Computational study for improvement of aerodynamic performance of airfoil by changing various aerodynamic properties

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Abstract

An airfoil is a cross-section of a wing that is normal to the span of the wing. Generally, we called it a two-dimensional view of the wing and play important role in the preliminary design of an aircraft. The selection of an airfoil is primarily based on various parameter such as thickness maintenance for structure and fuel, stall characteristics, lift and drag during cruise and ease of design for the manufacturer. The most important key point in the selection and design of an airfoil is to reach maximum pressure difference in top and bottom keeping high aerodynamics efficiency and without getting flow separation. The inverse computational method was mostly preferred for designing modern airfoil to get the desired parameter mentioned above. The main objective of this review paper is to trace the data of various airfoil which operate at different environmental condition, altering geometric parameter and operating at different Reynolds number to optimize maximum lift coefficient with maintaining high aerodynamics efficiency. The extensive data will also be useful for future investigation and research purpose

Keywords 1

Aerodynamics, Performance, Meshing, Airfoil.

1. Introduction

Lift created by the wing is mainly effected by the airfoil design. Airfoil is a 2D vision of an wing in the direction of stream flow. Due to the shape of airfoil, on the top surface there is less pressure and on the bottom surface there is more pressure than on the lower side difference between the two surfaces produce the lift on the airfoil. Besides the top and bottom surface, the geometry of airfoil consists of specific features like thickness, camber, position of thickness, position of camber, nose radius, trailing edge, leading edge, and chord length. The Centre of pressure and aerodynamic center are important parameters for an airfoil. Airfoils based on the geometry are characterized by NACA series, the NACA series are 4digit, 5 digit and 6 digit and many other airfoil series. The angle of attack gives a great contribution in production of lift in airfoils. By increase in angle of attack, the lift increases. Maximum lift will be attained at stall angle from which the airfoil starts stalling. There are many airfoil designs that are being designed and tested from the pre modern era to get efficient lift and low drag at various Reynolds number and at various angles of attack We are now studying many methods at various airfoil designs from the NACA 4 digit, NACA 5 digit and NACA 6 digit series to increase the performance like lift ,drag, Cl, Cd, L/D ratio and properties like aero elasticity ,noise generation of airfoils by changing their characteristics by changing thickness, by adding vortex generators by adding gurney flap. These ideas have been tested and found by many researchers very efficient in many ways and some of which are listed in our experiment too. As this previous

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experimental and analyzed data helped us to understand the concept better and by applying these new ideologies in this experiment, we have found some similar and some improved results.

2. Review of Literature

Many discoveries on changing aerodynamic characteristics of airfoils have proven to give effective flight results with decrease in consumption of high lift. Creative ideas are being used for making new improvements. Detailed studies discover the questions and answers in a new way which is patented in various publications by developing the use of conventional airfoils.

V M Moraris et al had presented research on aerodynamic properties and efficient features of a leading edge of airfoils with Kruger flap (at low Re no.) which is as follow:

The experiment in wind tunnel and CFD analysis of Clark Yairfoilhaving10%chord. Front edge Kruger flap was studied on the basis of aerodynamic efficiency at Reynolds number 0.6 × 106, 1 × 106. It was observed that at high angle of attack Cl increase up to 18% than as compare to normal with airfoil no flap and also delayed in flow separation was observed by angle of 3 degree.

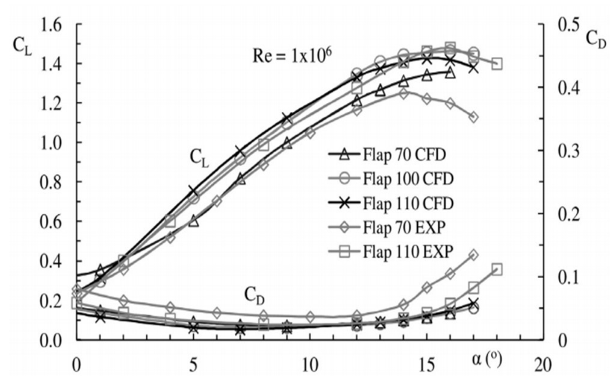

Figure 1: C_L and $C_{D\ plots}$ for Re = 1×10^6 over different angle of attack compiling result of experimental and CFD analysis with Flap deflection 70°,100° and 110°.

Rodolfsant et al had done research study on effect of open trailing edge on laminar airfoils:

Wind tunnel was used for the study of the experiment. It has mainly focused on NACA632-215 airfoil with laminar aerodynamic Properties to reduce performance by the impact of thickness of trailing edge. The Reynolds number and angle of attack are changed continuously which resulted in the decrease of aerodynamic efficiency. As the size of space between top surface and bottom surface at trailing edge increases, it causes decrease in efficiency of airfoil. So this impact can be reduced by rounding trailing edge. Lift coefficient grows slightly as space between two surfaces increase for angle of attack in the range of 10-20degree.liftcoefficient becomes maximum with increasing drag and does not depend on Reynolds number

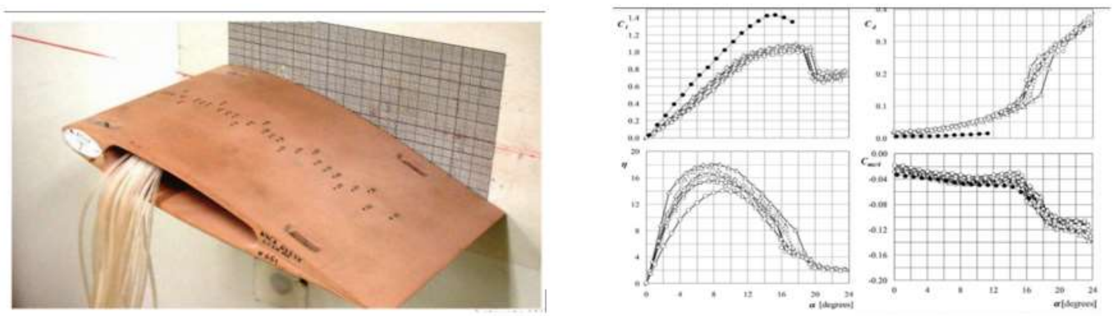

Figure 2: NACA 63_2-215 model, including pressure tap

T Winnermoller et al published his research work about design and calculative improvement of thick airfoil's having trailing edges which are not so sharp:

In thick airfoil due to contamination of particle lead to generation of friction and boundary layer separation also thick airfoil with sharp trailing edge was not favorable basically. Hence poor aerodynamics characteristics found. To improve the aerodynamic and structural performance the use of blunt trailing edge airfoil comes to picture. But due to shedding of a spinning mass of fluid and a use of plate with divider to generate steady flow at blunt trailing edge.

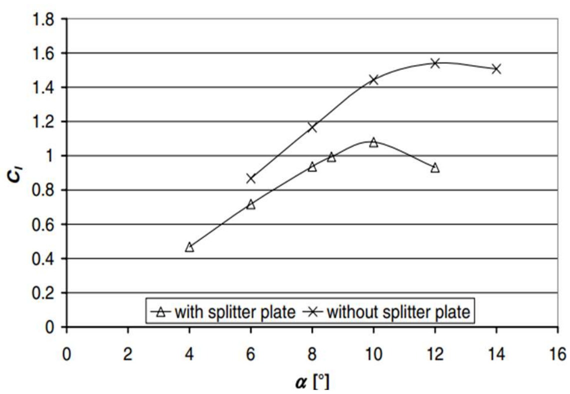

Figure 3: Cl vs alpha curve with splitter and without splitter

Patrick Hammer et al carried out their work on lift on a steady 2D symmetrical airfoil placed in viscous uniform shear flow:

Uniform flow was a poor approximation as many flow get disturbed due to surface roughness and obstacle. Here the study is completely based on non-uniform viscous flow ofNACA0012aerofoil at zero AOA and to excess some part of in viscid theory of lift generation in presence of shear. At Reynolds number of 1.2 × 104 asymmetry flow field was observed due to shear which was not mentioned in viscid theory. Negative sign force in symmetric airfoil at zero angle of attack was observed.

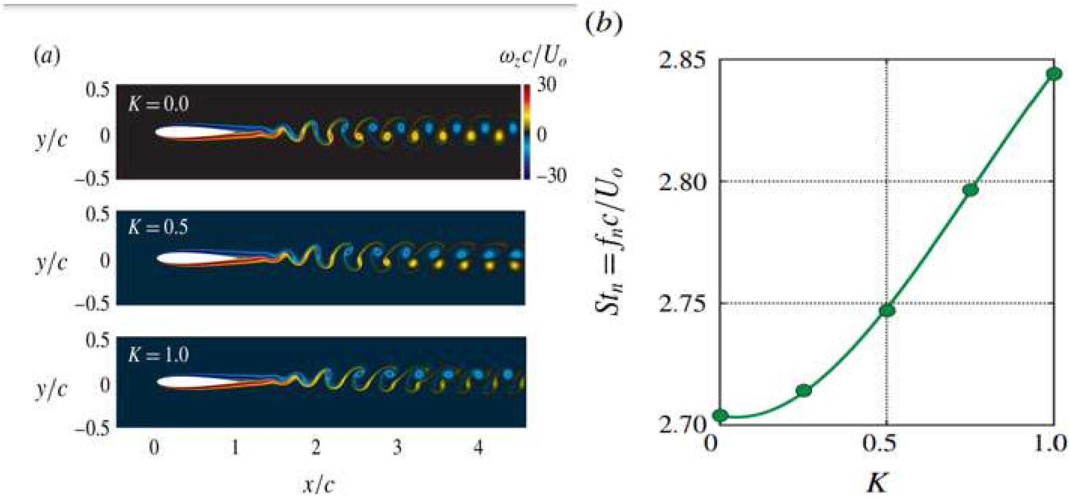

Figure 4: a) Instantaneus vortices field span wise b) shedding Strouhal number.

Russel Assenden et al have presented their published work on 2D NACA 23012 aerofoil performance degradation due to super cooled cloud, drizzle and rain drop icing:

Study deals with NACA23012 Airfoil Performance degradation due to various liquid hydrometer sizes. In boot activation the performance degraded too much and can be hazardous part. Ice formation by cloud, drizzle and raindrop contributing to reduction in maximum lift coefficient and increment in profile drag. Performance degraded as Cl max loss by12% increase in profile drag by 56%.

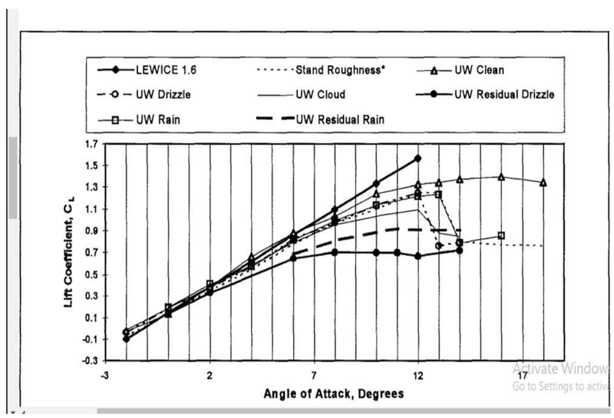

Figure 5: NACA23012 lift curve slope comparison for clean, cloud, drizzle and rain drop.

M Ochs et al have presented their research experimental study work on effect of rear edge shock waves on film cooling performance of gas turbine airfoils says:

The experiments were conducted on airfoils for analyzing shock wave film cooling interaction. The conditions of experiment are decided as high pressure, high temperature to make simulation like transonic region. These transonic flows when passed through turbine, shock waves influence them

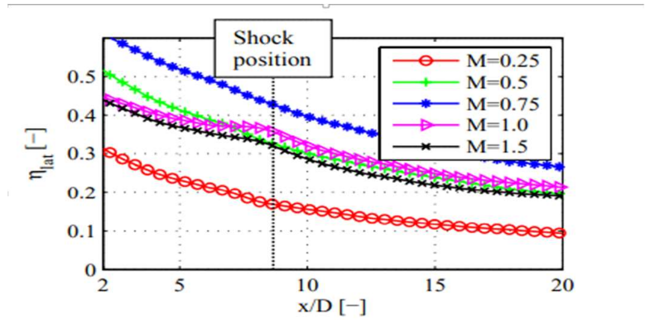

Figure 6: Laterally averaged adiabatic film cooling effectiveness of the fan shaped hole configuration at supersonic condition.

D R Polling et al had done research about the response of airfoils to periodic disturbances (The Unsteady Kutta Condition) concluding:

A NACA 0012 airfoil was studied for standard pitching motion flow over static airfoil placed in wake of pitching air foil. The frequencies are calculated by using laser Doppler Velocimetry. Average velocity was captured in both cases near trailing edge. Here standard Kutta condition is not valid. Instead, earlier proposed extension is used.

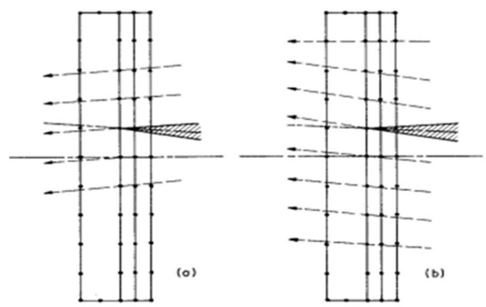

Figure 7: Instantaneous streamlines at trailing edge when alpha=2.25 degrees and corresponds to trailing edge at position x=25 y=0 a)upstream b)down stroke

James C Ross et al had done research on lift enhancement tabs on multi element airfoils:

Flat plate tab was used on a multi element 2D NACA 63- 215 airfoil. The tabs were placed at a height in between0.125 to 1.25% of chord of airfoil. The tabs were placed on trailing edge of airfoil. After performing experiments and computational analysis, tabs increase lift at reference AOA and max coefficient of lift.

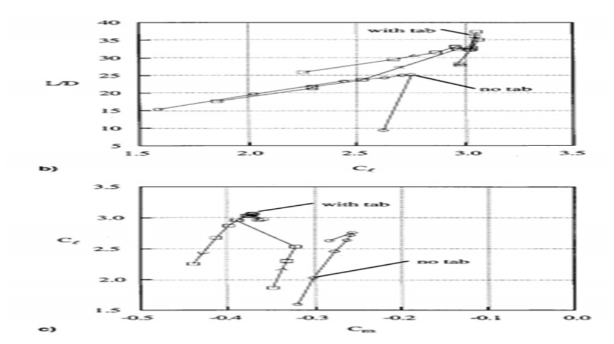

Figure 8: Aerodynamic effect of best tab tested in wind tunnel. Averaged time record of velocity fluctuations y=18 b) At position x=25 and y=0h/c=0.005, d/c=0.005,g/c=0.031

M R Ahemad et al had done research about the investigation on aerodynamics of asymmetrical airfoil in ground effect concluding:

The pressure distribution, lift, drag and main velocity over NACA0015 aerofoil were analysed in a low speed wind tunnel. The pressure coefficients and hence lift coefficients obtain higher values on lower surface. These values are for higher AOA and when aerofoil is close to surface. On the other hand, lift was dropped at lower AOA. The drag increases at higher AOA due to adverse pressure gradient.

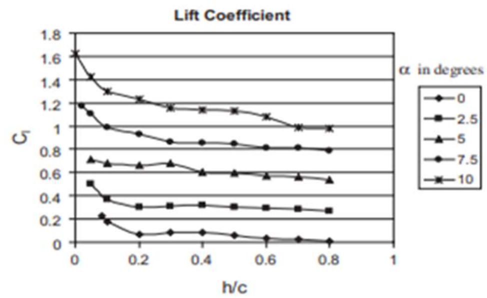

Figure 9: Coefficient of lift for different ground distances with different angles of attack

James Whitehead et al have presented their published work on reaction of artificial jet propulsion with Airfoil aerodynamics:

The interaction of synthetic jets with airfoil was studied. By using synthetic jet near trailing edge of airfoil, the shear layer which was separated, it reattaches to trailing edge of airfoil, the shear layer edge was separated, it reattaches to trailing edge of airfoil. The lift increases for momentum factor greater than a specific number.

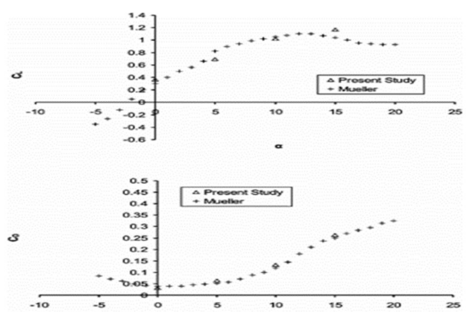

Figure 10: Comparison of data of present study with that of Mueller for a similar airfoil at Re=6*10^4 without jet excitation

J. N. Wood et al carried out their work on dynamic Behavior of 2 DOF airfoil:

The experiment was to study the fluid and construction interaction for a wing with two DOF (degree of freedom) for pitch and boost at Reynolds number for transitional regime. The configuration was setup with aero elasticity to perform flutter wing for stability and wind tunnel measurement are studied with DIC(digital image correlation).For experiment, the NACA 0012airfoil is used for the study which leads to a concept of simulating the explicitly of less frequency and less amplitude oscillation. The airfoil was also tested for limit cycle oscillation (LCO) for turning fluttering movement.

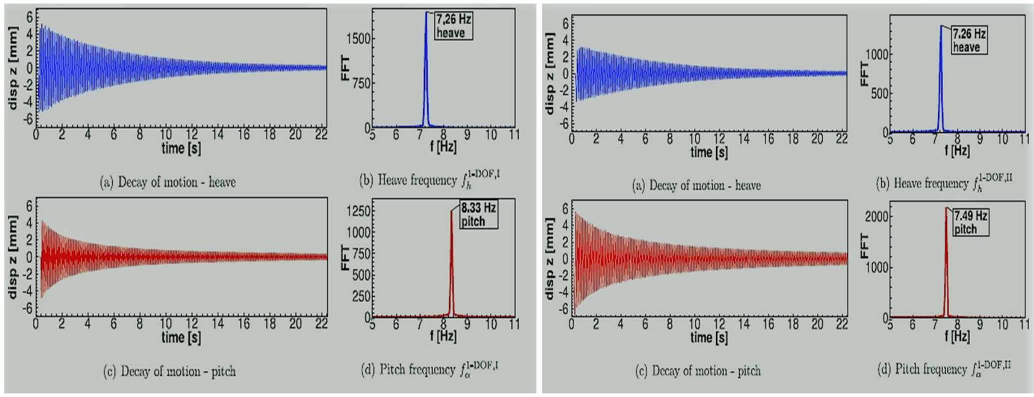

Figure 11: DIC measurement at Pw of the tree oscillation tests in still air for the 1-DOF.

Alexandre Medina et al published his research work about study of flow on an oscillating NACA0012 Airfoil Predicting:

The analysis was carried out with two-dimensional Ansys simulation, by aiming observational behavior of flow over NACA0012 airfoil. The airfoil having low frequency pitching was placed in Reynolds no of 10000.The airfoil was tested on different angle of attacks for obtaining a specific result for various strokes to configure the data flow of vortex. The lift and drag coefficient increase's when the velocity near wall region increases. The lift and drag coefficient increase's when the velocity near wall region increases.

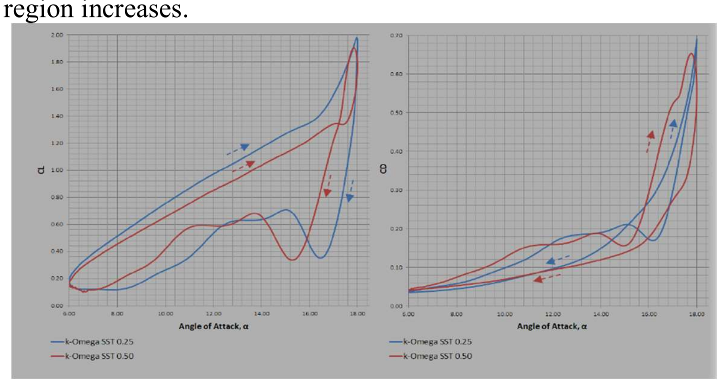

Figure 12: Hysteresis loops obtained with two dimensional Rans K-w SST computational analysis on lift and drag coefficient for the rotation axis at the centre of pressure(x=0.25 chord) and the middle chord(x=0.50 chord).

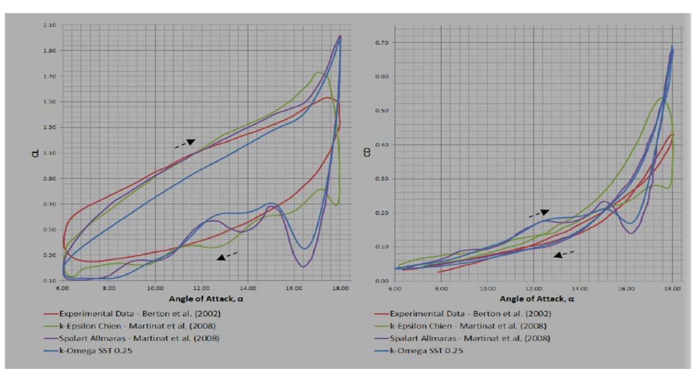

Figure 13: Hysteresis loops obtained with two-dimensional Rans K-w SST computational analysis on lift and drag coefficient were compared with the experimental results.

O John et al have presented their published work on aerodynamic performance of airfoils at low Reynolds Number:

The experimental behavior of flow of aerodynamics was studied by testing on Solid works, Ansys and Mat lab for computational analysis with various angles of attack and at low Reynolds number. The airfoil is also tested on multi-manometer for accurate results. The 3D printing of airfoil was done with the chord length 230 mm and total assembly width to be 305 mm. After this wind tunnel testing was also done.

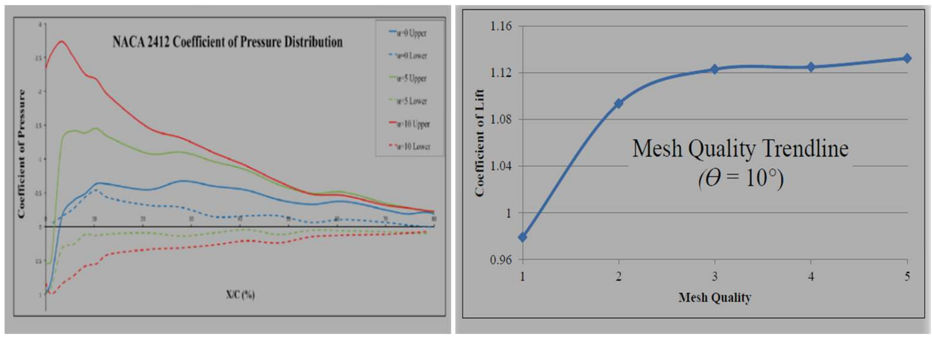

Figure 14: Coefficient of pressure vs percent chord length and Coefficient of lift vs mesh quality.

An Xiotong et al had done research study on effect of icing airfoils on aerodynamic characteristics of aircrafts:

The experiment was based on ice accretion. It contains the equations of motion for water droplets which was carried out by Lagrange method and the equations of energy and mass were calculated by Messinger method. Ice accretion affect all the control surface of an aircraft. The two dimensional airfoil was used for computational approach to solve the water droplet location by Lagrange method and it's trajectory of droplets was calculated by Messinger method.

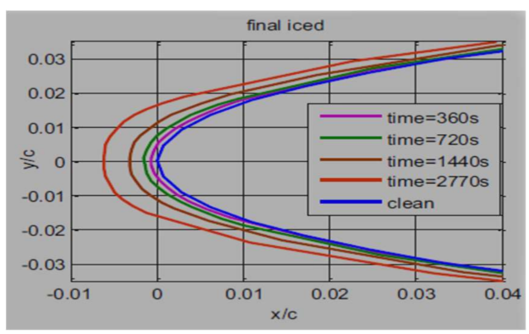

Figure 15: Ice shape at different time

Wenheng Li et al had presented research on deforming airfoils having flexible trailing edge:

In this scientific approach, investigation was done for the deformable wing of two types of airfoil. These two was used NACA4412 and NACA 0012 else shape changing trailing edge. The not movable and bendable nature was configured and compared for various parameters, numerical and simulation were used the changing angle of rear edge lift coefficient and L/D ratio of bendable trailing edge were larger than the not movable trailing edge.

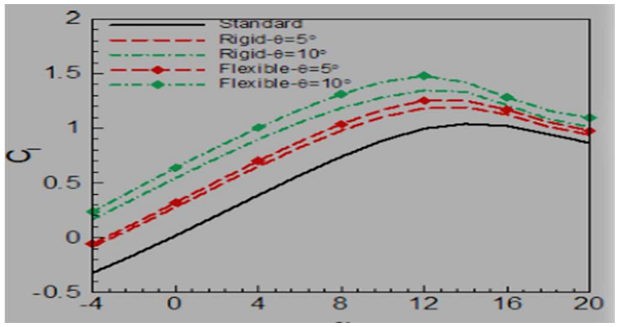

Fig16: Lift coefficient

Bruce L et al had presented research on lift enhancement on airfoils using a gurney flap and vortex generator is as follows:

NACA4412 airfoil was used to study the experiment for distribution of surface pressure and wake profiles. For obtaining the lift, drag, and longitudinal moment coefficients for many cases, the Gurney flaps were added. This addition showed improve in greatest lift coefficient from 1.49 to 1.96andreduction in the drag near the greatest lift condition. The vortex creators are used for baseline airfoil to make delay to boundary-layer.

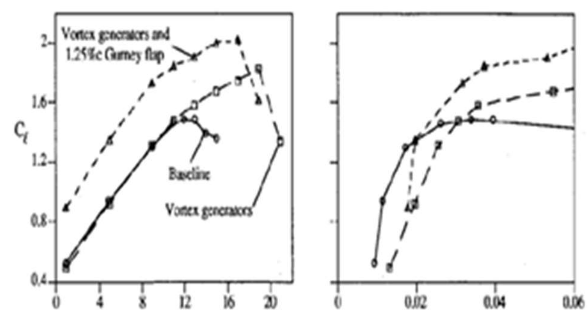

Figure 17: Variation of lift coefficient increment with Gurney flap height

W. Bhushan s patel et al had presented research is as follows CFD analysis of wind turbine blade at various angle of attack and at various Reynolds numbers:

Separation and yielded an increase in the maximum lift coefficient of 0.34.This study is about testing of NACA 0012 airfoil and finding out lift, draglift coefficient, drag coefficient for different angles of attack varying from 0°to 80°and different Reynolds number varying from 10000 to 800000. The results have been found out by CFD analysis. This involves the first important step of meshing the airfoil and the results are compared with the report of NCL energy. It was found that the lift and drag are higher when the Reynolds number is high.

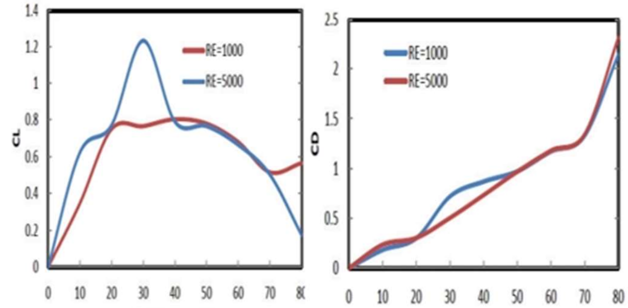

Figure 18: Comparison of Cl vs Angle of attack RE=1000,5000 Comparison of CD vs Angle of attack for RE=1000,5000

W. Olsen et al had presented research on effect of thickness on surface noise of airfoil:

This experiment is about the study of the effect of thickness of airfoil on noise produced by the airfoil. There are airfoils having different thicknesses like O.95, 0.32, 0.082cm, with small chord2. 54cm.The noise will be calculated, by making stream to flow at perpendicular to the plane of the airfoil at 50m/s. The value noise will be eliminated by the mufflers. This is done by changing the airfoils. Thus, the effect of thickness is calculated. It is noted that, the thin airfoil produces more noise than the thick airfoil.

MAAzlin et al had done research about the CFD analysis of winglet in low subsonic flow concluded as:

This study is about CFD examination of 3d - winglet that was done on rectangular wing of NACA653218 airfoil, the wing is of 660mm span and 121 mm chord. It was seen that for two cases semicircle and elliptical. The goal of analysis is to observe the aerodynamic properties of two winglet cases and check the performance of two winglet shapes by simulating at different angles, at less subsonic flow. The Cl, Cd and L/D values are also studied. Elliptical winglet with 45 angle was the best figure giving 8% improvement in lift to AOA slope and the best lift to drag ratio.

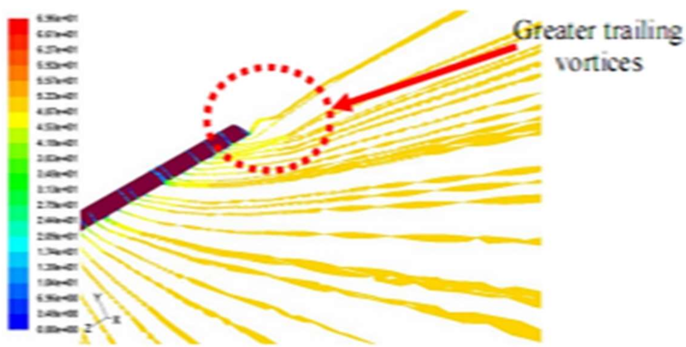

Figure 19: Effect of airfoil thickness on noise emitted by very small chord of airfoil. Airfoil chord=2.54cm; free field lossless data jet noise and background noise removed for spectra theta i=90 degree

Omer Faruk et al published his research work about aerodynamic performance of airfoils by using CFD analysis:

The CFD method was used to analyze the aerodynamic performance of different air foils. Increasing the lift and decreasing the drag results in increase of aerodynamic characteristics of wing. Lift force can be improved either by increasing the distribution of pressure or decrease in the boundary layer thickness at the boundaries of airfoil. To examine performance of an airfoil, aerodynamic coefficients are of most importance. Here, aerodynamic coefficients of four airfoils having varying angle of attacks are obtained and compared by with CFD.

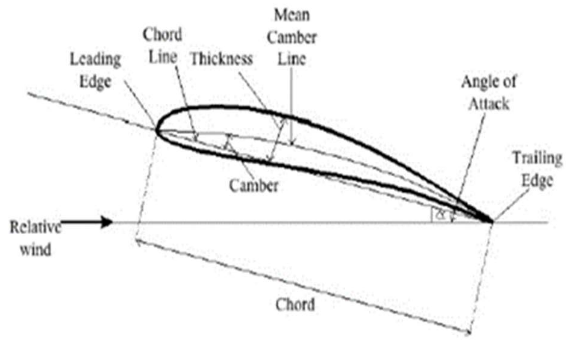

Figure 20: Airfoil Shape

William P Walker et al had done research about the unsteady aerodynamics of deformable airfoils:

In this experiment, a theory for the unsteady aerodynamics of deformable thin airfoils is studied specially restricted to rigid body motion. A polynomial approach is used to derive lift, moment about lateral axis and thrust for an airfoil is obtained in this study for harmonic oscillations as well as deformations. First and second polynomial results in the immovable motion of a body on the other hand the others represent the change of shape of a body. The observations are carried out with respect to time. The unsteady aerodynamic theory is utilized to check the results. The results containing numbers are used for many types of airfoil motion for studying many possibilities for production of thrust by using a not securely fixed airfoil.

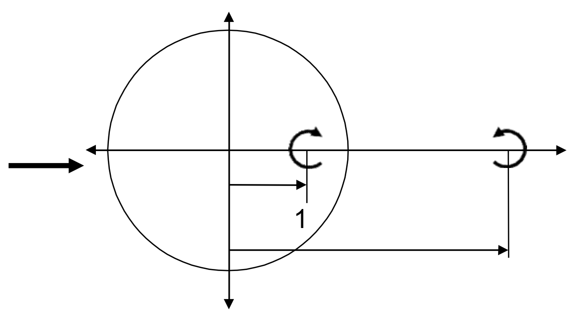

Figure 21: Vortex Location

Nesar Ali et al had done research about the comparison of oval wing and insect wing by using thin airfoil theory:

The thin airfoil theory states that the flow surrounding of airfoil is mostly similar to two-dimensional flow around a airfoil with less thickness. This is studied by a definite theory. Zero thickness as well as never ending wing span are used to gain this approach. Aircrafts consider the wing as a part of flying. More perfect construction of airfoil leads to improve balanced flying as well as it shows good aerodynamic characteristics.

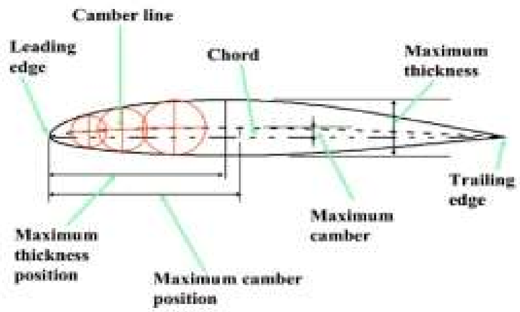

Figure 22: Thin Airfoil Theory figure

3. Critical Analysis

Now a day's aviation industry are blooming with their application and moreover many researchers are focusing on reduction of cost with high and reliable operating condition of an aircraft. The airfoil shape and their performance during operation are important design criteria that we need to improve during design phase. To obtain efficient airfoil design, researchers have studied different airfoil profiles by varying angle of attack with different Reynolds no. and simulating them into various software. The review paper gave us both quantitative and comparative work done on airfoil. On the basis of that selection and design criteria of an airfoil are improved. Such as flow will remain attach with airfoil when airfoil thickness is increased and blunt trailing edge with splitter is introduced to reduce vortex shedding.

4. Conclusion

The research mainly focused on various design criteria and gave efficient result such as reducing vortex shedding by using splitter plate behind the blunt trailing edge and improvement in flow attachment by reduction of airfoil thickness ratio. Also, the study reveal that operating condition will degrade in different environmental condition such as increment in profile drag was observed for cloud ice, drizzle and rain droplet. With this analyzed data on different airfoil by various researchers provide us great motivation to enhance existing properties and also to study new parts which were not yet to be explored. One such part in which our group was continuing study was vented airfoil which provides us a promising result by delaying flow separation and also further investigation is going on to enhance aerodynamics properties.

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