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Research Article

The Effect of Icing on the Performance of NACA 63415 Wind Turbine Blade

P. Satyannarayana Murthy[#*], T. Naveen Kumar[^] and A. Vinutha[#]

[#]Sanketika Institute of Technology & Management, Vizag, India
[^]Dept of Mechanical Engineering, Gayatri Vidya Parishad College of Engineering, Vizag, India

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Abstract

Wind turbines working in arctic environments suffer from power losses due to fall in efficiencies in the aerofoil blades when covered with ice. It is observed that icing hampers the performance of wind turbines. The performance of wind turbine is depend on the following parameters as mentioned atmospheric temperature, pressure, relative velocity of the blade and surface temperature of the blade. A two-dimensional, steady state computational fluid dynamic model is developed to investigate the effect of icing on the performance of wind turbines. In this study NACA 63415 aerofoil is taken for CFD analysis with a chord length of 1m. The aerodynamic characteristics of wind turbine blade are investigated using ANSYS Fluent CFD software. The model parameters such as maximum icing rate and maximum icing area ratio at different angle of attack are selected from the literature. An optimization study is performed to identify the maximum lift coefficient, drag coefficient and maximum lift to-drag ratio at different air flow rates of 6m/s, 12m/s and angle of attacks ±60^0. CFD analysis depicted a drop in lift and a rise in drag with actual angle of attacks because of ice accumulation.

Keywords: *Wind turbine, ice accretion, blade aerofoil 63415, CFD*

1. Introduction

Generally wind turbines are located at high altitudes at which the availability of wind is more. We know that temperature is low at high altitudes, which causes icing effect on wind turbine blades. Due to icing effect the impact falling on characteristics of aerofoil which are coefficient of lift, coefficient of drag, lift to drag ratios. So, for improving the performances of wind turbine blade we can carry out various numerical simulations with changing profile of the aerofoil blade at different flows rates. So it is always desirable for an aerofoil to possess best performance characteristics which can be achieving good lifting performance at different flow rates. The numerical simulations are carried out on dry conditions and various ice thickness rates at different flow rates.

1.1 Literature Review

The research is focused mainly on design, development and optimization of various aerofoil structures in order to improve performance of wind turbine blade. Generally wind turbines are located at high attitudes the availability of wind is more. But low temperatures at high altitudes which causes icing effect on surface of wind turbine blade. There are plenty of assumptions on which the aerodynamics and the fluid physics are based upon. One of such theory is turbulence theory for which the research continues as a never ending process. Many methodologies have been adopted to decrease the turbulence of which some are direct methods and some are indirect.

To improving the performance of NACA 63415 aerofoil had led to carry out in this thesis work. In this work considering uniform icing with various flow rates 6m/s, 12m/s. A goal driven optimization study is performed to identify the maximum lift coefficient and drag coefficient and maximum lift to-drag ratio at different air flow rates and angle of attack. CFD analysis depicted a drop in lift and a rise in drag with actual angle of attacks because of ice accumulation.

L. Wright, M.G. Droubi, S.Z. Islam: A two-dimensional, steady state computational fluid dynamics model is created to investigate the Effect of icing on performance of wind turbine. Using a NACA 7715 aerofoil with a chord length of 1m, the aerodynamic characteristics of wind turbine blade is investigated using ANSYS Fluent. A goal driven optimization study was performed to identify the maximum lift-to-drag ratio of the wind turbine blade at different air flow rate and angle of attack. He can be concluded from this study that the ice formations documented in the report published by Li *et al* would

*Corresponding author: **P. Satyannarayana Murthy**

have had a detrimental impact of the NACA 7715's lift capabilities. The ice thicknesses of up to 3cm caused a 60% fall in lift coefficient. The study has shown that only a thin coating of ice on the surface of an aerofoil can alter the aerodynamic properties.

Yan li, *et.al* Has carried out investing Icing on the blade surfaces of wind turbines is a serious problem in cold regions, which greatly affects the performance of wind turbines. Ha can carried out a wind tunnel tests on the wind turbine blades with the NACA7715 aerofoil at The chord of the blade is 0.22 m, and the height of blade is 0.2 m. The icing area and icing rate depend on the angles of attack and wind speeds. The maximum icing rate is 6.6% and the maximum icing area ratio of icing area against aerofoil area is 21.8% at -80 degrees angle of attack.

Li yan, *et.al* carried out analysis on SB-VAWT that is NACA 0015 at a flow rates of 4m/s, 6m/s, 8m/s and humidity of air is 0.5L/min, 1L/min and at a temperature of 0^0C to -6^0C and at an angle of attack is 0^0, 15^0, 30^0, 180^0. Based on his conclusions Icing on blade aerofoil makes drag force increases and lift to drag ratios are decreases, icing on the symmetrical blade aerofoil at the angle of 0°and 180°can change the aerofoil to dissymmetrical shape, which causes the pressure field changed and leads to the increase of drag force and decrease of the aerodynamics performance.

Y.li, *et. al* has done an wind tunnel experiment on NACA0018, NACA7715 profile wind turbine blades at a temperature of -15^0C and zero angle of attack with a flow velocity of 6m/s. He concluded that the icing on blade surface mainly depend on aerofoil type and for symmetrical aerofoil's the icing distribution on leading edge, for unsymmetrical aerofoil's the icing distribution on both leading edge and trailing edge.

1.2 Objectives of work

The objective of this study focusing on the improving performances of aerofoil in dry condition, icing condition with various thickness by changing the aerofoil profile. The analysis simulations are carried out at various flow velocities and various angle of attacks for achieving aerodynamic performance characteristics of aerofoil which are lift, drag coefficients and L/D ratios. Study the methods and techniques of CFD simulation. Visualizing the flow vectors over aerofoil at various flow rates. Understanding the changes in flow parameters and boundary conditions. Plotting of results ie pressure contours and velocity contours. Optimizing aerofoil design requirements

2. Modeling

The modeling of NACA 63415 aerofoil profile is done by using CATIA V5 Wireframe and surface design module. The CFD Solver chosen to carry out the analysis is ANSYS FLUENT. CFD Analysis is used to carry out the simulation works involving fluid flows and temperature flows by various methods, algorithms and numerical techniques to solve various fluid flow problems. The NACA 63415 aerofoil profile is done by importing the aerofoil coordinates from an aerofoil tool generator to MS excel and thereby running the macros in excel to import the excel point coordinates in to CATIA V5. All the coordinates are joined by spline tool.

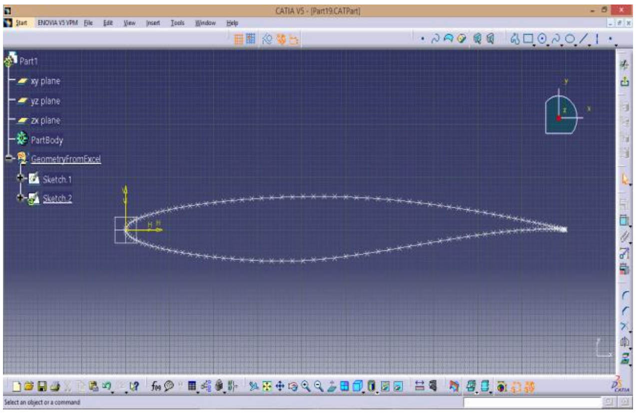

Fig1: Generated aerofoil boundary from coordinates

The generated 3D points in CATIA are projected onto a 2D XY plane. The generated points are joined separately for upper and lower cambers of the aerofoil using spline tool.

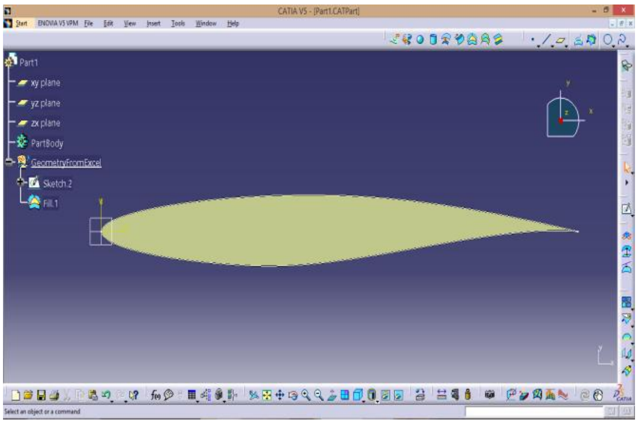

Fig 2: Generated aerofoil Surface from the Coordinates

3. CFD Analysis

ANSYS 15.0 software is used for CFD analysis and the solver chosen is Fluent. The CATIA part file is imported into ANSYS Fluent geometry by using IGES format. The air domain is created in ansys fluent geometry module. The CFD domain for analysis are shown in Fig 4. The closure part around the aerofoil was fine meshed ie 0.03m element size and outer was coarse meshed ie 0.1m element size. The inputs given for meshing are stated below.

Table 1: Mesh details

Physics Preference	CFD
Solver Preference	Fluent
Advanced size function	On: Proximity & Curvature
Relevance center	Fine
Smoothing	High
Maximum face size	0.1m
Maximum size	0.1m
Growth rate	1.2

In the mesh sizing given the element size for the frozen around the foil is taken as 0.03m and growth. The inflation parameters around the foil was taken as follows

Table 2: Mesh Inflation details

Inflation Option	Total Thickness
Total Thickness	500
Maximum layers	5

Give names for all the edges in the domain by using create named selection option. The names of the edges taken as inlet, outlet, wall, foil. Click on generate mesh to complete the discretization.

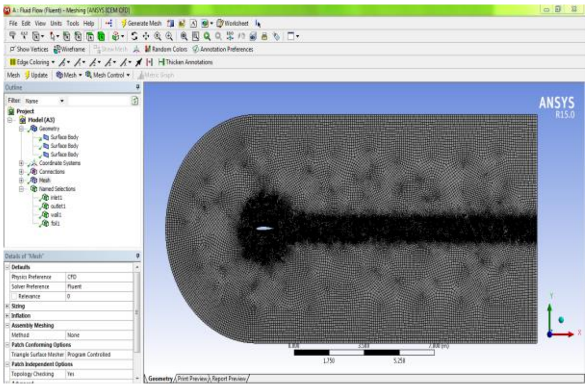

Fig 3: Meshed areas showing air domain along with region of influence.

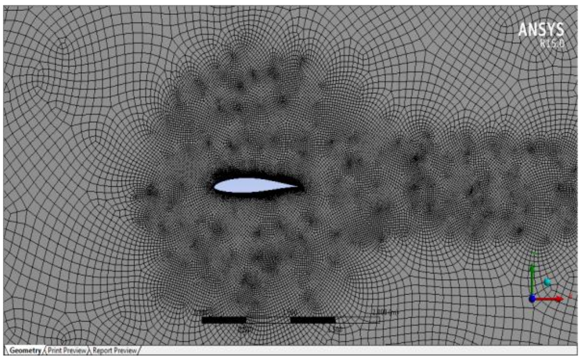

Fig 4: Fine mesh on frozen with 0.03m

The analysis requires higher number of iterations to converge the solution. Hence the iterations chosen for analysis is 4000 iterations.

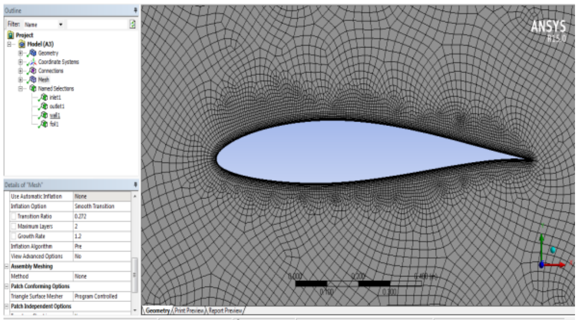

Fig 5: Mesh inflation around aerofoil

In fluent Setup module the solver inputs taken as density based and steady state analysis. The turbulence model used for this study is K-epsilon (k-ε) two equation model. The working medium is taken as air with density value taken as per environment condition.

Boundary conditions for the domain is outlet condition as Gauge pressure, inlet as velocity magnitude and direction with temperature. The upper chamber and lower cambers are taken as walls. Select type as interior for interior-surface body and upper and lower walls of outer domain as symmetry.

For creating lift and drag coefficients plot, go to monitors tab, select the zones names upper and lower and click on print and plot. Solution initialization with Standard initialization with compute from inlet. The number of iterations taken for analysis is 4000. Note the residual values, coefficient of lift and drag values and go for post processing.

After converges the solution comprises the visualizing of pressure, velocity contours along with scaled residuals. For clear visualization of results got to result tab, choose user location and plots and click on insert contour and select the variable ie pressure, velocity and any output variable and select number of contours that have to be displayed. For vector representation click on insert vector and select the variable ie pressure, velocity and any output variable. There choose the symbol and size of the arrow to visualize the vectors.

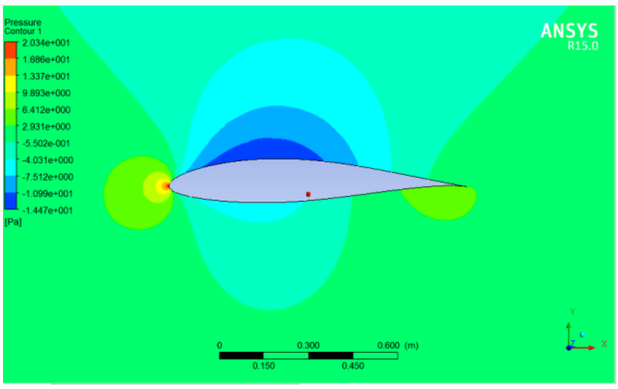

Fig 6: Pressure contour for dry condition

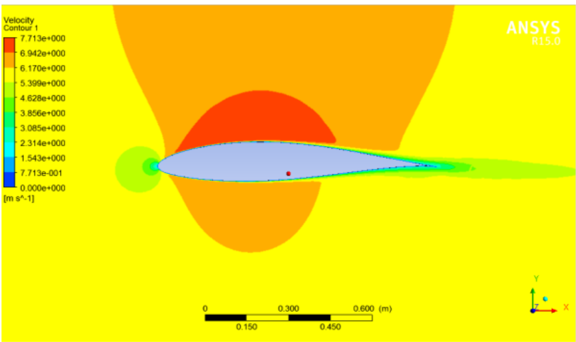

Fig 7: Velocity contour for dry condition

The Pressure and Velocity Contours show that the free stream velocity over the upper camber of the aerofoil is higher when compared with that of velocity on the lower side. The results shown in the figures 7 and 8 is well validated through Bernoulli's principle pressure is higher on the bottom side of the aerofoil and lower on the top side of the aerofoil, this causes lifting performance of the aerofoil.

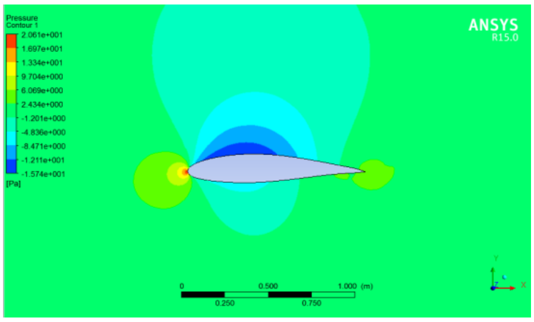

Fig 8: Pressure contour for 7 %icing condition

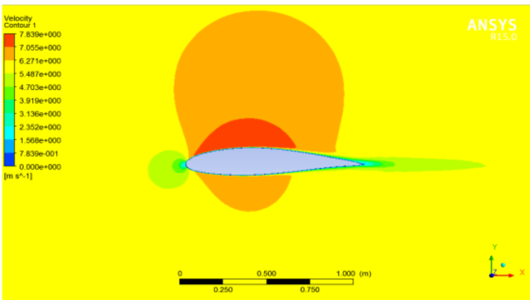

Fig 9: Velocity contour for 7 %icing condition

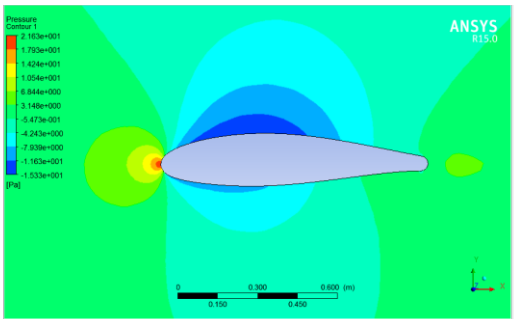

Fig: 10 Pressure contour for 14%icing condition

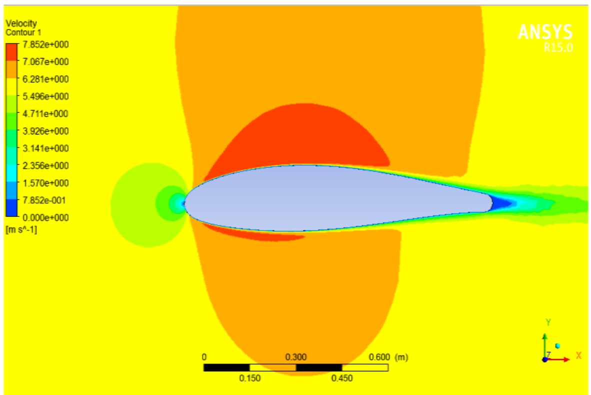

Fig 11: Velocity contour for 14%icing condition

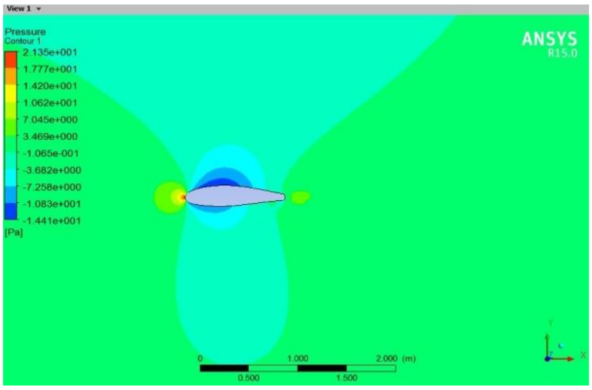

Fig 12: Pressure contour for 21%icing condition

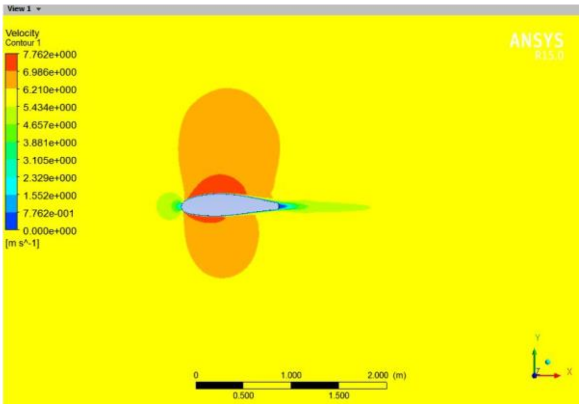

Fig 13: Velocity contour for 21%icing condition

For dry condition NACA 63415 aerofoil thickness is taken as zero percentage in the above procedure. Considering icing is 1cm thickness which is 7% of actual aerofoil perimeter. After that considering icing is 2cm thickness which is 14% of actual aerofoil perimeter. Finally the icing is 3cm thickness which is 21% of actual aerofoil perimeter. For analysis of these icing aerofoils procedure followed same as above.

Validation

The limited information is available for the NACA 63145 aerofoil, so that a secondary simulation was initiated using the NACA 2412 aerofoil between the 0^0

and 12⁰ angle of attack. During Simulation the conditions for foil NACA 63145 is used for foil NACA 2412 at different angle of attack. From the above obtained results we observed that there is a similarity between experimental and simulation values.

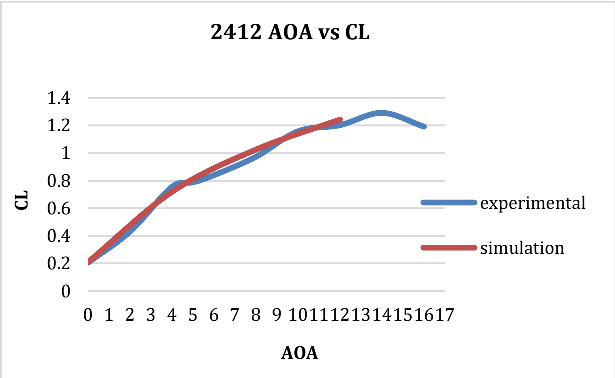

Chart 7: NACA 2412 validation

4. Results and discussions

From the results for the flow rate of 6m/s the above graph were obtained. The performance of aerofoil is resulting from coefficient of lift values. In this work the maximum coefficient of lift values for 6m/s is occurred at stall angles -4 to 20° angle of attack. In dry conditions the maximum coefficient of lift value obtained at 20° AOA is 1.1975, for icing condition with 7% thickness rate the maximum coefficient of lift value obtained at 20° AOA is0.9994, for icing condition with 14% thickness the maximum rate coefficient of lift value obtained at 40° AOA is 1.135, for icing condition with 21% thickness rate the maximum coefficient of lift value obtained at 20° AOA is 0.9186.

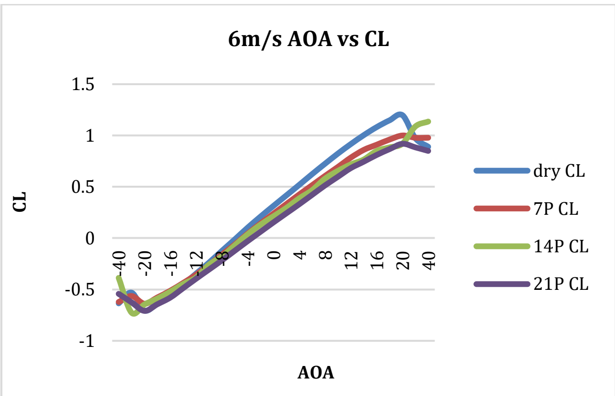

Chart 1 lift coefficient vs. angle of attack

From the results for the flow rate of 12m/s the above graph were obtained. The performance of aerofoil is resulting from coefficient of lift values. In this work the maximum coefficient of lift values for 12m/s is occurred at stall angles -4 to 20° angle of attack. In dry conditions the maximum coefficient of lift value obtained at 20° AOA is 5.0763, for icing condition with 7% thickness rate the maximum coefficient of lift value obtained at 30° AOA is 4.333, for icing condition with 14% thickness the maximum rate coefficient of lift value obtained at 30° AOA is 4.4704, for icing condition with 21% thickness rate the maximum coefficient of lift value obtained at 20° AOA is 3.6977.

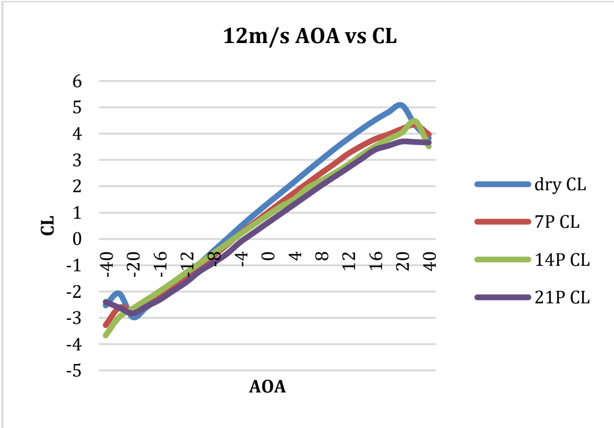

Chart 2: Lift coefficient vs. angle of attack

From the results for the flow rate of 6m/s the above graph were obtained. The performance of aerofoil is resulting from coefficient of drag values. In this work the corresponding coefficient of drag values for 6m/s are as follows at corresponding angle of attack. In dry conditions the corresponding coefficient of drag value obtained at 20° AOA is 0.21329, for icing condition with 7% thickness rate the corresponding coefficient of drag value obtained at 20° AOA is 0.176, for icing condition with 14% thickness the corresponding coefficient of drag value obtained at 40° AOA is 0.98015, for icing condition with 21% thickness rate the corresponding coefficient of drag value obtained at 20° AOA is 0.2340.

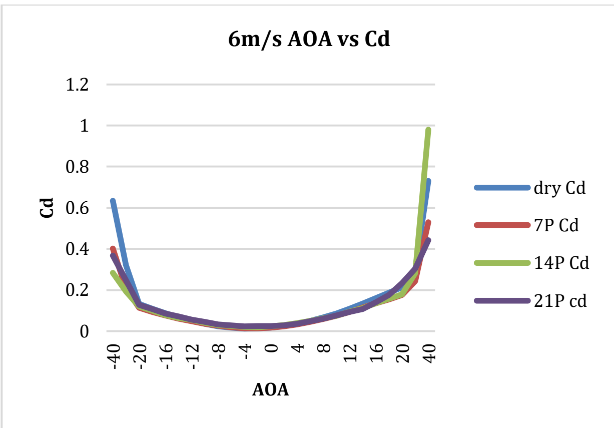

Chart 3: Drag coefficient vs. angle of attack

From the results for the flow rate of 12m/s the above graph were obtained. The performance of aerofoil is resulting from coefficient of drag values. In this work the corresponding coefficient of drag values for 12m/s are as follows at corresponding angle of attack. In dry conditions the corresponding coefficient of drag value obtained at 20° AOA is 0.86851, for icing condition with 7% thickness rate the corresponding coefficient of drag value obtained at 30° AOA is 0.990, for icing condition with 14% thickness the corresponding coefficient of drag value obtained at 30° AOA is 1.1335, for icing condition with 21% thickness rate the corresponding coefficient of drag value obtained at 20° AOA is 0.7801.

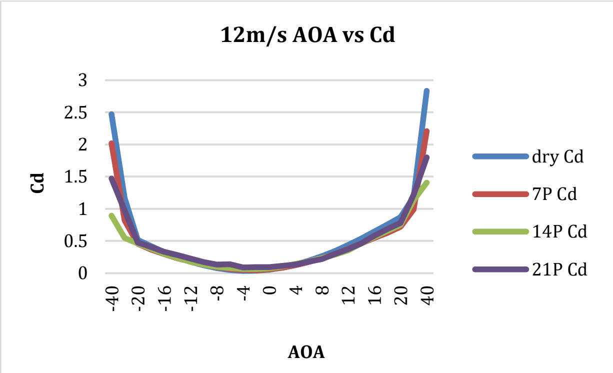

Chart 4: Drag coefficient vs. angle of attack

The Lift coefficient and Drag Coefficient values are changing in four conditions due to change in area and profile of aerofoil for these conditions the trailing edge considering as blunted edge. The lift and drag coefficients from each simulation were documented in Microsoft Excel for the two flow rates 6m/s and 12m/s. the Lift coefficient and Drag Coefficient and L/D ratios results were plotted in graphs as shown in chart 5 follow the characteristic pattern. The first stall was occurred for 6m/s aerofoil is in between -6 to 20°. At the both flow rates the aerofoil was able to produce significantly high values of lift while varying drag across the linear range. During stall angles the performances of aerofoil increases at various angles of attack for both flow rates. Due to the difference in Reynolds Number induced by the change in flow velocity, it is not expected that both set of results are identical. In dry conditions the maximum L/D ratios are 18.031, for icing condition with 8% thickness rate the maximum L/D ratios are 14.459, for icing condition with 14.9% thickness rate the maximum L/D ratios are 9.783, for icing condition with 21.8% thickness rate the maximum L/D ratios are 9.1684.

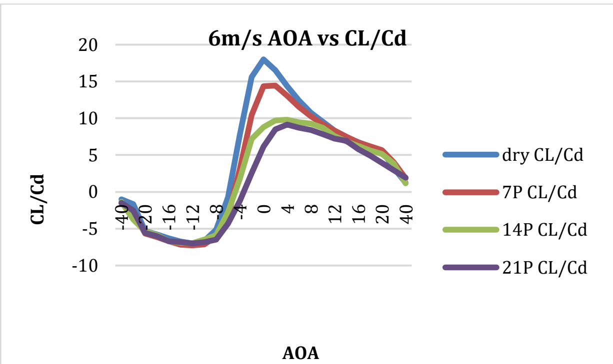

Chart 5: C_L/C_d vs. angle of attack

The first stall was occurred for 12m/s aerofoil is in between -6 to 20°. During stall angles the performances of aerofoil increases at various angles of attack for both flow rates. In dry conditions the maximum L/D ratios are 24.508, for icing condition with 7% thickness rate the maximum L/D ratios are 17.593, for icing condition with 14.9% thickness rate the maximum L/D ratios are 11.978, for icing condition with 21.8% thickness rate the maximum L/D ratios are 9.772.

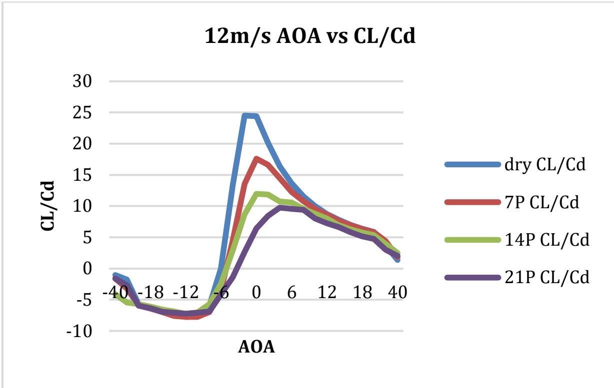

Chart 6: C_L/C_D vs. angle of attack

After getting the results which are plotted in the graphs which shows that the angle of attack trending towards ±60°. The aerofoil displaying and oscillating behavior where the lift coefficient drops and rises again. At the critical angle of +30° to -5°, flow separation caused the lift to decrease while drag increases inducing a preliminary stall on the aerofoil. This procedure is often repeated and the aerofoil can endure multiple stalls indicated by the increase in lift as the angle increases followed by another stall at ±60°. The exact number of stalls induced by this aerofoil can only be determined by increasing the number of simulated pitch angles. The NACA 2412 and NACA 7715 are a commonly used cambered aerofoil which was used as a comparison between used and concept aero foils in this study. The operating range of the NACA 7715 aerofoil is between -5° to the critical angle of 30°. The comparison between the NACA 7715 and NACA 63415 aerofoil's lift coefficients at the same angle of attack and Reynolds number. The comparison shows that the NACA 63415 aerofoil generated higher lift coefficient than the NACA 7717 cross the linear operating range, in addition to the increased lift properties the NACA 63415 aerofoil continues to produce lift for a further 10° of pitch angle before reaching stall. Therefore the concept aerofoil NACA 63415 produced a higher lift coefficient over a longer range of attack angles against its NACA 7715 counterpart.

Conclusions

- CFD model of 63415 aerofoil 2D simulations were performed at dry conditions, icing with 7%, 14% and 21% to visualize the airflow and pressure distribution.

- From the CFD analysis identifying critical places in geometry which are resulting bad aerodynamics at various angle of attacks and icing effects.
- From the CFD results it is observed that critical angle of attack is in between -6 to +30 AOA at both 6m/s and 12m/s operating conditions.
- $\frac{c_l}{c_d}$ Ratios are high from -6 AOA to +10 AOA on velocities 6m/s and 12m/s.
- For 6m/s flow velocity the calculated 7% ice thickness is caused a 20.09% fall of lift coefficient.
- For 12m/s flow velocity the calculated 7% ice thickness is caused a 20.69% fall of lift coefficient.
- For 6m/s flow velocity the calculated 14% ice thickness is caused a 21.72% fall of lift coefficient.
- For 12m/s flow velocity the calculated 14% ice thickness is caused a 33.98% fall of lift coefficient.
- For 6m/s flow velocity the calculated 21% ice thickness is caused a 45.26% fall of lift coefficient.
- For 12m/s flow velocity the calculated 21% ice thickness is caused a 49.17% fall of lift coefficient.
- Mainly In icing conditions NACA 63415 aerofoil gives highest performances, for 7% icing condition the maximum lift coefficient is 4.33, for 14% icing condition the maximum lift coefficient is 4.0387, for 21% icing condition the maximum lift coefficient is 3.6977

References

L. Wright, M.G. Droubi, S.Z. Islam (2015) Computational fluid dynamics simulation for predicting effect of icing on offshore wind turbine blade, FLUCOME2015.

Yan Li, Kotaro Tagawa, Fang Feng, Qiang Li, Qingbin He (2014) A wind tunnel experimental study of icing on wind turbine blade aerofoil. Energy Conversion and Management 85, 591-595.

Adriána Hudecz, Holger Koss, Martin O. L. Hansen (2013) Ice Accretion on Wind Turbine Blades, IWAISXV.

Li Yan, Chi Yuan, Han Yongjun, Li Shengmao, Tagawa Kotaro (2011) Numerical simulation of icing effects on static flow field around blade aerofoil for vertical axis wind turbine, research of wind energy, DOI:10.3965/j.issn.1934-6344.2011.03.041-047.

Y.Li, Q.D.Liu, J.Tang, S.L.Wang, F.Feng (2015) A Visualization Experimental Study of Icing on Blade for VAWT by Wind Tunnel Test. International Conference on Power Electronics and Energy Engineering.

Oloufemi Fakorede, Hussein Ibrahim, Adrian Ilinca and Jean Perron (2016) Experimental Investigation of Power Requirements for Wind Turbines Electro thermal Anti-icing Systems, Intech open sciences.

Erik Rindeskär Modelling of icing for wind farms in cold climate Examensarbetevid Institutionen för Geovetenskaper. Uppsala (2010).

Ozcan Yirtici, Ismail H. Tunce, Serkan Ozgen (2016) Ice Accretion Prediction on Wind Turbines and Consequent Power Losses, The Science of Making Torque from Wind (TORQUE).

S. Barber, Y. Wang, S. Jafari, N. Chokani, R. S. Abhari (2010) The Impact of Ice Formation on Wind Turbine Performance and Aerodynamics, European Wind Energy Conference.