TURBULENCE ANALYSIS ON A 5KW HORIZONTAL AXIS WIND TURBINE USING CFD

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ABSTRACT

This work is devoted to the analysis of turbulence around a 5KW horizontal axis wind turbine. Here, A two dimensional S809 airfoil with three different chord lengths which is obtained through mathematical calculations was designed using CREO. The S809 airfoil which is a 21% chord thickness airfoil utilized in horizontal-axis wind turbine. It is developed for stall-controlled turbine rotors and also was designed to achieve a sustained maximum lift with minimal sensitivity to surface roughness. Turbulent analyses of the airfoils were carried out in ANSYS FLUENT using Spalart-Allmaras turbulent model at angle of attack of five and wind velocity 8 m/s. Turbulence viscosities, effective turbulence and viscosity ratio of the airfoils were predicted and the results are compared. The results indicate that the aerodynamic behavior of the airfoil can be strongly affected by the turbulence level both qualitatively and quantitatively.
Keywords: Effective turbulence; Horizontal axis wind turbine; Turbulence viscosity; Aerodynamic behavior; S809 airfoil.

INTRODUCTION

Atmospheric turbulence is the set of seemingly random and continuously changing air motions that are superimposed on the wind's average motion. Atmospheric turbulence impacts wind energy in several ways, specifically through power performance effects, impacts on turbine loads, fatigue and wake effects, and noise propagation. In the wind energy industry, turbulence is quantified with a metric called turbulence intensity the standard deviation of the horizontal wind speed divided by the average wind speed over some time period, typically 10 minutes. If the wind fluctuates rapidly, then the turbulence intensity will be high. Conversely, steady winds have lower turbulence intensity. S Khelladi [1] reference studying the aerodynamics of the wind turbine side in a controlled environment without any uncertainties due to atmospheric phenomena gives Power performance, Aerodynamic analysis and stress tensor ad the equations for solving the incompressible flow and *e*quation of vortices also studied. A. Honrubia [2] in his studies measurement taken from June to august 2009 in the south of Spain where a complex terrain is found. The wind profile has been recorded to study the effect of the atmospheric conditions over the energy generated by a wind turbine. A cup anemometer and LIDAR equipment is used to predict the turbulence. Chia-RenChun [3] investigated the effects of ambient turbulence on the wake flows and power production of a horizontal-axis wind turbine. Based on the measured data, prediction models for the centerline velocity deficit, turbulence intensity, and wake radius and velocity profile were proposed. The experimental results showed that the power productions in the grid-generated turbulent flows were slightly higher than that in the smooth flow. Ph. Devinant [4] his paper presents wind tunnel test data for the aerodynamic properties—lift, drag, pitching moment, pressure distributions. An airfoil used on a wind turbine is subjected to incident flow turbulence levels of 0.5–16% and placed at angles of attack up to 90 degree. Victor Maldonado [5] tested using wind tunnel, the effect of free stream turbulence with large integral scale on the aerodynamic performance of an S809 airfoil based wind turbine blade at low Reynolds number. Ali M.Abdelsalam [6] work was the study of the wake characteristics in the near and far wake region of a horizontal axis wind turbine, with an exact representation of the rotor blades. The result showed good agreement with the experimental data. EimaTamahAlShammari [7] presented the grouping of turbines in large farms introduces that a wind turbine operating in the wake of another turbine and has are reduced power production because of a lower wind speed after rotor. In this study, the adaptive neuro-fuzzy inference system is designed ad adapted to estimate wake effect in a wind farm. Zifeng Yang [8] conducted an experimental study to characterize the dynamic wind loads and evolution of the turbulent vortex and flow structures and the wake of a horizontal axis wind turbine. The detailed flow field measurements were correlated with the dynamic wind load measurements to elucidate the underlying physics associated with power generation and fatigue loads acting on wind turbines operating in an atmospheric boundary wind. L.E.M Lignarolo [9] analyzed the wake of a wind turbine, which is the driving phenomenon for energy recovery in a wind farm and for the interaction between wind turbines. The stream wise development of the wake velocity, pressure and total enthalpy of the flow is determined. Hsiao Mun Lee [10] In his presentation, the volumetric velocity field were measured, for the first time, using Tomography Particle Image Velocimetry on a model of the rotating blade of a 5KW horizontal axis wind turbine to study the stall delay phenomenon at two different global tip speed ratios of 3 and 5

THE MATHEMATICAL MODEL

The mathematical model implemented in this work for the fluid dynamics design of a wind turbine is based on the BEM theory. By applying the momentum and angular momentum conservation equations, it is possible to obtain the forces acting on the blades, and so the torque and power at the rotor shaft. The wind turbine with (N) number of blades with a tip radius (R)

and chord (c) is considered. Assuming that the blades are rotating at an angular velocity of Ω, Let $U\infty$ be wind the speed and angle ϕ is the angle between the relative wind speed and the plane of rotation.

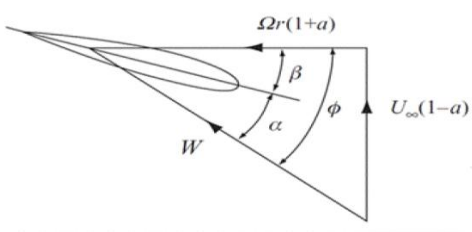


Fig 1. Velocities on blade element

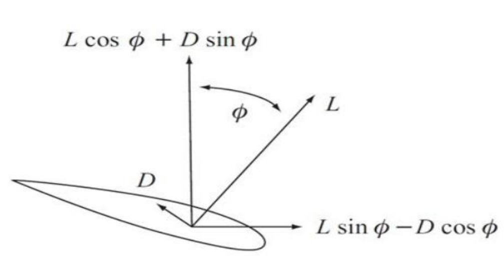


Fig 2. Forces on blade element

Velocity vector is represented in figure 1 as,

$$U_A=U\infty\,(1-a) \quad (1)$$

$$U_T=\Omega(1+a') \quad (2)$$

Where,$_A$=$Axial\ velocity\ of\ the\ wind$

U_T=$Tangential\ velocity\ of\ the\ wind$

The relative wind velocity can then be given as:

$$W= ((U\infty\,(1-a))^{2} + (\Omega r\,(1+a'))^{2})^{0.5} \quad (3)$$

The angle at which the relative wind velocity coincides with the plane of rotation is given by:

$$\phi=tan{-1}\,(U\infty\,(1-a)\,/\,\Omega(1+a')) = 1-a\,/\,(1+a')\lambda r \quad (4)$$

The angle of attack, which is defined as the angle between the chord line and the relative wind velocity and is given by:

$$\alpha = \phi-\beta \quad (5)$$

The lift and drag forces acting on the aerofoil as depicted is broken down into two components. The first component is the force in the plane of rotation and the other being the force perpendicular to the plane of rotation. The forces in the plane of rotation yield the torque on the turbine and the forces perpendicular to the plane of rotation will result in thrust.

BLADE GEOMETRY

Using a mathematical model the performance of a wind turbine is evaluated with the following characteristics: Three-blade rotor, wind velocity of 8 m/s and blade external radius of 3m. The S809 aerodynamic cross-section profiles are considered for this proposed work. The chord, twist angle and in flow angle is shown from Figs. 4 - 6. The blade specifications at various sections are given in Table 1. Using this data, the blade was designed in the designing software CREO using the calculated parameters. CREO design software supporting product design for discrete manufacturers and is developed by PTC. Airfoil with varying chord length can be designed to create wind turbine blade. Unlike other designing software, the airfoil co ordinates will be directly imported instead of typing each component.

Fig. 3. Blade Designed In CREO

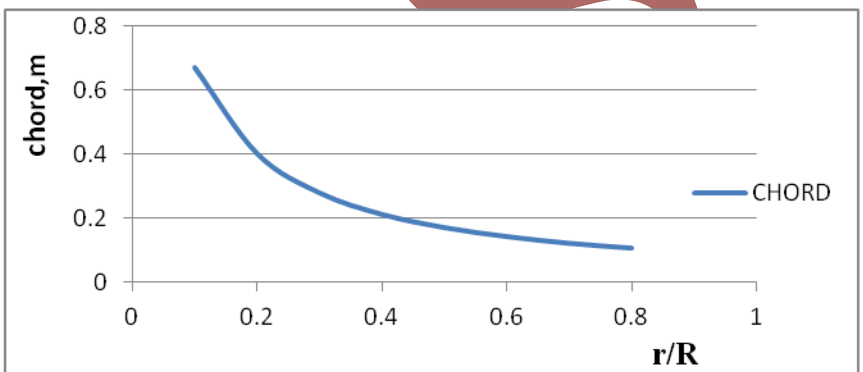


Fig.4. Chord distribution

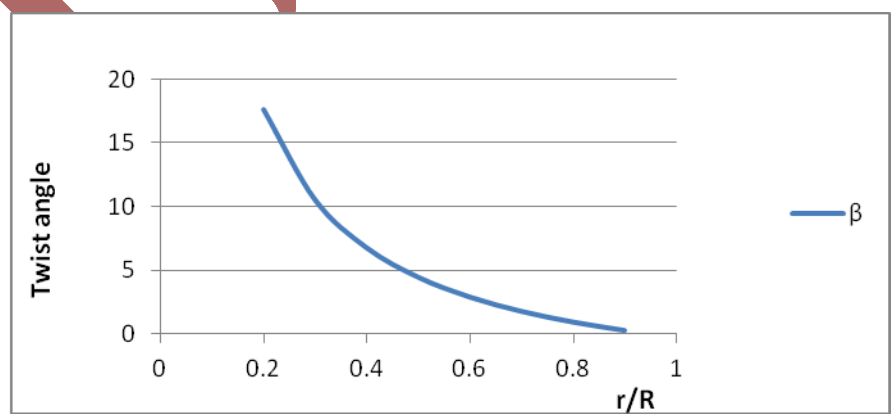


Fig.5. Twist angle distribution

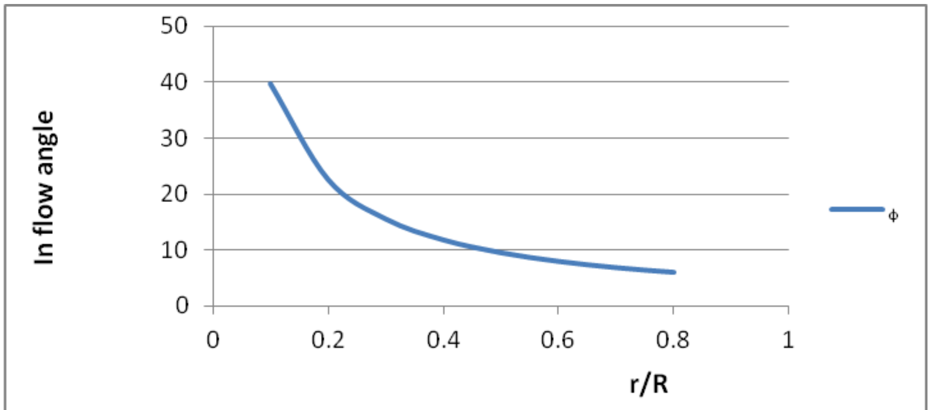


Fig.6. In flow angle distribution

Table 1: Design Data

ELEMENTS	r/R	SECTIONAL RADIUS , r	RADIUS OF BLADE,R	CHORD	ANGLE OF ATTACK	C/R	Β	ϕ
1	0.1	0.3	3	0.67	5	0.223	34.8	39.8
2	0.2	0.6	3	0.402	5	0.134	17.619	22.619
3	0.3	0.9	3	0.28	5	0.093	10.524	15.524
4	0.4	1.2	3	0.213	5	0.071	6.768	11.768
5	0.5	1.5	3	0.172	5	0.057	4.462	9.462
6	0.6	1.8	3	0.144	5	0.048	2.907	7.907
7	0.7	2.1	3	0.123	5	0.041	1.788	6.788
8	0.8	2.4	3	0.108	5	0.036	0.946	5.946
9	0.9	2.7	3	0.096	5	0.032	0.29	5.29
10	1	3	3	0.086	5	0.028	-0.237	4.763

COMPUTATIONAL FLOW ANALYSIS FOR TURBULENCE:

The CFD analysis of airfoil S809 is performed for a velocity of 8 m/s at angles of attack of five. ANSYS is used to mesh the airfoil, which is designed in CREO and exported to FLUENT for analysis. Inlet velocity for the experiments and simulations is 8 m/sec and turbulence viscosity ratio is 10. A fully turbulent flow solution was used in ANSYS FLUENT, where SpalarteAllmaras equation was used for turbulent viscosity. A simple solver was utilized and the operating pressure was set to zero. Calculations were done for the "linear" region, i.e. for angles of attack 5 degrees.

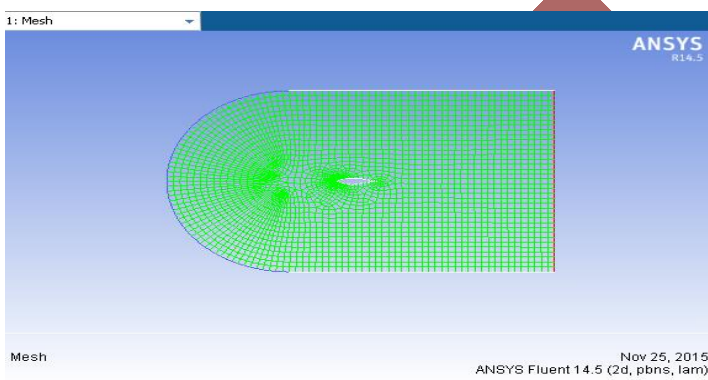


Fig. 7. Meshed geometry of root airfoil

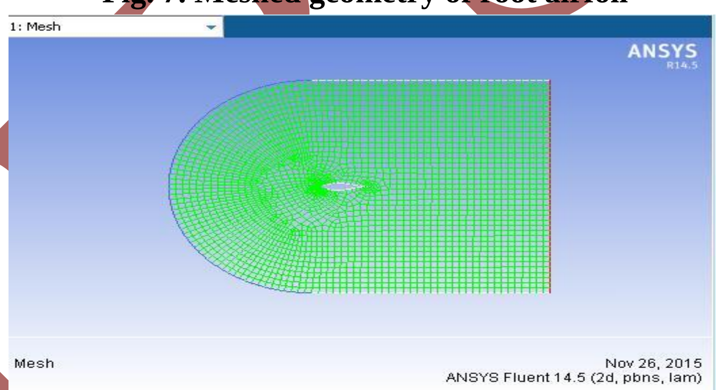
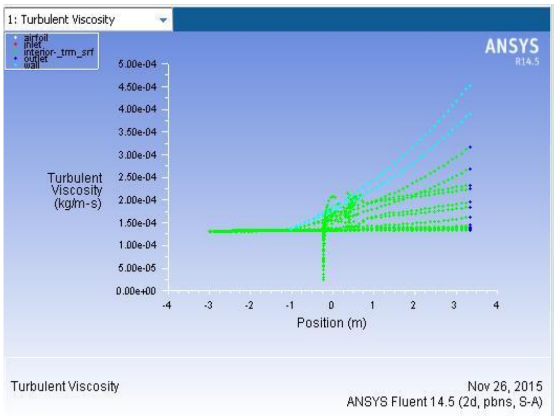


Fig. 8. Meshed geometry of middle airfoil

RESULTS AND DISCUSSION

The majority of flows encountered in real life are turbulent in nature. Turbulence flow is an unsteady periodic motion in which the velocity components in all three directions fluctuate and as a result, there is a significant change in mass and momentum interchange that takes place between each neighboring layers of fluid. The motion of a turbulence flow is predominantly rotational which the viscous effects of boundaries and the separation of fluid from the surface produce. From the experimental analysis from figure 10, when the position increases the turbulent viscosity increases. Figure 11, shows the variation of effective viscosity with respect to change in position. In figure 12 shows that in most of the cases when the position increases, turbulence rate also increases. In tip, the turbulence level increases compared to other two. This is shown in figure 13-15. Due to vortices around the tip, the turbulence level increases. Middle airfoil result shows the turbulence level in between the other two, which is shown in figure 16-18. From the results obtained, it can be understood that the turbulence level in tip airfoil is higher compared to the rest of two.



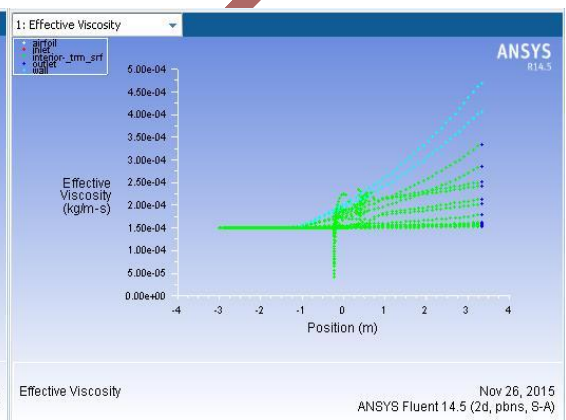
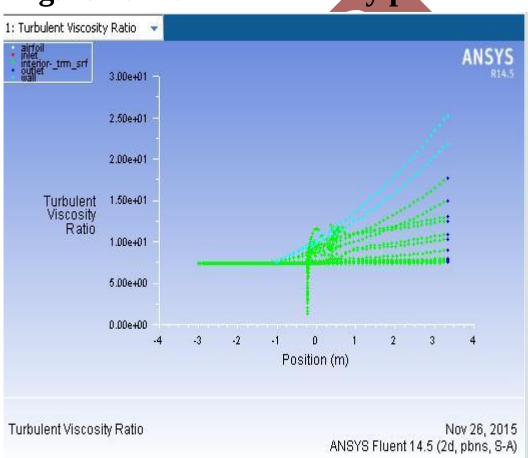


Fig. 9. Turbulence viscosity plot of root airfoil Fig. 10. Effective viscosity plot of root airfoil



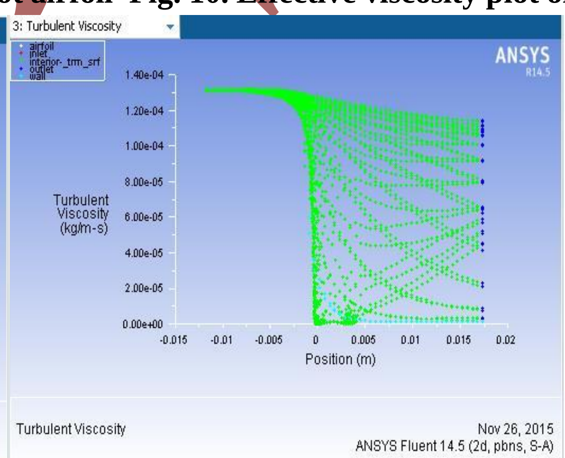
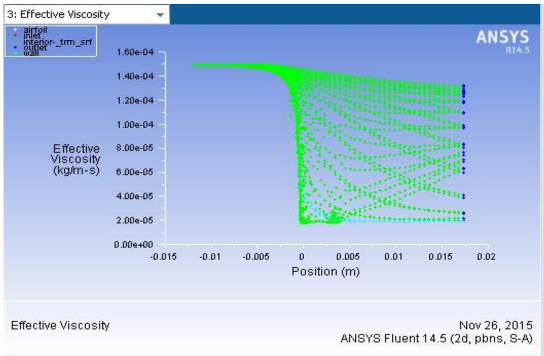


Fig. 11. Turbulence viscosity ratio plot of root airfoil Fig. 12. Turbulence viscosity plot of middle airfoil



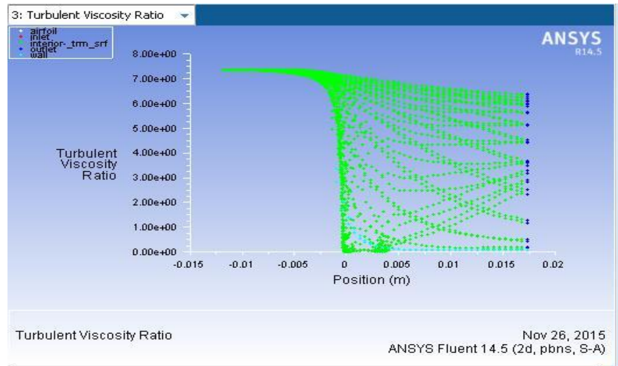
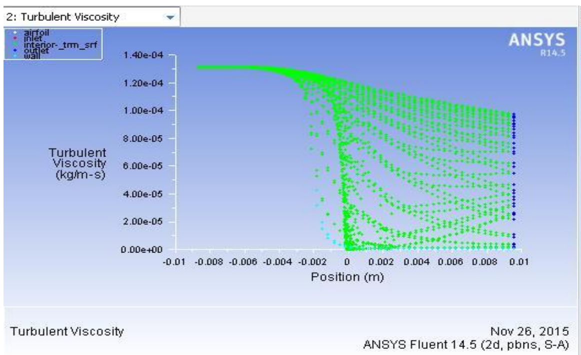


Fig. 13. Effective viscosity plot of middle airfoil Fig. 14. Turbulence viscosity ratio plot of middle airfoil



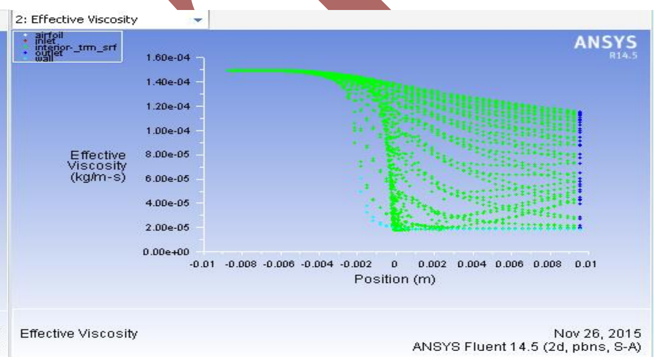


Fig.15. Turbulence viscosity plot of tip airfoil Fig.16. Effective viscosity plot of tip airfoil

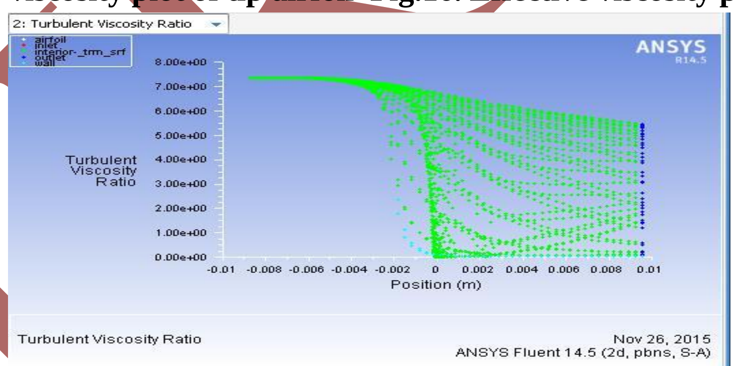


Fig.17. Turbulence viscosity ratio plot of tip airfoil

CONCLUSIONS

In this project, for analyzing the turbulence over a 5KW horizontal axis wind turbine, the S809 airfoil for the desired wind turbine has been selected and designed. The modification factor and models were also combined into the BEM theory to predict the blade performance and there is a good comparison of radius ratio and various angles in each section between the improved BEM theory and numerical simulation. Turbulence analysis has been carried out for a three different chord length of a selected airfoil by predicting turbulence viscosity, effective viscosity and turbulence viscosity ratio. The motion of a turbulence flow is predominantly rotational which the viscous effects of boundaries and the separation of fluid from the surface produce. Due to the irregularity nature of turbulent flows which makes the flow increasingly complex, a modeling approach using the Spalart-Allmaras in an attempt to describe the flow behavior of turbulent flows. This model does have the capability to accurately predict the flow fields of shear flow and separated flow. Thus, the overall analysis shows, the tip i.e. low chord airfoil experience more turbulence compared to other two. Due to more turbulence, the co efficient of lift of the tip airfoil is decreased than others are.

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