Int. J. Mech. Eng. & Rob. Res. 2014

International Journal of Mechanical Engineering and Robotics Research

ISSN 2278 – 0149 www.ijmerr.com
Vol. 3, No. 4, October 2014

Research Paper

EFFECT OF AEROFOIL THICKNESS OVER PRESSURE DISTRIBUTION IN WIND TURBINE BLADES

S Prathiban[1]*, M Manickam[1], P Renuka Devi[1], and T T M Kannan[2]

*Corresponding Author: S Prathiban, ✉ srprathiban88@gmail.com

Renewable energy is the energy extracted from the natural resources like wind, rain, etc. Since wind power is growing at a rate of approximately 30% annually and now it has the capacity to generate 430 TWh annually, which is about 2.5% of worldwide electricity usage. Although a variable source of power, the intermittency of wind seldom creates problems results wind power to supply up to 20% of total electricity demand. Thus, much research is focusing to utilize this vast adequate wind resource because the evolutions of serious problems like air pollution which leads to global warming due to the consumption of more conventional fossil fuels, coal and nuclear energy resources. The study on the effect of aerofoil thickness in wind turbine blades is one of the effective methods to improve its performance. In this paper numerical simulation was carried out to study the effect of aerofoil shape using commercially available CFD software. The main scope is to increase the resultant force produced by each blade which is resolved as Lift and Drag. Lift is an aerodynamic force on the body in the direction normal to the flow direction, while Drag is an aerodynamic force on the body parallel to the flow direction. For a windmill to operate efficiently the lift force should be high and drag force should be low. In this work NACA 4415 is chosen as a wind turbine blade cross section. From this basic configuration thickness of the cross section is changed and the effect of thickness is studied through lift curve slope.

Keywords: Wind turbine blades, Aerofoil thickness, Numerical simulation, CFD software

INTRODUCTION

Wind turbine is a device which converts kinetic energy from air to mechanical energy. Further mechanical energy converted into electrical energy. This energy conversion is the result of several phenomena. The wind is characterized by its speed and direction, which are affected by several factors, e.g., geographic location, climate characteristics, height above ground, and surface topography. Although the

[1] Department of Mechanical Engineering, Ponnaiyah Ramajeyam College of Engineering and Technology, Thanjavur, India.

[2] Department of Mechanical Engineering, PRIST University, Thanjavur, India.

performance of wind turbines is dominated by various factors, the performance of airfoils is the most influential. The low Reynolds number airfoils designed for small aircraft were widely used in the early stage development of modern horizontal axis wind turbines. Aerofoil designed for aircraft are not always suitable, however, because the range of operational Reynolds number is wide and because the inflow wind is fluctuated. Atmospheric turbulence causes important fluctuating aerodynamic forces on wind turbines. Turbulence is an important source of aerodynamic forces on wind turbine rotors. Turbulence is an irregular motion of fluid that appears when fluids flow past soil surfaces or when streams of fluid flow past or over each other. However, the turbine geometry which affect the aerodynamic performance of the wind turbine as well as its power performance. The development of aerofoil series tailored for a specific wind turbine is not effective, it is conjectured that by varying the thickness of the airfoil cross section it become effective. In this research, the thickness of the cross section of the wind turbine blade (aerofoil) is changed for the specific wind turbine blade and their effectiveness was verified by simulating CFD analysis. The scope of this work was to provide a preliminary evaluation of the effect of thickness on aerofoil performance. This blade-root aerofoil was designed to have a high maximum lift coefficient which is largely insensitive to surface-roughness induced premature transition. The results of three considered wind-turbine aerofoil exhibit effects of aerofoil thickness and maximum lift coefficient on the sensitivity of the maximum lift coefficient to its performance. Because the design specifications for these aerofoil are not consistent, however, the results cannot be used to conclusively determine these effects. Accordingly, a matrix of three natural-laminar-flow aerofoil has been designed and analyzed numerically to quantify these effects.

The wing extends in the y direction (the span direction). The free stream velocity $V\infty$ is parallel to the XZ Plane. Any Section of the wing cut by a plane to the XZ plane is called Aerofoil.

Figure 1: Aerofoil Section

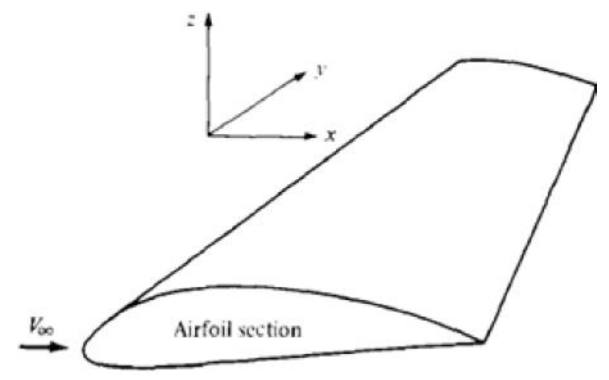
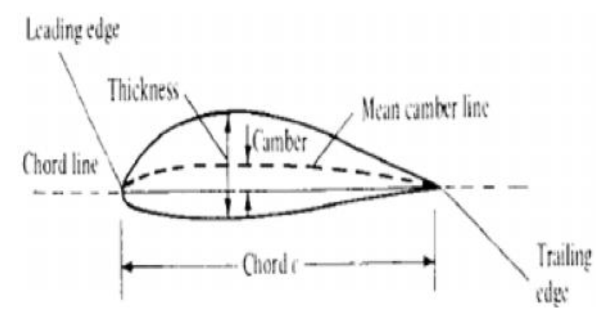


Figure 2: Nomenclature of Aerofoil



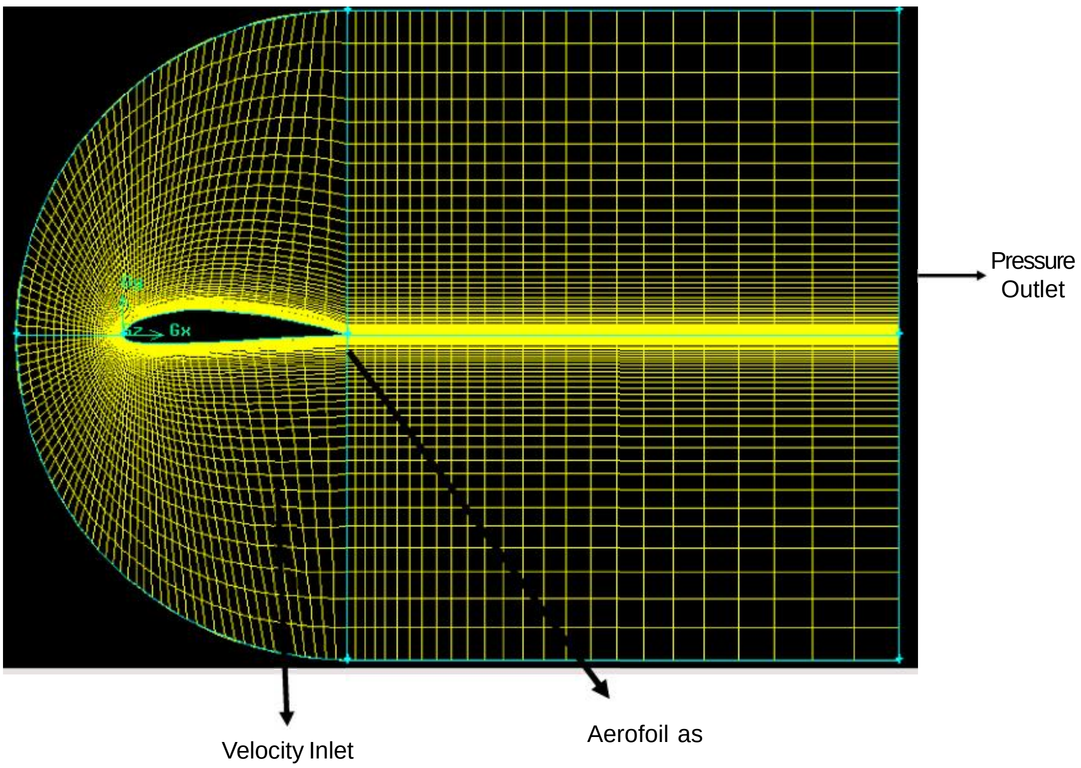
LITERATURE REVIEW

Peter Fuglsang and Ioannis Antoniou (2003), studied the two aerofoil cross sections for the wind turbine blades by Numerically and Experimentally. Two-dimensional wind tunnel testing was carried out for the Risø-B1-18 and Risø-B1-24 aerofoil in the VELUX wind tunnel at Re = 1.6×10^6. The measurements comprised both static and dynamic inflow.

Static inflow covered inflow angles from 5^0 to 30^0. Dynamic inflow was obtained by pitching the aerofoil in a harmonic motion around various mean angles of attack. The test matrix involved smooth flow, various kinds of leading edge roughness, stall strips, vortex generators and Gurney flaps. Franck Bertagnolio made a Numerical Study of the Static and Pitching RISØ-B1-18 Aerofoil. The objective of this report is the better understanding of the physics of the aero-elastic motion of wind turbine blades in order to improve the numerical models used for their design. In this study, the case of the RISØ-B1-18 aerofoil which was equipped and measured in an open jet wind tunnel is studied. Two and three-dimensional Navier-Stokes calculations using the k–€ SST and Detached Eddy Simulation turbulence models are conducted. An engineering semi-empirical dynamic stall model is also used for performing calculations. Computational results are compared to the experimental results that are available both for the static aerofoil and in the case of pitching motions.

Mac Gaunaa (2006) studied the unsteady 2D Potential-flow Forces on a Thin Variable Geometry Aerofoil Undergoing Arbitrary Motion. In this report analytical expressions for the unsteady 2D force distribution on a variable geometry aerofoil undergoing arbitrary motion are derived under the assumption of incompressible, irrotational, inviscid flow. The aerofoil is represented by its camber line as in classic thin-aerofoil theory, and the deflection of the aerofoil is given by superposition of chord wise deflection mode shapes. Jeppe Johansen and Niels Sorensen (2006) made a study on Profile Catalogue for Aerofoil Sections Based on 3D Computations This report is a continuation of the Wind Turbine Aerofoil Catalogue which objective was, firstly to provide a database of aerodynamic characteristics for a wide range of aerofoil profiles aimed at wind turbine applications, and secondly to test the two-dimensional Navier-Stokes solver EllipSys2D by comparing its results with experimental data. In the present work, the original two-dimensional results are compared with three-dimensional calculations as it was surmised that the two-dimensional assumption might be in some cases responsible for discrepancies between the numerical flow solution and the actual fluid flow, and thereby the incorrect prediction of aerofoil characteristics. In addition, other features of the flow solver, such as transition and turbulence modeling, and their influence onto the numerical results are investigated. Conclusions are drawn regarding the evaluation of aerofoil aerodynamic characteristics, as well as the use of the Navier-Stokes solver for fluid flow calculations in general. The aim of their work is to evaluate the prediction capabilities of the computational code EllipSys3D compared to its two-dimensional version EllipSys2D on one side, and the experimental results (when available) on the other side. In order to perform this study, the flow around three-dimensional blade sections for chosen aerofoil profiles will be computed. Several aspects of the numerical code are investigated. The derived aerofoil characteristics show that the maximum lift coefficient at the tip is low and that the maximum lift coefficient is high at the root compared to 2D aerofoil characteristics. The use of the derived characteristics in aeroelastic calculations shows good agreement with measurements for power and flap moments. Furthermore, a fatigue analysis shows a reduction in the loads of up to 15% from load calculations with the derived aerofoil characteristics compared with a commonly used set of aerofoil characteristics. The numerical optimisation is based on both the 3D CFD computations and measurements on a 41-m rotor with LM 19.1 and LM 19.0 blades, respectively. The method requires measurements or CFD calculations of power and loads from a turbine and is promising since a set of lift and drag curves is derived that can be used to calculate mean values of power and loads. The maximum lift at the tip is low and at the root it is high compared to 2D aerofoil characteristics. In particular the power curves were well calculated by use of the optimised aerofoil characteristics. In the quasi-3D CFD computations, the aerofoil characteristics are derived directly. This Navier-Stokes model takes into account rotational and 3D effects. The model enables the study of the rotational effect of a rotor blade at computing costs similar to what is typical for 2D aerofoil calculations. The depicted results show that the model is capable of determining the correct qualitative behavior for aerofoils subject to rotation. The method shows that lift is high at the root compared to 2D aerofoil characteristics. The different systematic methods show the importance of rotational and 3D effects on rotors. Furthermore, the methods show high maximum lift coefficients at the inboard part of the blade and low maximum lift coefficients

Figure 3: Model of Computational Domain and Their Corresponding Boundary Conditions



at the outboard part of the blade compared to 2D wind tunnel measurements.

RESULTS AND DISCUSSION

Numerical Simulation on Aerofoils

The free-stream air is assumed to be approaching the aerofoil with free-stream velocity and pressure with angle of attack ~. Convergence criteria are set such that the normalized residuals for each parameter are less than 10E-6. From the simulated flow field, Normal and Axial Force magnitudes are determined. From that it's Coefficients C_n and

Table 1: C_l and C_d for NACA 4415

Case I-4415					
AOA	Cn	Ca	Cl	Cd	Cl/Cd
-4	-0.16917	0.021334	-0.16689	0.038532	-4.33112
-2	0.016918	0.026797	0.017843	0.026189	0.681307
0	0.206814	0.025335	0.206814	0.025335	8.163281
4	0.586195	-0.00029	0.584787	0.040602	14.40306
8	0.95623	-0.05346	0.954364	0.080142	11.90845
12	1.272314	-0.11938	1.269331	0.147758	8.590628
14	1.3741	-0.14736	1.368933	0.189442	7.226129
16	1.432116	-0.16288	1.421534	0.238174	5.96846
18	1.419043	-0.15584	1.397747	0.290296	4.814908
22	1.335012	-0.08504	1.269658	0.421257	3.013978
25	1.391531	-0.04124	1.278584	0.55071	2.3217

Figure 4: Variation of C_l, C_d, C_l/C_d, C_p for NACA 4415

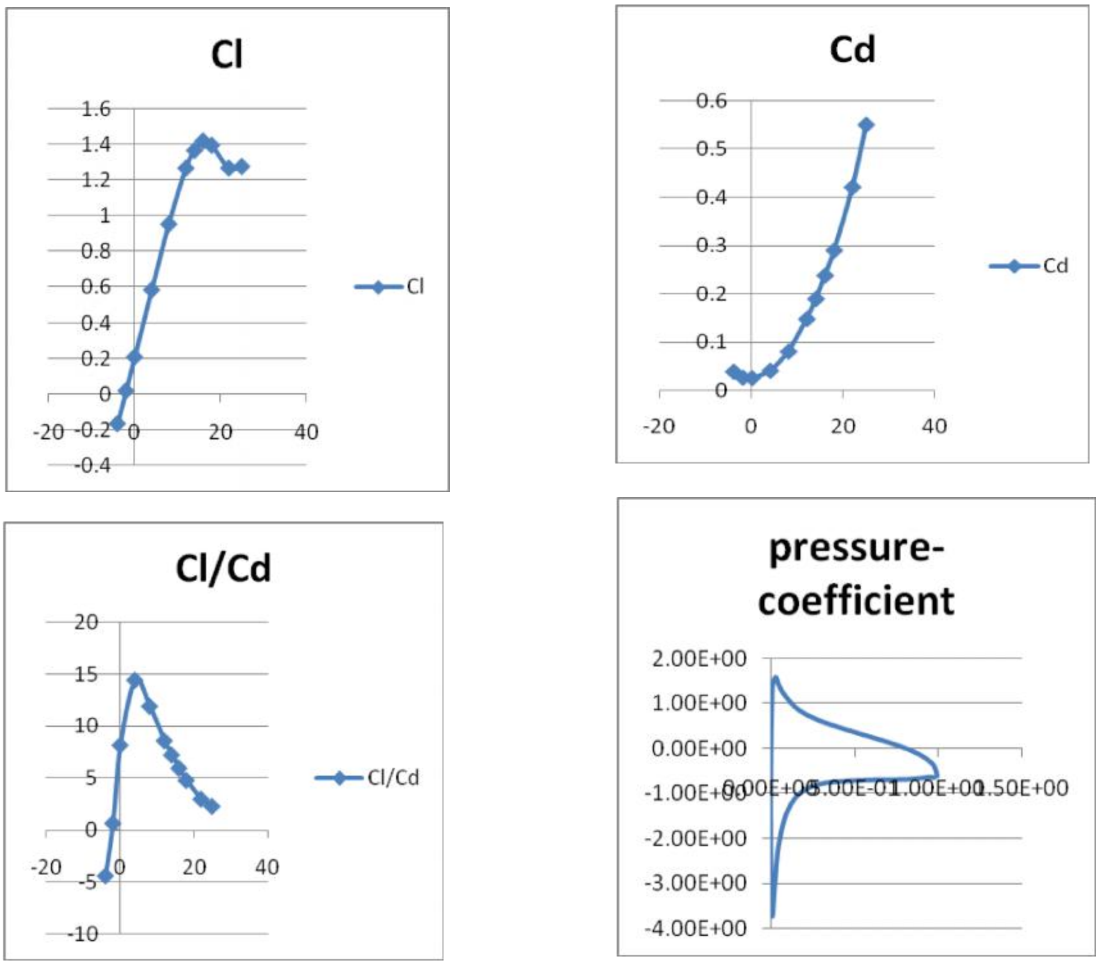


Table 2: C_l and C_d for NACA 23012

Case II-23012					
AOA	Cn	Ca	Cl	Cd	Cl/Cd
-4	-0.23658	0.03208	-0.23376	0.048504	-4.8194
-2	-0.0612	0.036718	-0.05988	0.038831	-1.54205
0	0.121566	0.035833	0.121566	0.035833	3.392537
4	0.496026	0.014128	0.493832	0.048695	10.14141
8	0.85739	-0.03484	0.853895	0.084825	10.06659
12	1.171403	-0.10239	1.167093	0.143395	8.139008
14	1.299714	-0.13751	1.294373	0.181004	7.151078
16	1.338008	-0.15403	1.328632	0.220742	6.018941
18	1.390634	-0.16781	1.374427	0.270133	5.08797
22	1.359629	-0.13437	1.310961	0.38474	3.407393
25	1.375847	-0.09241	1.285995	0.497706	2.583845

Table 3: C_l and C_d for NACA 63-413

Case III-63413					
AOA	Cn	Ca	Cl	Cd	Cl/Cd
-4	-0.09015	0.035659	-0.08744	0.041861	-2.08891
-2	0.108288	0.038986	0.109583	0.035183	3.114642
0	0.307543	0.035342	0.307543	0.035342	8.702028
4	0.704362	0.005583	0.702257	0.054703	12.83758
8	1.063465	-0.04767	1.05975	0.100799	10.5135
12	1.272041	-0.09436	1.263862	0.172742	7.31648
14	1.381505	-0.11334	1.367888	0.224243	6.100025
16	1.402129	-0.11015	1.378174	0.280597	4.911587
18	1.360302	-0.07956	1.318309	0.34469	3.824619
22	1.402425	-0.03833	1.314664	0.489818	2.683985
25	1.539957	-0.01397	1.401579	0.638152	2.196309

Figure 5: Variation of C_l, C_d, C_l/C_d, C_p for NACA 23012

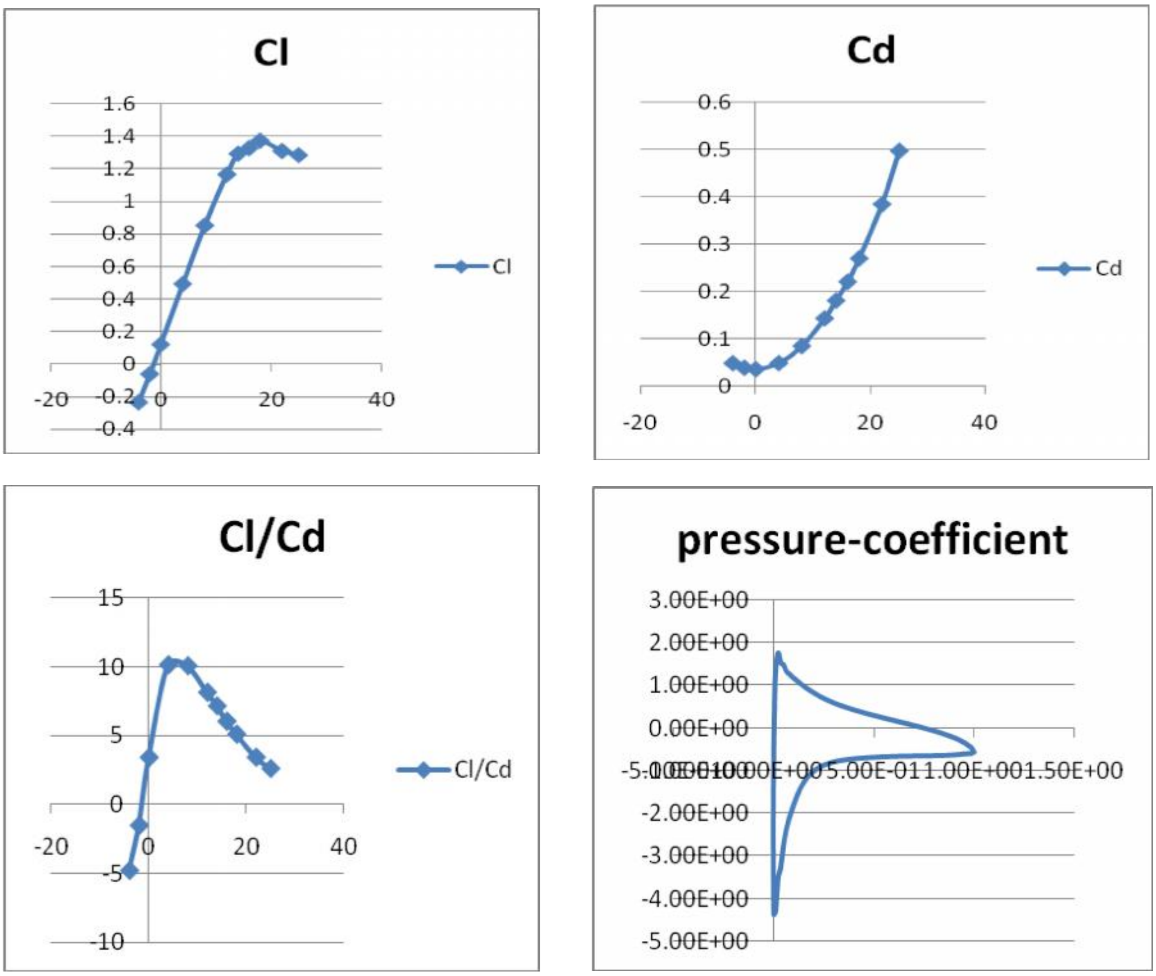


Figure 6: Variation of C_l, C_d, C_l/C_d, C_p for NACA 63413

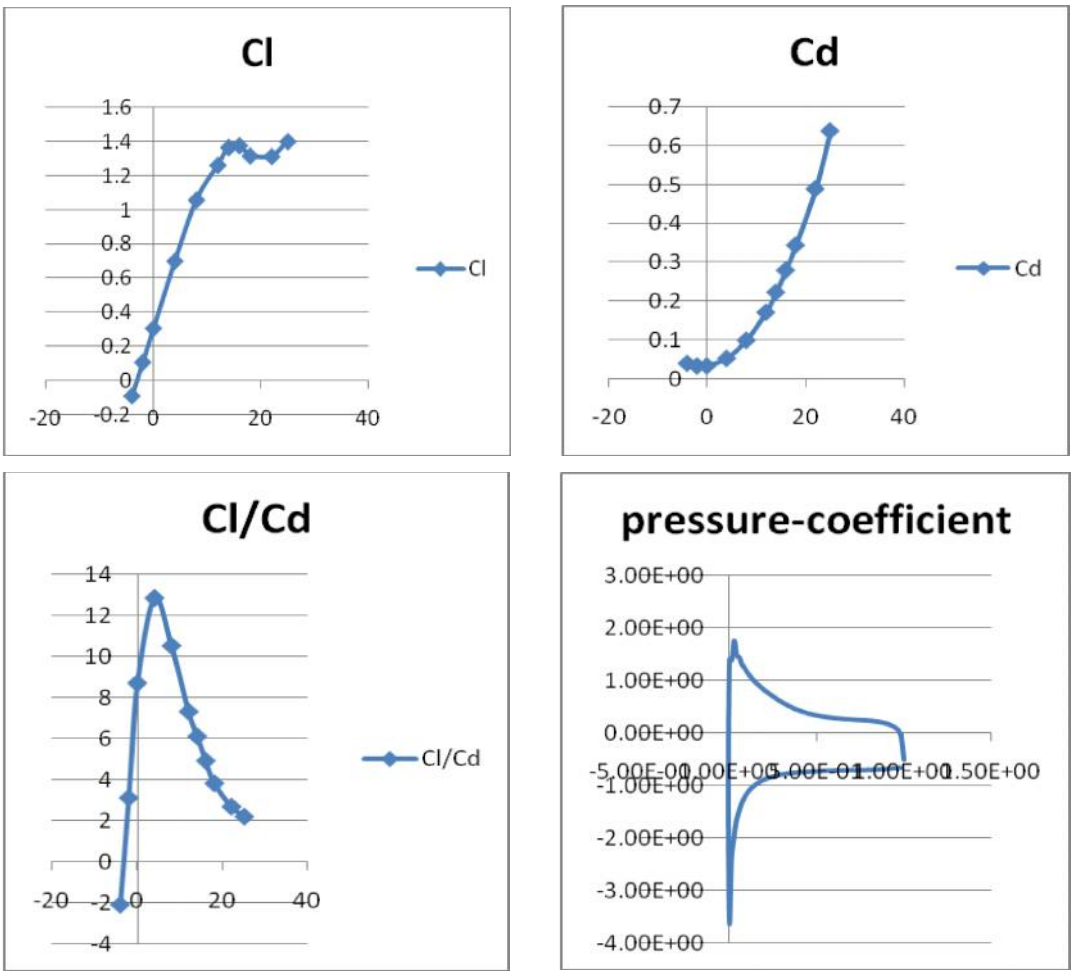
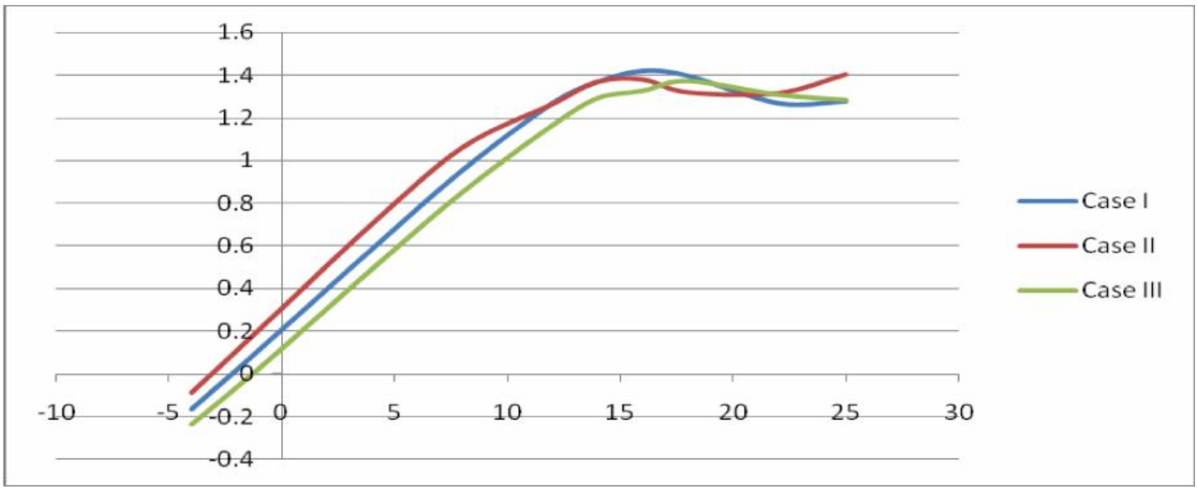


Figure 7: Comparison Graph for All Cases



C_a is calculated. By Using the well known relation derived in chapter 2, the value of Lift force (L) and Dreg force (D) and from that it's Coefficients C_l and C_d is found. Figure 3 a-c Represents variation of C_l with angle of attack ~=for the three considered cross sections is shown. And its numerical values are tabulated from Tables 1 to 3.

Similar kind of C-Grid is used for the three considered sections having fine mesh near the surface because we need to calculate the properties of the flow near the Surface of the Aerofoil. Flow is carried out for Different angle of attack (~) ranging from –4 to 25 deg and the corresponding values of C_n, C_a, C_l, and C_d are calculated and their values are tabulated and graphically shown below.

CONCLUSION

Aerofoil of various thickness has been studied and the parameters like coefficient of lift, drag were plotted with various angle of attack. Also the aerodynamic ratio L/D were considered and discussed for the different cases of aerofoil. From the above data it is very clear that Aerodynamic efficiency of Case I (NACA 4415) is very high approximately 14 when compared to other cases. Also the value of maximum coefficient of lift for the case I is larger around 1.4.but the stall angle for case I is around 14 degrees. This is small when compared to other cases (for case II it is around 18 degrees and for case III it s around 25 degrees). So Based on the flow separation point of view, Case III is better but based on the magnitude of force case I provides a Optimum benefit. Since in the wind turbine blade designs, every cross section is twisted to around 40 degrees. Thus optimum performance at higher angle of attack is required, so based on that point modern low speed aerofoil series case III is the optimum choice.

ACKNOWLEDGMENT

We express sincere thanks to our Beloved Principal Prof.M.Abdul Gani Khan,Ponnaiyah ramajayam college of Engineering and technology,Thajavur for given valuable suggestions and Motivate this Efforts.

REFERENCES

1. Chalothorn Thumthae and Tawit Chitsomboon (2006), "Optimal Pitch for Untwisted Blade Horizontal Axis Wind Turbine", The 2nd Joint International Conference on Sustainable Energy and Environment.
2. Chiristian Bak (2005), "Know-Blade Task-3.3 Report for Rotor Blade Computations with 3D Vortex Generators", Risø National Laboratory, Roskilde, Denmark.
3. Danmei Hu, Ouyang Hua and Zhaohui Du (2006), "A Study on Stall-Delay for Horizontal Axis Wind Turbine", *Journal of Renewable Energy*, Vol. 31, pp. 821-836.
4. Franck Bertagnolio (2004), "Numerical Study of the Static and Pitching RISO-B1-18 Airfoil", Riso National Laboratory, Roskilde, Denmark.
5. Frederik Zahle (2005), "Operation and Control of Large Wind Turbines and Wind Farms", Riso National Laboratory, Roskilde, Denmark.
6. Jeppe Johansen and Niels N Sorensen (2006), "Aerodynamic Investigation of Winglets on Wind Turbine Blades Using

CFD", Riso National Laboratory, Roskilde, Denmark.

7. Mac Gaunaa (2006), "Unsteady 2D Potential Flow Forces on a Thin Variable Geometry Aerofoil Undergoing Arbitrary Motion", Riso National Laboratory, Roskilde, Denmark.

8. Ole Sangill (2005), "Profile Catalogue for Aerofoil Sections Based on 3D Computations", Riso National Laboratory, Roskilde, Denmark.

9. Peter Fuglsang and Ioannis Antoniou (2003), "Wind Tunnel Tests of Risø-B1-18 anRisø-B1-24", Pitney Bowes Management Services Danmark A/S.

10. Sorensen N N, Johansen J and Conway S (2005), "Know-Blade Task-3.2 Report Tip Shape Study Revised Version", Riso National Laboratory, Roskilde, Denmark.