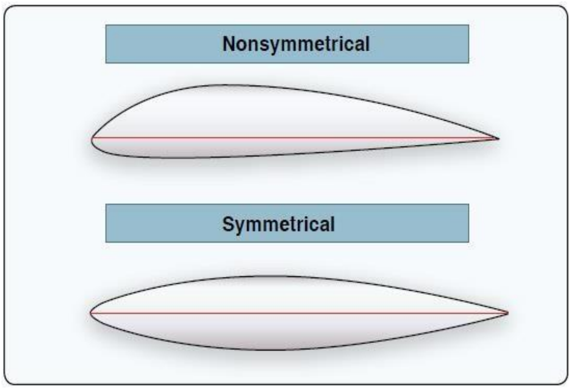


Fig. 2: Types of airfoils

Geometry of Airfoil

- The LE is the front edge of the airfoil and the TE is the rear point of airfoil.
- The chord line is the shortest distance between LE to TE of an airfoil.
- The camber line is the line which cut equal portion of upper and lower surfaces ofairfoil.
- Thickness of airfoil is the distance between upper and lower surfaces of airfoil.
- AOA is the angle between relative wind and chord line.
- Aspect ratio is the ratio between span square to the wing area

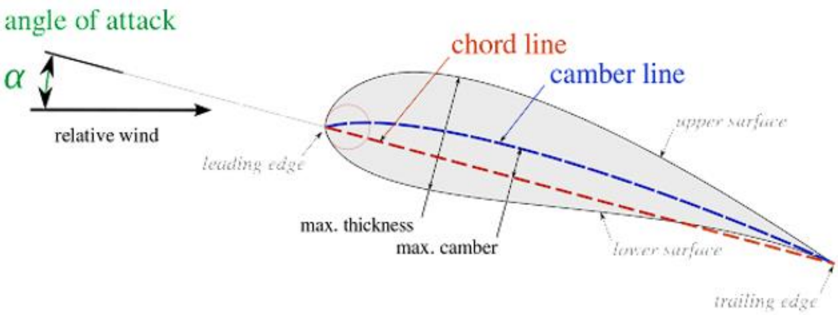


Fig. 3: Airfoil geometry

NACA Series Airfoil

NACA design airfoil for wings. After word NACA a numerical digit shows that describeproperties of airfoil. We can use it as an equation that give all information about airfoil like camber thickness and crossection of airfoil.

NACA airfoils
Digit Airfoils: NACA BNHL

- First digit B show that max. camber.
- Second digit N gives the location of max. camber from leading edge.
- Third and fourth digit HL gives the maximum chord thickness.

Example: NACA 4421 has max. camber at 4% located at 40% of chord form LE and give max. chord thickness at 21%.

5-digit Airfoil: NACA XCVBN

- First digit X give the design Cl 0.3(0.15*X).
- Second digits give the point of max. camber at (5*C).

- Third digit V give the simple and reflex camber. If it is simple, then it shows 0 andif it is 1 it shows 1.
- Fourth and Fifth digit BN gives the max. thickness of chord.

Example: NACA 23021 has design CL 0.3(0.15*2) a pt. max. camber (5*3) located at 15% of chord with a simple camber at a 21% max. thickness of chord length.

6-digit airfoil: NACA WER-TYU

- First digit W show the series of airfoil.
- Second digit E shows the min. pressure area percent of chord.
- Third digit R shows the low drag.
- Forth digit T shows the design Cl in $1/10^{th}$.
- Fifth- and sixth-digit YU gives the max. thickness of chord in percent.

Example: NACA 623-425 has 6 series airfoils with min pressure area of 20% of chord and maintain low drag 0.3 above and below with 0.4 design Cl and a max. thickness of25% of chord.

7-digit airfoil: NACA POILMNB

- First digit P show the series of airfoil.
- Second digit O shows the min. pressure area on top region in $1/10^{th}$.
- Third digit I shows the min. pressure area on bottom region in $1/10^{th}$.
- Forth digit L shows the letter which shows profile of airfoil.
- Fifth digit M shows design Cl in $1/10^{th}$.
- Sixth- and seventh-digit NB gives the max. thickness of chord in percent.

Example: NACA 723B217 has 7 series airfoils with 20% min pressure area on upper surface with 30% min pressure area at bottom surface with B series airfoil which has 0.2design Cl and 17% of max. thickness of chord.

II. BACKGROUND

Haotian Chen and colleagues, 2023-. Airfoils provide planes lift and keep them flying in the atmosphere. Different airfoils have different performance characteristics based on their forms, which affects plane flying conditions and people's safety. As a result, the form of an airfoil must be thoroughly analysed and debated upon since it is an engineer's professional obligation to defend people's safety through engineering expertise. In this work, physical and mathematical models are used to analyse the form and properties of an airfoil. Models such as Bernoulli's Equation and the Ideal Gas Law, which are essential engineering models, are used. Professional computational tools, such as Mat lab, are also used to improve data accuracy and ease in data analysis. Based on existing airfoil data, this study offers some suggestions for future airfoil designs that will need to accommodate additional flying situations and aircraft types.

Krishna Sharma *et.al.,2022*-The profile of an aerofoil is critical in any aerodynamic system. When the form of an aerofoil changes, so do its aerodynamic properties. Our research focuses on changes in aerodynamic parameters such as coefficient of lift (Cl) and coefficient of drag (Cd) caused by slight changes in an aerofoil's coordinates and angle of attack. We selected the standard symmetric aerofoil naca 0015 as a reference because of its excellent low-wind performance, and eight novel aerofoil designs were created by varying the chord thickness distance from the leading edge of the standard naca 0015 aerofoil without modifying its maximum chord thickness in percent. Wind turbine blade aerodynamic airfoils have a significant impact on wind turbine aerodynamic efficiency ANSYS FLUENT 19.2 was used to perform CFD (Computational Fluid Dynamics) study at various angles of attack ranging from 0° to 12. Flow changes for different aerofoil designs have been recorded, and the findings are being utilised to determine the optimal aerofoil that may be recommended for usage in wind turbines.

Constantin Cristian Andrei *et.al.*,2021-Based on these test conditions, this article analyses Reynolds Averaged Navier-Stokes (RANS) turbulence models and assesses the NACA 23012 airfoil. To compare turbulence models for high-fidelity CFD simulations, ANSYS-Fluent version 22.1 was employed. To predict the influence of turbulence on flow, a turbulence model should be utilised. The turbulence model is a collection of constitutive equations that are used to solve the flow-governing Navier-Stokes equations. Most engineering turbulence models (Spalart - Allmaras, k- Standard, k- SST, k- Standard, k- Realisable, and k- RNG) are based on the Boussinesq hypothesis because it provides a low-cost computation for addressing turbulence viscosity. Three sample turbulence models are utilised in this work: Spalart-Allmaras, k- SST, and k- Standard. The flow is studied at various angles of attack (AoA), ranging from -2° to 18°. These AoA correspond to Re = 3106 and M = 0.13, respectively. Simulations are incompressible and steady-state. Flow velocity, pressure, and density do not change with time. When these CFD scenarios are compared to Abbott's [2] experimental data, these turbulence models provide close results with a 5% error margin for low and medium AoA.

Nurcholish Arifin Handoyono *et.al.*, 31 July 2019- The fast growth of wind power facilities in Indonesia has established wind energy as one of the emerging renewable technologies with significant potential in Indonesia. The windmill blade, which is one of the key components of the windmill, plays a role in converting wind potential energy into motion energy and then into electrical energy, which is impacted by the form of the windmill blade. The National Aeronautical Committee Advisory (NACA) is in charge of aeronautics and sets rules for various airfoil shapes. A comparison of variants of NACA airfoil types (NACA 4412, NACA 23012, and NACA 16-212) to establish the value of Cl / Cd from the variation of NACA airfoil types. The results of simulations using Qblade software revealed that the greatest alpha of the three types of airfoils had a value of 134, alpha 6, and the Cp value for the highest TSR was 0.44 at TSR 5.5. Furthermore, the NACA 4412 airfoil blades may be modified by using lighter material variants to make the windmill blades simpler to spin and so increase the resulting power.

Radhakrishnan PM *et.al.*, (2019)-Using geometry data acquired by the National Advisory Committee for Aeronautics, two-dimensional models of the airfoils were built, drawn, and meshed in ANSYS Mechanical. At a 4° angle of attack, ANSYS FLUENT is used to compute flow across the two-dimensional NACA 2415 and 23012 airfoils. The calculations are performed at high Reynolds numbers under standard roughness conditions. A C-Mesh is a common mesh for modelling an airfoil in a stream, and that is what we will be utilising. We will define the velocity at the system's intake as entering at a 4° angle of attack and a total magnitude of 1. The gauge pressure at the intake will likewise be set to zero. The only thing we can infer about the outflow is that the gauge pressure is zero. We shall treat the airfoil as if it were a wall. The CP (Coefficient of Pressure) distribution, CL (Coefficient of Lift), and CD (Coefficient of Drag) are estimated and compared with the experimental findings based on the study.

Florina Costea *et.al.*, (2018)-The major goal of this study was to compare two different wind turbine layouts. The geometric specifications of these two turbines are the identical, however one has 4 digit NACA0018 blades and the other has 5 digit NACA63-415 blades. This scholarly research does a numerical evaluation of the impact of airfoil shape on VAWT efficiency. CFD techniques with Ansys Fluent software are employed in this investigation. All simulations are for unsteady flow with a Reynolds number of 1e06 and the SST turbulence model. The wind velocity is 12 m/s at the design site, and the wind turbine geometric characteristics are 3.25m diameter and 4.87m height. For each wind turbine arrangement, the power coefficient fluctuation through tip speed ratio will be displayed. The vorticity magnitude contours at different positions of the blades are provided to quantify the recirculation zone impacts on efficiency. The findings will suggest the viability of optimising future wind turbine airfoils that are more complicated.

M.Umapathi *et.al.*, *(*2015)-The purpose of this CFD analysis of NACA 2313 and NACA 7322 is to determine the most efficient airfoil design from the two airfoils. The airfoil coordinates were created using the NACA 4 digit airfoil generator. ANSYS FLUENT 14.5 is used to compute the results. The analysis is based on characteristics such as the coefficient of lift, the coefficient of drag, the coefficient of pressure, and the pressure surrounding the airfoil. The comparison is performed at 6° and 10° angles of attack. An airfoil with a high coefficient of lift/coefficient of drag ratio is thought to be superior than the other. Based on the simulation findings, the airfoil NACA 2313 is shown to be better to NACA7322.

Mahendra Agrawal *et.al.*, (2013)-The goal of this study is to examine the fundamental aerodynamic theory of wings and to offer an overview of wind tunnel testing. This is followed by the results of the NACA4412 wind tunnel testing and data analysis. Lift increases as the angle of attack increases to a particular degree, and it reaches its maximum at that moment. If the angle of attack is raised further, drag will become the main force, and the wind will enter stall mode.

H.C. Ravi *et.al.*, (July 2013)- H.C. Ravi, N. Madhukeshwara, and S. Kumarappa conducted research on the NACA4412 airfoil profile with a Reynolds number of 3106. The researchers investigated the transition from laminar to turbulent flow using two independent computational models, the k-epsilon model and the Spalart-Allmaras model. The numerical findings were then compared to the experiment results. The results demonstrated that both numerical models produced equivalent results, particularly at high Reynolds numbers. In a separate study, D.R. Troolin, E.K. Longmire, and W.T. Lai explored the effects of a flap on the NACA 0015 airfoil. The flaps were originally designed for automobiles, and the researchers were able to effectively mimic their operation.

DESIGN OF AIRFOIL

From the airfoil we require most is the factors i.e greatest lift, minimal drag, thickness limitations and a pitching moment and other performances. Main purpose of airfoil is increase lift and decrease drag. Through airfoil design we need to know the BL characteristics the can give us relation between shape of airfoil and the pressure betweenairfoil surfaces upper and lower. In design of airfoil we can have main purpose is that tocreate most lift and less drag. We can decrease by change of shape and size of airfoil.

In airfoil construction we need only 2 dimension geometry.In this we can need to avoid 3dimensional effects like wingtip effect, properties of airfoil are use across the midway in unit span.To find the effect of properties of airfoil we need to done wind tunnel test. It can some factors to us that we need to know in airfoil construction.

We can represent the airfoil data with chord length because due to chord length we caneasily made any size of airfoil simply multiply the data by that chord length.

In construction of airfoil we need to know the Reynolds no so that we can test our airfoil middle span in wind tunnel that we can easily find the 2 dimensional properties of airfoil.As we know that if we need more lift we want more kinetic energy to reduce the drag theskin friction drag that I son upper and lower surface of airfoil. We can use high reynolds no so we get more velocity that implies more kinetic energy due to this we can create more lift.

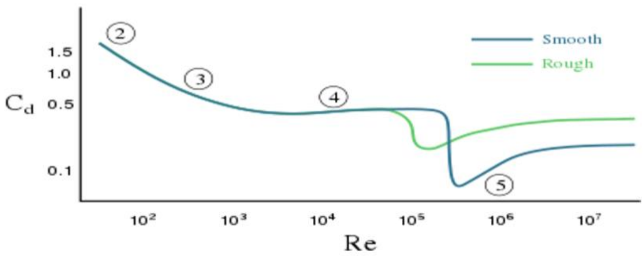


Fig. 3: Reynold no vs Cd

Designing in a direct manner

In direct airfoil design techniques we need all sections of airfoil and all parts effects onpressure and performance. After that we can draw an shape and that is modified according to performance required.

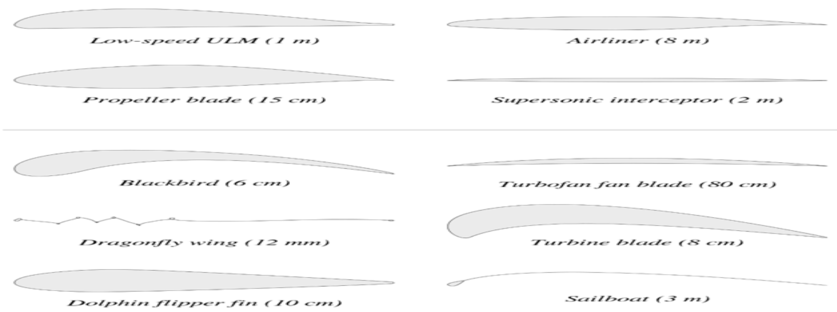


Fig. 4: different types of airfols

In this type of approach, there are two major subproblems.

- The process of modifying the shape in order to improve performance.
- The choice of the performance metric.

To modify the shape we need a airfoil which is first made we don't design a new airfoil.
Design of airfoil doesn't need any specification of any part of airfoil.

Fixed wing hang gliders decides because of low speed pressure distribution with Cl is1.4.

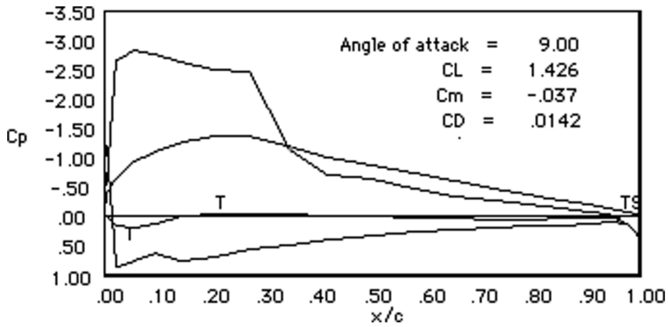


Fig.5: Pressure distribution at AOA 9

Glider has low speed performace . the wing fall from sky with reducting liftcoefficient.Pressure dist.

At Cl of 0.6 . Separation at bottom surface have less pressure which restricts the max.speed.at an angle of 1 degree.

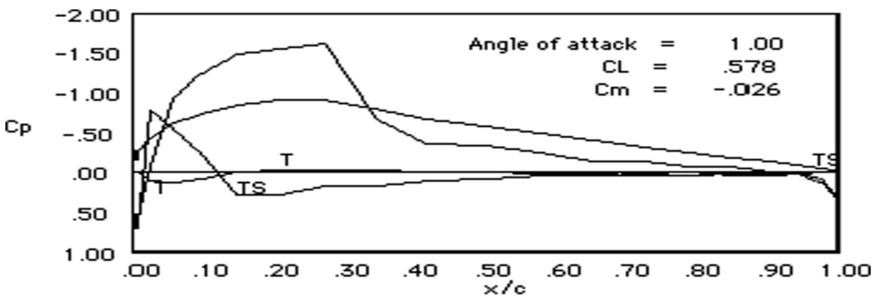


Fig. 6: Pressure distribution at AOA 1

The pressure at low Cl be removed by reduce the bottom surface and increasing lower surface thickness in this Cl around 0.2. so we need to double check for confirm tha Cl.

III. ANALYSIS OF FIVE DIGIT AIRFOIL

NACA 21004

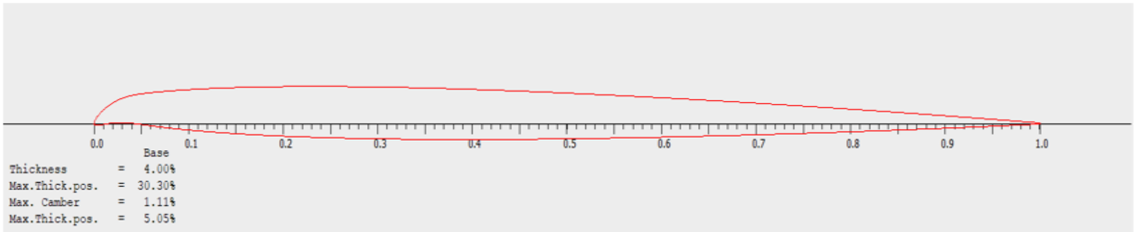


Fig 7: NACA 21004 Airfoil

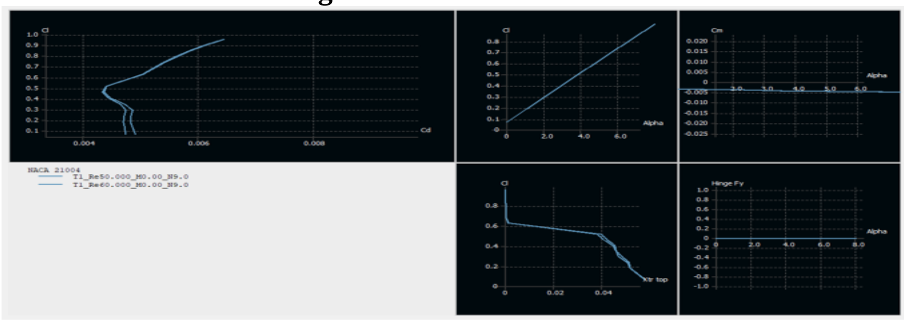
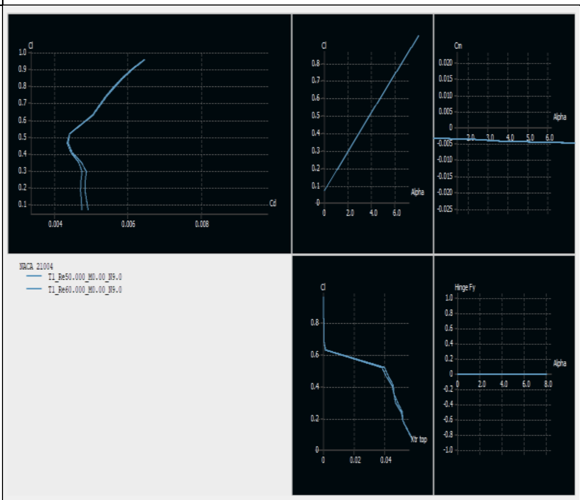
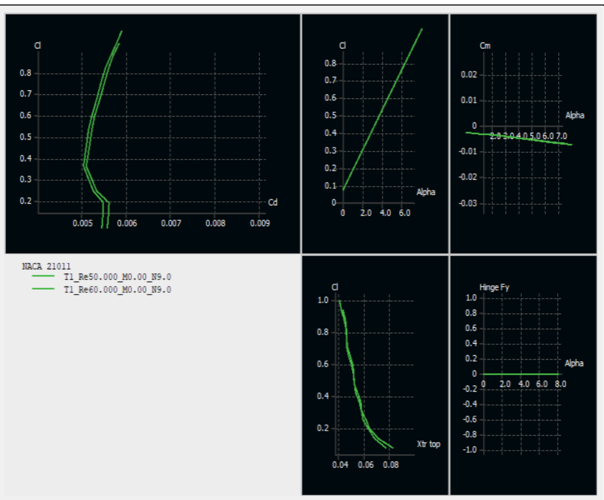
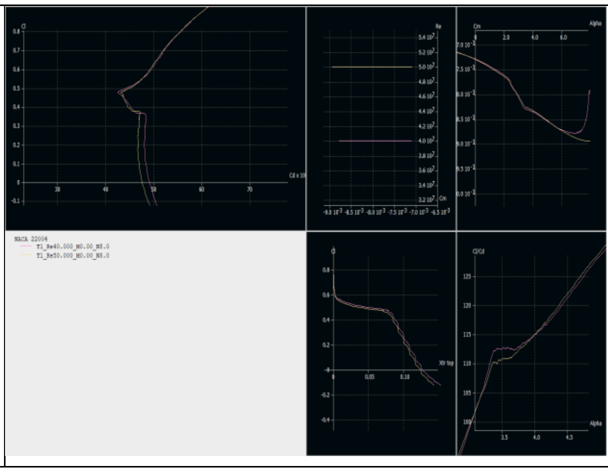


Fig 8: Analysis of NACA 21004

IV. RESULTS AND CONCLUSIONS

The discussion and conclusion on the basis of results which is obtained through proper Angle of attack and Reynolds number is applied. Theoretical analysis is not good enough to produce easier results due to rigorous minor differences in values. Hence the results obtained through analysis which gives the better results with the references.

AIRF OIL	Analysis	Result
21004		In this Airfoil it shows that if we increase AOA with Increase in Reynolds no Cl increase and Cd decrease. decrease. At 5 degree of AOA there is sudden increase in coefficient of lift. So we can say that at 5degree of AOA it gives better Result.
21011		In this Airfoil it shows that if we increase AOA with Increase in Reynolds no Cl increase and Cd decrease. decrease. At 6.5 degree of AOA there is sudden increase in coefficient of lift. So we can say that at 6.5 degree of AOA it givesbetter Result.

22004		In this Airfoil it shows that if we increase AOA with Increase in Reynolds no Cl increase and Cd decrease. decrease. At 7.5 degree of AOA there is sudden increase in coefficient of lift. So we can say that at 7.5 degree of AOA it givesbetter Result.

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