Numerical Investigation for Wind Turbine Blade For Higher Reynolds Number For Darrieus Rotor

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Abstract - *In present work an attempt is made to investigate the Lift and Drag forces for different Reynolds number and angle of attack for wind turbine blade for three different chord length 5 cm, 10 cm, 15 cm. In present work NACA 0021, NACA0015, NACA0009, NACA4421 airfoil profile is considered for analysis of wind turbine blade. The Lift and Drag forces are calculated at different angle of attack varying from 0 o to 80o for five different higher Reynolds number from 10,000, 40,000, 160,000, 360000 and 800000 by Computational Fluid Dynamics (CFD) analysis. The values of CL and CD at higher Reynolds number is much important in analysis of Darrieus and horizontal axis type of wind turbine blade, still it these values are not available from the literature reviewed . From CFD analysis it is concluded that as Reynolds number increase lift forces and drag forces decreases for particular chord length and if chord length increases CL and CD increases. And Comparison has been done in four blade profile (NACA0021, NACA0015,NACA0009, NACA4421) for all three chord length and from that we concluded that NACA 4421 provides maximum lift and drag at higher Reynolds number.*

*Key Words***:** Angel of attack, Chord length, Drag coefficient, Lift coefficient, NACA Blade profile.

1.INTRODUCTION

DAILY aily huge consumption of electricity in India there is need simple economical device which will produce electricity very fast. This need of modern society will be fulfill by simple three blade wind turbine which is called darrius turbine. Selection of aerofoil shape of blade is the most critical part of a wind turbine design as ultimately blade is responsible for conversion of kinetic energy into mechanical energy. Aerodynamics is a science and study of physical laws of the behavior of objects in airflow and the forces that are produced by airflows. In the early stage, the research on wind turbine blade design was limited on theoretical study, field testing and wind tunnel testing which need a lot of efforts and resources. Due to the development of computer aided design codes, they provide another way to design and analyzed the wind turbine blades. So aerodynamic performance of wind turbine blades can be analyzed using Computational Fluid Dynamics (CFD), which

is one of the branches of fluid mechanics. Aerodynamic studies are quite mature for flows with large Reynolds number. However, large Reynolds number. However, there are not much analytical, numerical or experimental studies available for flows at very high Reynolds numbers. In order to extract the maximum kinetic energy from wind, researchers put much effort on the design of effective blade geometry. Consideration of 2D geometries, i.e., airfoils, for such studies seems to be a good starting point to improve understanding of higher Reynolds number flows.

2.LITERATURE REVIEW

In this regard, some experimental studies are reported in Schmitz F. W., 1967, Sunada S. et al., 1997 [5], Sunada S. et al., 2002 [6], M Nazmul 2015 [7]. Numerical studies, for analysis as well as for design and experimental validations of airfoils at ultralow Reynolds number are presented in Kroo and Kunz, 2000, Kunz and Kroo, 2000 [1, 2]. The effects of aerofoil profile modification on a vertical axis wind turbine performance are presented in by Md Farath Ismail , Krishana vijayrahgavan 2015 [8] . The effect of Blockage-tolerant wind tunnel measurements for a NACA 0012 at high angles attack is presented by J.M Rainbird , J .Peiro 2015 [9]. From literature survey, it is observed that, study of lift and drag forces on aerofoil, for very high Reynolds number at angle of attack is not explode more. So, in present work an attempt is made to study the Lift and Drag forces on a wind turbine blade for very high Reynolds number and different angle of attack. In present work NACA 0015 and naca0021 airfoil profile is considered for analysis of wind turbine blade. The Lift and Drag forces are calculated at different angle of attack from 0o to 80o for five different Reynolds number from 10,000, 40000, 160000,360000 and 800000 for three different chord lengths by computational fluid dynamics analysis.

3.MATHEMATICAL EQUATIONS

3.1 Lift Coefficient *(C_L)*

It is a dimensionless coefficient that relates the lift generated by aerofoil, the dynamic pressure of the

fluid flow around aerofoil, and a reference area associated with the body. This is given as follows

$$C_L = \frac{L}{\frac{1}{2}\,\rho v^2 A} \text{ ,Lift force (L) = } C_L \times \frac{1}{2} \times \rho \times V^2 \times A \qquad (1)$$

3.2 Drag Coefficient (C_D)

It is a dimensionless quantity that is used to quantify the drag or resistance of an object in a fluid environment such as air for aerofoil. This is given as follows

$$C_D = \frac{D}{\frac{1}{2}\rho v^2 A} \text{ , Drag force (D) = } C_D \times \frac{1}{2} \times \rho \times V^2 \times A \qquad (2)$$

3.3 Agle Of Attack (α)

The angle of attack is the angle between an airfoil cord line and the oncoming air.

4. GEOMETRY & MESH GENERATION

In present analysis, C type mesh with two way velocity inlet method is used. The close view of mesh and boundary condition used in analysis is shown in fig.2 and fig.1 respectively. The pressure based implicit steady solver with Standard k-ε model turbulence model with PRESTO second order upwind scheme is used for analysis.
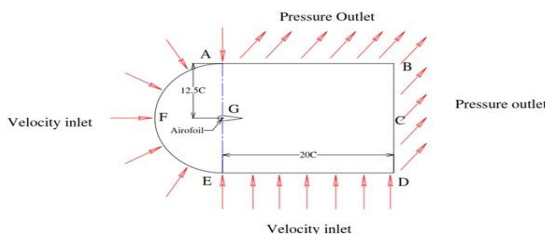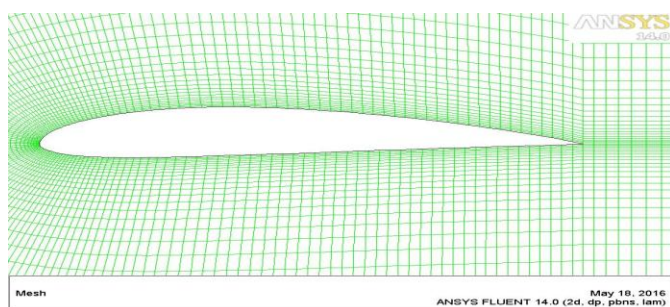

Fig -1: Geometry With Boundry Conditions

Fig -2: Close view of C type mesh for NACA4421

5. GRID INDEPENDENCE TEST

Grid Independence Tests are performed for finding the

least resolution or number of cells required to obtain accurate solutions. It is helpful in saving time and memory space in working out a numerical simulation. In this method one or parameters are obtained at various resolutions, starting from lower to higher. As the number of cells increases the parameter converges to an asymptotical value indicating the accuracy of solutions and minimum cells required for it. By doing the Grid Independence Test we will be able to save the computational time. The Grid Independence Test was done for an airfoil at 10 degree angle of attack by the above Boundary conditions by using all the turbulence models. The figures given below are the graphs for Grid Independence Test, for an airfoil at 10 degree angle of attack for the k- ε turbulence model. The k-ε turbulence model converges needs more number of iterations as compared to the other two models. Hence the results shown below are plotted for the k- ε model
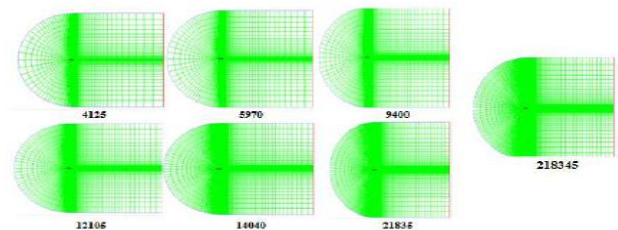

Fig -3: Grid independence study mesh

Lift Coefficient, Drag Coefficient and for the different element size. Based on the results, we can select the element size of 14040 as the best element size.

6. EXPERIMENTAL SETUP

The measurements have been conducted in an open wind tunnel at the University of SPPU in SND.COE&RC YEOLA, . This tunnel test section long with two perspex windows and flow cross- section is approximately 0.3m×0.3m×1m, interval of wind velocity is from 1 to 30 m/s. Fig. 4

Fig -4: Wind Tunnel Assembly

The airfoil used in the present study is an NACA4421 profile (chord length, c, of 150 mm and span wise length, s, of 200

mm). Stationary end plates are kept on the two sides of the airfoil, with a small gap of about 1 mm, to help maintain two dimensionality of the flow. The experiments have been conducted at 25 m/s wind velocity (V) in tunnel which is corresponding to 800000 Reynolds number (Re).

The airfoil is forced stationary wind velocity to learn lift and drag coefficient, the airfoil profile is attached to electronic two- component coefficient transducer. The values for drag and lift are displayed digitally on the measurement amplifier. The angular position of the airfoil (angle of attack at air foil) in the flow is set by means of a graduated dial.

7.RESULT & DISCUSSSIONS

7.1 NACA0021

Initially, CFD analysis is carried out for NACA0021 and three different chord length 5cm ,10 cm ,15 cm and for five different Reynolds number = 10,000,40000, 160000,360000, 800000. Geometric details are shown in Fig.1. Map meshed used for simulation, close view of map mesh used near aerofoil is shown in Fig.2 the obtained results are plotted in fig.4, fig.5 for angle of attack 10^0 and 70^0 respectively on velocity contour around aerofoil. The results obtained by simulation for representing variation of lift coefficient with reference to angle of attack for various Reynolds number. The Reynolds number is varied by changing free stream velocity at inlet.
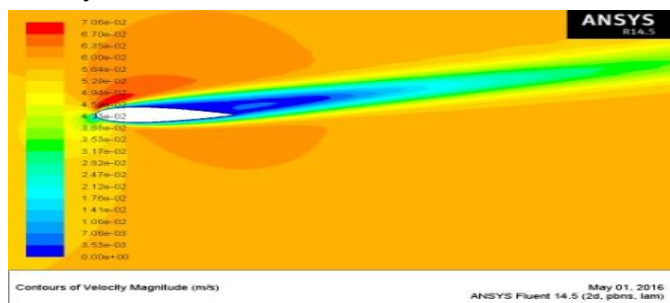

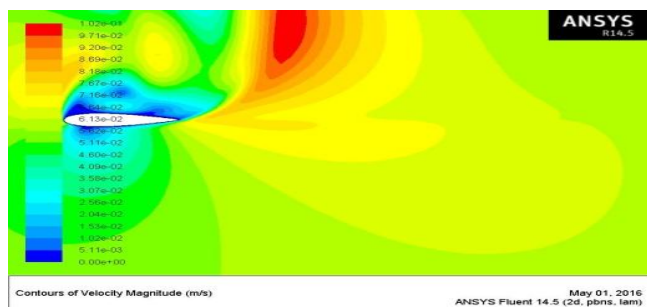**Fig -5**: velocity counter for angle of attack 10^0

Fig -6: velocity counter for angle of attack 70^0

Comparison of lift coefficient and drag coefficient for different Reynolds number and same chord length for NACA0021
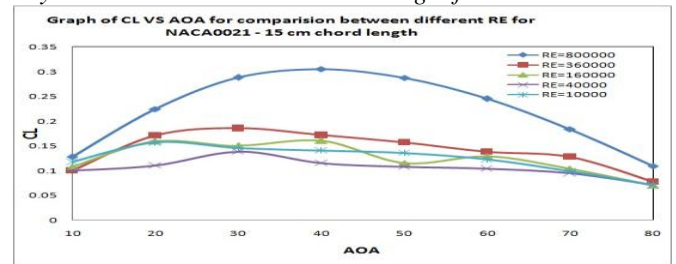

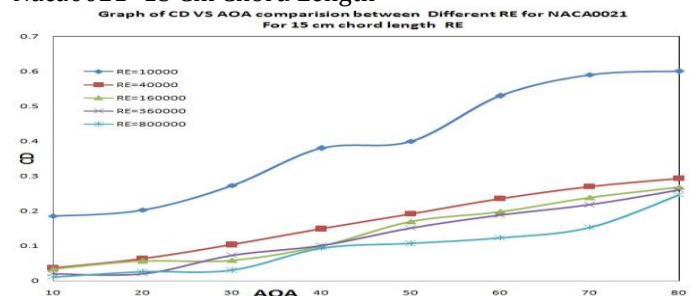**Fig -7**: Graph Of CL Vs AOA For Comparison Of Re For Naca0021 -15 Cm Chord Length

Fig -8: Graph Of CD Vs AOA For Comparison Of Re For Naca0021 -15 Cm Chord Length

Comparison has been done between Reynolds number as for same chord length i.e. 5 cm, 10 cm, 15 cm for NACA0021. That as Reynolds number increases lift coefficient increases with respect to increase in angle of attack, this happens due to increase in Reynolds number flow gets accelerated on upper surface of aerofoil and gets decelerated lower surface of aerofoil, so because of that pressure difference increases so lift coefficient increases. It is also observed that for same chord length and same Reynolds number lift coefficient increase with increase in angle of attack and it reaches maximum value suddenly decreases, This phenomena called as stalling. It has been seen that drag coefficient increase with increasing angle of attack. It is observed that for same chord length Reynolds number 800000 gives maximum lift and drag coefficient value, and Reynolds number 10000 show minimum lift and drag coefficient value. Form all above comparisons NACA0021 and chord length 15 cm shows highest lift coefficient up to 0.3 at RE=800000 .

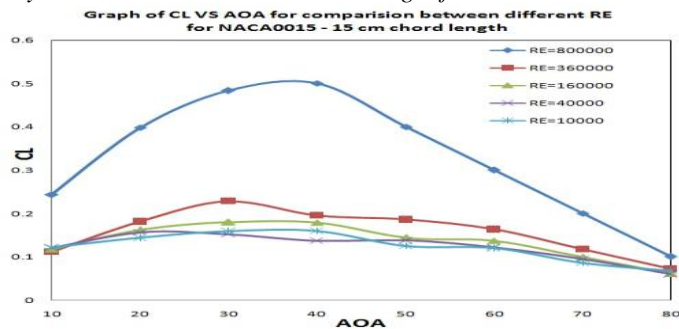*Comparison of lift coefficient and drag coefficient different Reynolds number and same chord length for NACA0015*

Fig -9: Graph Of CL Vs AOA For Comparison Of Re For Naca0015 -15   Cm Chord Length
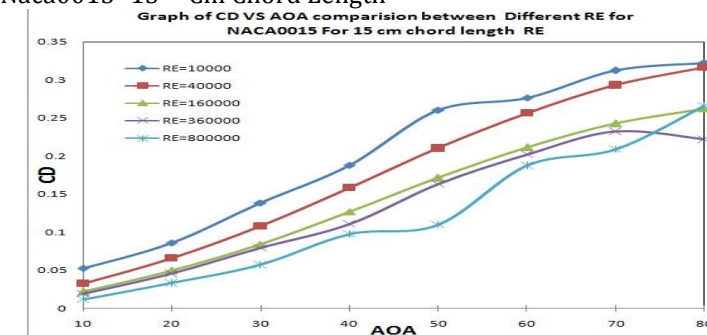

Fig -10:Graph Of CD Vs AOA For Comparison Of Re For Naca0015 -15 Cm Chord Length

Comparison has been done between Reynolds number as for same chord length i.e. 5 cm, 10 cm , 15 cm for NACA0015, and it is observed that as Reynolds number increases lift coefficient increases with respect to increase in angle of attack, It is also observed that for same chord length and same Reynolds number lift coefficient increase with increase in angle of attack and it reaches maximum value suddenly decreases, This phenomena called as stalling. It has been seen that drag coefficient increase with increasing angle of attack. From all figures it is observed that for same chord length Reynolds number 800000 gives maximum lift and drag coefficient value, and Reynolds number 10000 show minimum lift and drag coefficient value. Form all above comparisons NACA0015 and chord length 15 cm shows highest lift coefficient up to 0.45 at RE=800000.

Comparison of lift coefficient and drag coefficient different Reynolds number and same chord length for NACA0009
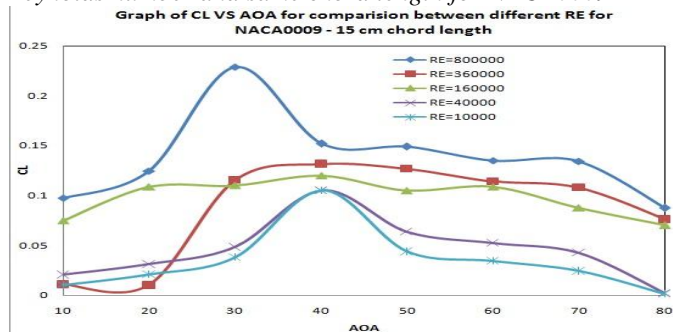

Fig -11: Graph Of CL Vs AOA For Comparison Of Re For Naca0009 -15 Cm Chord Length
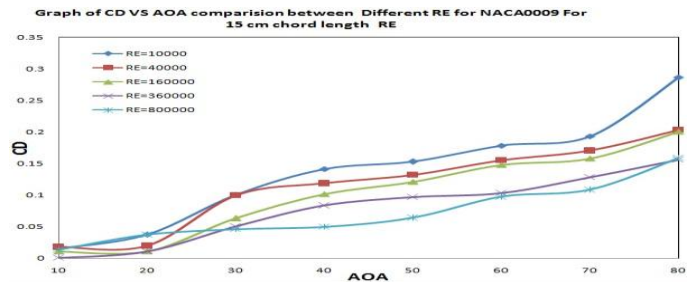

Fig -12: Graph Of CD Vs AOA For Comparison Of Re For NACA0009 -15 Cm Chord Length

Comparison has been done between Reynolds number as for same chord length i.e. 5 cm, 10 cm, 15 cm for NACA0009, and it is observed that as Reynolds number increases lift coefficient increases with respect to increase in angle of attack, It is also observed that for same chord length and same Reynolds number lift coefficient increase with increase in angle of attack and it reaches maximum value suddenly decreases, This phenomena called as stalling. It has been seen that drag coefficient increase with increasing angle of attack. From all figs it is observed that for same chord length Reynolds number 800000 gives maximum lift and drag coefficient value, and Reynolds number 10000 show minimum lift and drag coefficient value. Form all above comparisons NACA0009 and chord length 15 cm shows highest lift coefficient up to 0.24 at RE=800000.

Comparison of lift coefficient and drag coefficient different Reynolds number and same chord length for NACA4421
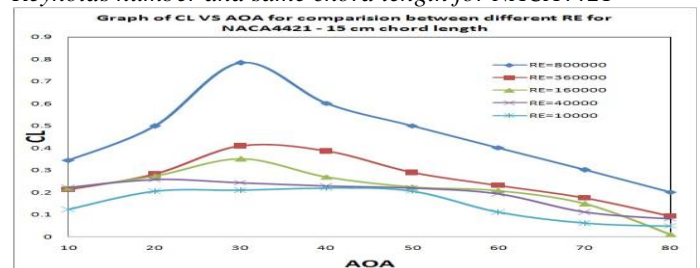

Fig -13: Graph Of CL Vs AOA For Comparison Of Re For Naca4421 -15 Cm Chord Length
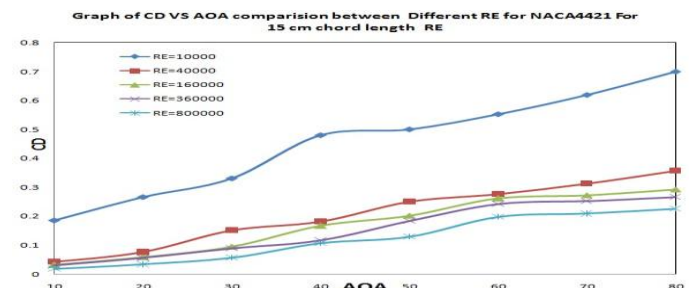

Fig -14: Graph Of CD Vs AOA For Comparison Of Re For Naca04421 -15 Cm Chord Length

Comparison has been done between Reynolds number as for same chord length i.e. 5 cm, 10 cm , 15 cm for NACA0009, and it is observed from fig 13 to fig 14. That as Reynolds number increases lift coefficient increases with respect to

increase in angle of attack, It is also observed that for same chord length and same Reynolds number lift coefficient increase with increase in angle of attack and it reaches maximum value suddenly decreases, This phenomena called as stalling. It has been seen that drag coefficient increase with increasing angle of attack. From all figs it is observed that for same chord length Reynolds number 800000 gives maximum lift and drag coefficient value, and Reynolds number 10000 show minimum lift and drag coefficient value. Form all above comparisons NACA4421 and chord length 15 cm shows highest lift coefficient up to 0.8 at angle of attack 30 and RE=800000.

Comparison of lift coefficient and drag coefficient same Reynolds number and same chord length for NACA0021, NACA0015, NACA0009, NACA4421
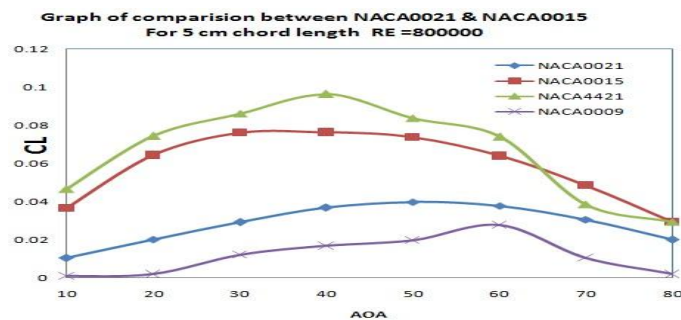
For 5 cm chord length

Fig -15: Graph Of CL Vs AOA For Comparison Of four blade profile for 5 cm Chord length and RE=800000
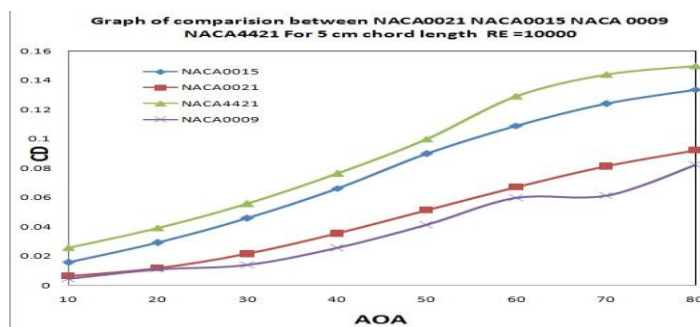

Fig -16: Graph Of CD Vs AOA For Comparison Of four blade profile for 5 cm Chord length and RE=10000

From fig 15 to fig 16 Comparison has been between four blade profile (NACA0021, NACA0015, NACA0009, NACA4421) for lift coefficient Vs angle of attack for same Reynolds number (like Ranging from 10000, 40000, 160000, 360000, and 800000) and same chord length for 5 cm and it has been observed that among all Reynolds number NACA4421 shows highest lift coefficient 0.12 at angle of attack 30^0 at RE=8000000. And four blade profile (NACA0021 NACA0015 NACA009 NACA4421) for drag coefficient Vs angle of attack for same Reynolds number (like Ranging from 10000, 40000, 160000, 360000, and 800000) and same chord length for 5 cm, and it has been observed

that among all Reynolds number NACA4421 shows highest drag coefficient =0.16 at angle of attack 80^0 and for RE=10000 for 5 cm chord length.
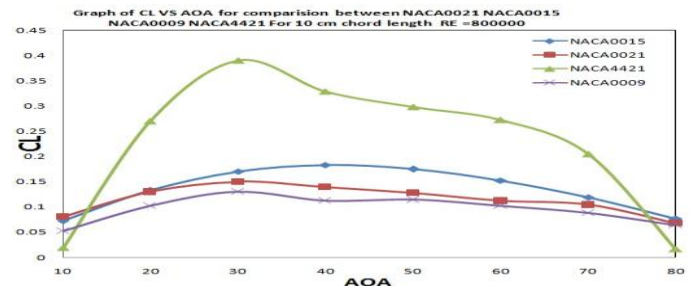
For 10 cm chord length

Fig -17: Graph Of CL Vs AOA For Comparison Of four blade profile for 10 cm Chord length and RE=800000
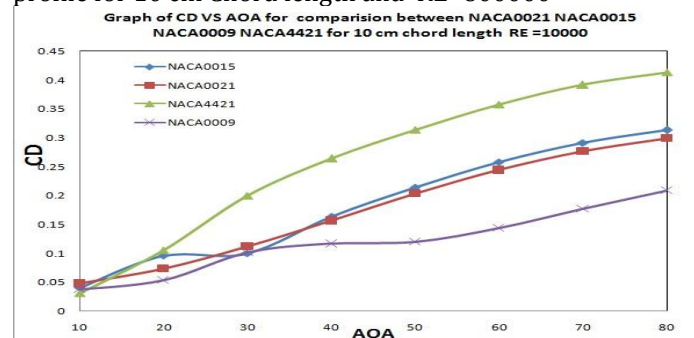

Fig -18: Graph Of CD Vs AOA For Comparison Of four blade profile for 10 cm Chord length and RE=10000

From fig 17 to fig 18 Comparison has been between four blade profile (NACA0021, NACA0015, NACA0009, NACA4421) for lift coefficient Vs angle of attack for same Reynolds number (like Ranging from 10000, 40000, 160000, 360000, and 800000) and same chord length for 10 cm, and it has been observed that among all Reynolds number NACA4421 shows highest lift coefficient 0.4 at angle of attack 30^0 at RE=800000. And four blade profile (NACA0021 NACA0015 NACA009 NACA4421) for drag coefficient Vs angle of attack for same Reynolds number (like Ranging from 10000, 40000, 160000, 360000, and 800000) and same chord length for 5 cm, and it has been observed that among all Reynolds number NACA4421 shows highest drag coefficient =0.4 at angle of attack 80^0 and for RE=10000 for 10 cm chord length
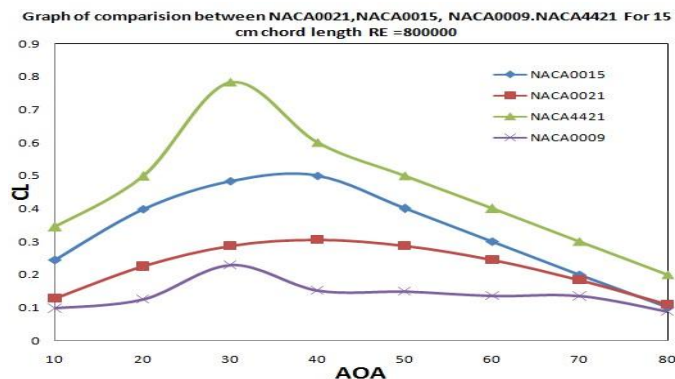
For 15 cm chord length

Fig -19: Graph Of CL Vs AOA For Comparison Of NACA0021 & NACA0015 for 15 cm Chord length and RE=800000
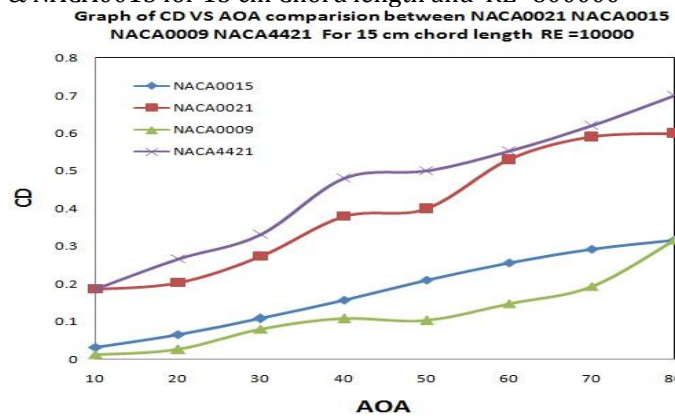

Fig -20: Graph Of CD Vs AOA For Comparison Of NACA0021 & NACA0015 for 15 cm Chord length and RE=10000

From fig 19 to fig 20 Comparison has been between four blade profile (NACA0021, NACA0015, NACA0009, NACA4421) for lift coefficient Vs angle of attack for same Reynolds number (like Ranging from 10000, 40000, 160000, 360000, and 800000) and same chord length for 15 cm, and it has been observed that among all Reynolds number NACA4421 shows highest lift coefficient 0.78 at angle of attack 30^0 at RE=8000000. And four blade profile (NACA0021 NACA0015 NACA009 NACA4421) for drag coefficient Vs angle of attack for same Reynolds number (like Ranging from 10000, 40000, 160000, 360000, and 800000) and same chord length for 5 cm, and it has been observed that among all Reynolds number NACA4421 shows highest drag coefficient =0.7 at angle of attack 80^0 and for RE=10000 for 10 cm chord length

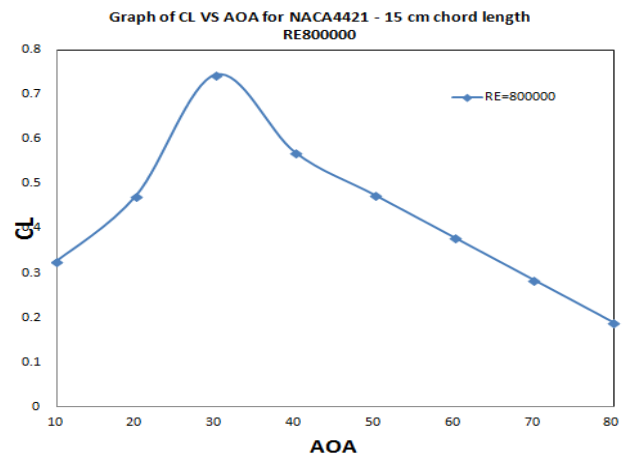## 7.EXPERIMENTAL RESULTS FOR OPTIMUM DESIGN

Fig -21: Graph Of CL Vs AOA For Comparison Of NACA4421 for 15 cm Chord length and RE=800000
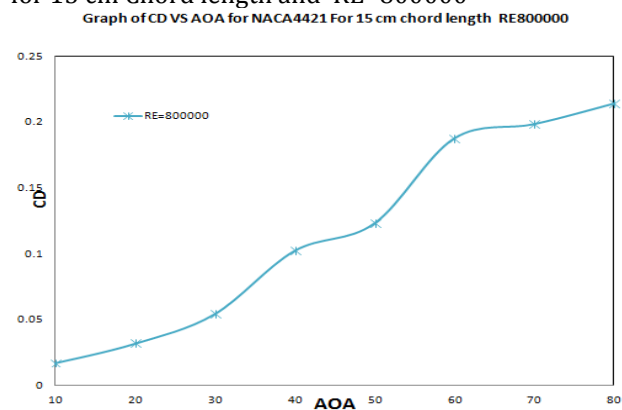

Fig -22: Graph Of CD Vs AOA For Comparison Of NACA4421 for 15 cm Chord length and RE=800000

From fig 21 to fig 22 Comparison has been between four blade profile (NACA0021, NACA0015, NACA0009, NACA4421) for lift coefficient Vs angle of attack for same Reynolds number (like Ranging from 10000, 40000, 160000, 360000, and 800000) and same chord length for 10 cm, and it has been observed that among all Reynolds number NACA4421 shows highest lift coefficient 0.74 at angle of attack 30^0 at RE=800000. And four blade profile (NACA0021 NACA0015 NACA009 NACA4421) for drag coefficient Vs angle of attack for same Reynolds number (like Ranging from 10000, 40000, 160000, 360000, and 800000) and same chord length for 15 cm, and it has been observed that among all Reynolds number NACA4421 shows highest drag coefficient =0.21 at angle of attack 80^0 and for RE=800000 for 15 cm chord length
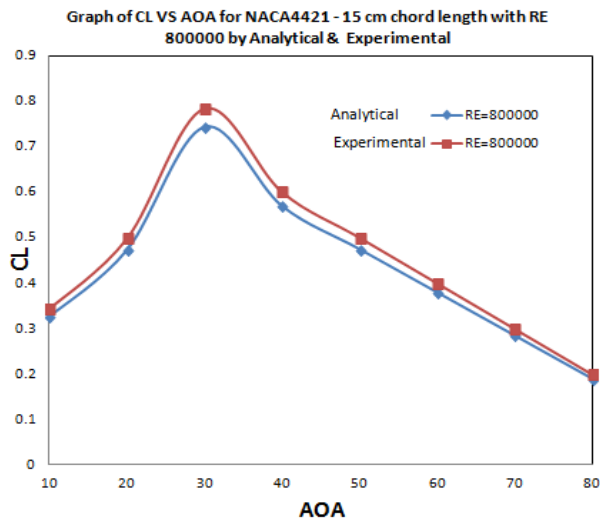
Fig -23:Graph Of CL Vs AOA For Comparison Of NACA4421 for 15 cm Chord length for RE=800000 by Analytical & Experimental
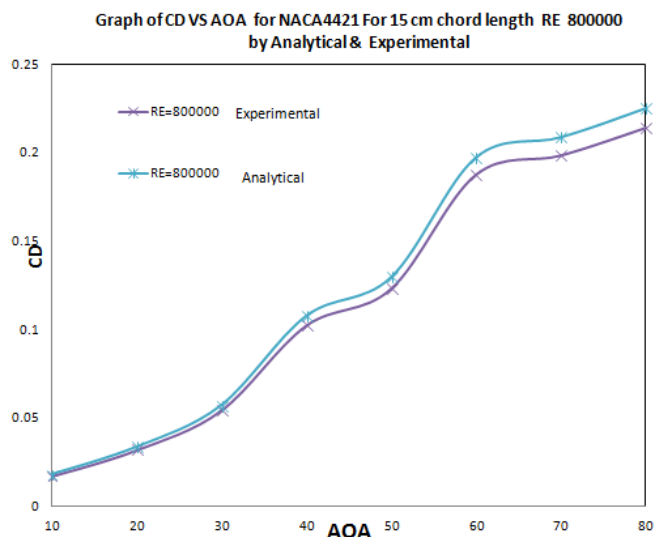

Fig -24:Graph Of CD Vs AOA For Comparison Of NACA4421 for 15 cm Chord length for RE=800000 by Analytical & Experimental

From fig 23 to fig 24 Comparison has been between four blade profile (NACA0021, NACA0015, NACA0009, NACA4421) for lift coefficient Vs angle of attack for same Reynolds number (like Ranging from 10000, 40000, 160000, 360000, and 800000) and same chord length for 10 cm, and it has been observed that among all Reynolds number NACA4421 shows highest lift coefficient 0.74(experimentally) & 0.78(analytically) at angle of attack 30^0 at RE=800000. And four blade profile (NACA0021 NACA0015 NACA009 NACA4421) for drag coefficient Vs angle of attack for same Reynolds number (like Ranging from 10000, 40000, 160000, 360000, and 800000) and same chord length for 15 cm, and it has been observed that among all Reynolds number NACA4421 shows highest drag

coefficient 0.21(experimentally) & 0.22(Analytically) at angle of attack 80^0 and for RE=800000 for 15 cm chord length.

8. CONCLUSIONS

1. CFD analysis is carried out for four different blade profile (NACA0021 NACA0015 NACA0009 NACA4421) five different Reynolds number (Range from 10000, 40,000, 160000 360000, 800000) and eight different angles of attack 10° to 80° for three different chord length (i.e. 5 cm, 10 cm ,15 cm.)

2. So it observed that if Reynolds number increases lift coefficient increases with respect to increase in angle of attack, this happens due to   increase in Reynolds number flow gets accelerated on upper surface of aerofoil and gets decelerated lower surface of aerofoil, so because of that pressure difference increases so lift coefficient increases.

3. It is also observed that for same chord length and same Reynolds number lift coefficient increase with increase in angle of attack and it reaches maximum value suddenly decreases, This phenomena called as stalling.

4. It has been seen that drag coefficient increase with increasing angle of attack and it reaches maximum value at angle of attack 80^0, in every case.

5. Comparison has been done between lift coefficient VS angle of attack and Drag coefficient VS angle of attack for same Reynolds number and three different chord lengths for four different blade profile NACA0021 NACA0015 NACA0009 NACA4421. So from all graphs it is observed that if we increase the chord length lift and drag coefficient increases. This happens due to if we increase the chord length Surface area around aerofoil increases, because of that lift increase.

6. After all comparisons between NACA0021 NACA0015 NACA0009 NACA4421 it has been found that NACA4421 with chord length 15 cm and Reynolds number RE=800000 shows highest lift coefficient 0.78(at angle of attack 30^0.

7. After CFD analysis NACA4421 with chord length 15 cm shows highest lift coefficient 0.78 (Analytically) & 0.74(experimentally) at angle of attack 30^0 and RE=800000 among all chord length and all Reynolds number and all blade profile used.

8. So NACA4421 with chord length 15 cm shows highest Drag coefficient 0.22 (Analytically) & 0.21(experimentally) at angle of attack 80^0 and RE=800000 among all chord length and all Reynolds number and all blade profile used.

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Prof. V.G. Bhamare received B.E. and M.E. (Thermal) degrees in mechanical engineering. He is pursuing Ph.D. degree in mechanical engineering from Nagpur University, Maharashtra, India.

He has been working as HOD and an Assistant Professor with the Mechanical Engineering Department, SNDCOE&RC, Yeola, Maharashtra. He has 11 years of teaching and 4 years of industrial experience. He has published 8 national papers and 1 International paper.

BIOGRAPHIES

Parashar S. S.   borned in Manmad, situated in Maharashtra India in year 1992. She completed her high school education from St. Xavier's English Medium School in Manmad. She is graduated in Mechanical Engineering from S.N.D.C.O. Engineering and Research Center Yeola. Now persuing Master degree in Design branch from S.N.D.C.O. Engineering and Research Center yeola.

As her interest is towards design and development, she had shown her Skill in design field. She had done two project in Design field. The First project is ""Vibratory Super Finishing unit". This project was showcased in DIPEX- 2014.

Snehal has also Presented Paper on the topic"Stress Analysis & Optimazation of forged steel single cylinder engine connecting rod subjected to dynamic loading" in year 2015, are organized by International Journal of Engineering, Education & Technology, India.