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NUMERICAL COMPARISON OF AERODYNAMIC PERFORMANCE OF NACA 4415 FISH TAIL AIRFOIL BLADE WITH CONVENTIONAL NACA 4415 AIRFOIL BLADE

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ABSTRACT

The numerical values of the lift coefficient and drag coefficient of NACA 4415 fish tail airfoil blade and conventional NACA 4415 airfoil blade were obtained using CFD program ANSYS-FLUENT at angle of attack from -6° to 42°. The values of the stall angle and angle corresponding to the maximum lift-to-drag ratio for both blades were determined and compared. The result indicated that Lift and drag coefficients increased with increasing angle of attack for both blades. It is also observed that the NACA 4415 FT blade has greater stall angle than the conventional blade.

1. INTRODUCTION

Energy is produced from wind using kinetic energy of the wind. The energy produced from fossil fuels have two problems of resources depletion and environmental pollution. Because of this reason, renewable energy had become necessary as alternative source of energy. One of this form of that energy is wind energy. Wind turbines use wind to extract kinetic or mechanical energy of the air into electrical energy. But wind turbines have very poor efficiency. Because of that there is a need for a number of researches to be conducted in order to investigate wind turbines blades and their aerodynamic parameters. One of these parameters, is wing (which is the blade) because wind hits the wings and energy of wind is converted into mechanical energy. Wings profiles are referred to as airfoils. The important parameter for wing design is the airfoil profile because the blade efficiency increases according to the airfoil profile, so there are a lot of studies both numerical and experimental on the airfoil profiles as in the literature. Experimental investigations are more important because of their accuracy. However, they are time consuming and costly. But whenever we want to change a parameter for any study, it is very difficult because of time and cost. Fortunately, with computational fluid dynamics (CFD), investigation and the study will be very fast and easy. These programs can give as correct results as experimental methods. Also, CFD programs can be easier, cheaper and faster compared to experimental methods. NACA airfoil types were investigated in the literature. Generally, a lot of Investigators studied lift and drag performances of Conventional NACA airfoils. There are over 1600 airfoils profiles coordinate (Cartesian) data which can be obtained from online resources. [1]. Şahin and Acir, performed a numerical and experimental analysis of the lift and drag performances of NACA 0015 airfoil at different attack angle at low Reynolds number in low speed wind tunnel. The model airfoil has a chord length of 100mm and span of 100mm. The numerical analysis was performed using CFD program FLUENT and results obtained from experiment and numerical were compared [2]. Yao et al., have computed aerodynamic performance analysis of NACA0018 wind turbine airfoil by using numerical simulation method. The authors investigated lift, drag performances and surface pressure by changing attack angle using different turbulence model [3]. Lianbing et al. have investigated performance of wind turbine NACA0012 airfoil using FLUENT programs. Spalart Allmaras turbulence model to numerical solutions was used by Lianbing et al. of airfoil at 3×106 Reynolds number for lift and drag performance and stall angle [4]. Ravi et al. studied over

NACA4412 airfoil profile at 3×106 Reynolds numbers. The authors investigated transition from laminar flow to turbulence flow by using two different numerical models which were k-epsilon and Spalart Allmaras. Numerical results were compared with experimental results. They indicated that the two numerical models gave similar results at high Reynolds number [5]. Morshed et al, investigated the variation of drag coefficient with Reynolds number for symmetric NACA 0015 airfoil, cambered NACA 4415 airfoils. The samples have equal volume and are fabricated from wood (Gamari). They were tested in sub-sonic wind tunnel and obtained experimental data at different Reynolds's Number. Lift Coefficient vs. Angle of Attack at different Reynolds Number for both airfoils was also investigated. A stall angles of approximately 14o and 16o for NACA0015 and NACA 4415 airfoil respectively [6]

In the present work, the lift and drag coefficient of NACA 4415 fish tail airfoil blade and conventional NACA 4415 airfoil blade were investigated numerically. K-epsilon model of ANSYS-FLUENT was used. The numerical results obtained were compared.

2.0 WIND TURBINE DEVELOPMENT

Wind technology became popular towards the end of 20th century, to a world of new opportunities. Developments of wind technology were adapted to wind turbines and helped to hasten re-emergence. A few of the many areas which have contributed to the new generation of wind turbines include material science, aerodynamics, analytical methods, testing and power electronics. Material science has brought new composites materials for the blades and alloys for the metal components. Developments in computer science facilitate design, analysis, monitoring and control.

2.1 Wind Turbine Power Extraction

Wind turbine is use to converts the kinetic energy from the wind to mechanical energy which is used to rotate the turbine blade. As wind passes across the rotor blade, aerodynamic force (resultant of lift and drag) is created. This force is used to rotating the blade which is rigidly attached to the hub.

The Wind power depends on the following parameters.

Amount of air(volume)

Speed of air (velocity)

Mass of air (density)

The flow through the area of intensity (flux)

2.2 Blade Structure

Many materials have been used for wind turbine blade construction. For the blade structure, steel can be used because of its high stiffness and well understood processing techniques. However, its specific strength (yield strength/density) is too low and it is too difficult to form twist optimized blades [7]. Aluminum was also used but it was found to be too fatigue sensitive and insufficiently stiff and wood is widely used on smaller turbines but its properties are generally too variable to produce variable designs. Although it has excellent fatigue properties, it is rarely used for modern wind turbine blades [8].

2.3 How Blades capture wind Power

Wind turbine blades work by generating lift due to their shapes. The more curved side generates low air pressure while high pressure air pushes on the other side of the airfoil Motion of air over airfoil creates pressure differential between upper and lower surfaces of the blade, thereby creating a net upward force to lift the blade. The aerodynamic forces are lift and drag. Lift is perpendicular to direction of air flow while drag is in the air flow direction. For pre-stall angles of attack, lift is far more than drag, such that net upward force is created.

For a blade or wing section, lift and drag are dependent on fluid velocity u, density ρ, viscosity μ, and blade/wing area A. By Buckingham π Theorem, dimensionless parameters Lift Coefficient C_L, Drag Coefficient C_D, and Reynolds Number are defined as

$$C_L = \frac{L}{\frac{1}{2}\rho u^2 A} \quad (1)$$

$$C_D = \frac{D}{\frac{1}{2}\rho u^2 A} \quad (2)$$

$$Re = \frac{\rho u c}{\mu} \quad (3)$$

where L and D are lift and drag force respectively, C_L and C_D are lift and drag coefficients of airfoil respectively, C is airfoil cord length, V is velocity of wind, ρ is density of air

Lift increases with increase in angle of attack α, however, when angle of attack reaches a certain limit, stall occurs. This is the situation of sudden loss in lift as a result of boundary layer separation from the upper surface [7].

.2.4 Methods of Blade Analysis

Three approaches to blade or wind turbine analysis can be identified: blade element momentum theory (BEM), computational fluid dynamics (CFD) and experimental fluid dynamics (EFD).

Computational Fluid Dynamics (CFD) is a complete package analytical tool. It provides numerical approximation to the equations that govern the fluid motion (continuity, momentum and energy). For the steady flow of a constant-property fluid, the equations that govern the flow around the air foil model are time-averaged continuity equation (4), and momentum equation (5), given below respectively as

$$\frac{\partial U_i}{\partial x_j} = 0 \quad (4)$$

$$U_j \frac{\partial U_i}{\partial x_j} = \frac{\partial}{\partial x_j}\left(\vartheta \frac{\partial U_i}{\partial x_j} - U_i U_j\right) - \frac{1}{\rho}\frac{\partial P}{\partial x_i} \quad (5)$$

Where i,j=1,2,3, = mean velocity vector in x,y,z directions, P is static pressure, ρ is density and ϑ is kinematic viscosity.

3.0 METHODOLOGY

The Fish Tail blade used was developed from NACA 4415 airfoil profile. The curves of the leading and trailing edges of the fish tail are parabolic from equations (6) and (7) for leading and trailing edge respectively.

$$x^2 = 46.875y \quad (6)$$

$$x^2 = 93.75(y - 80) \quad (7)$$

The blade profile was developed with a CATIA part design and exported as step (.stp) file format. The CFD models are shown in plate I and II below.

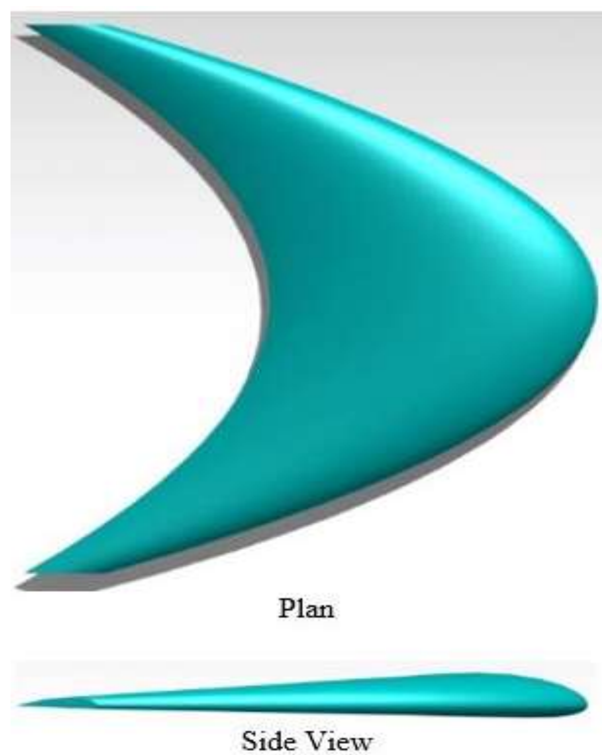

Plate 1: NACA 4415 airfoil FT CFD Model

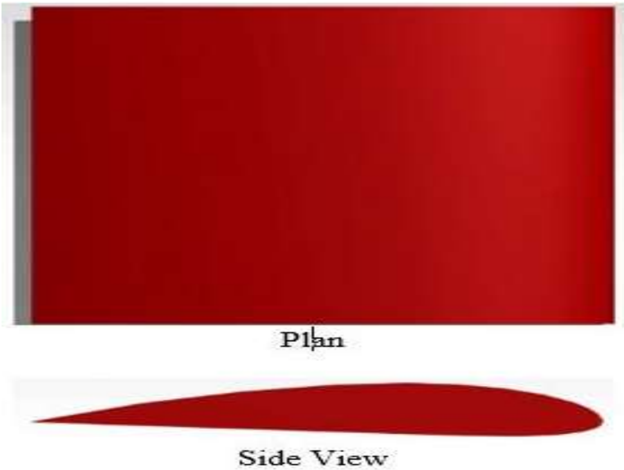

Plate II: Conventional NACA 4415 airfoil CFD Model

The lift and drag coefficients were obtained numerically with ANSYS-FLUENT program at wind velocity of 15 ms^{-1} using k-epsilon model. The angle of attack was varied at different attack angle between -6° to 42° and the lift and drag coefficient were measured for both NACA 4415 Fish Tail Airfoil Blade and Conventional NACA 4415 airfoil blade

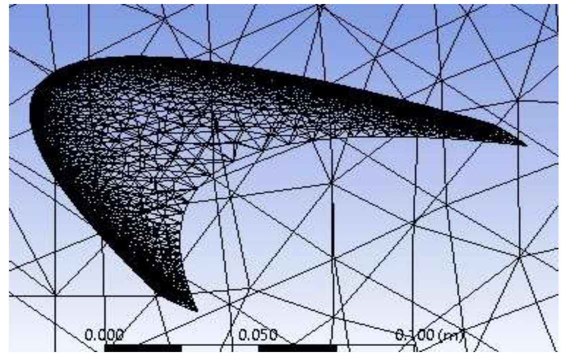

Plate III: Mesh around the FT blade

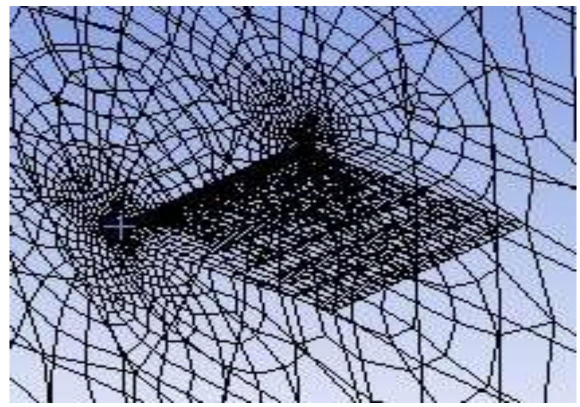

Plate IV: Mesh around the conventional blade

4.0 RESULT AND DISCUSSION

The mesh around the two blades are visualized to show the nature of the fluid domains used in the CFD simulation. The pressure contours for the upper and lower faces of the NACA 4415 FT blade in CFD-post were also visualized. The aerodynamic parameters lift and drag coefficients were obtained, the lift-to-drag ratio was also evaluated.

4.1 Meshes around the blades

Plate III and IV shows the meshes around NACA 4415 airfoil FT blade and conventional NACA 4415 airfoil blade respectively.

4.2 Pressure Contours

Plate V show the pressure contours for the upper and lower faces of the NACA 4415 FT blade.

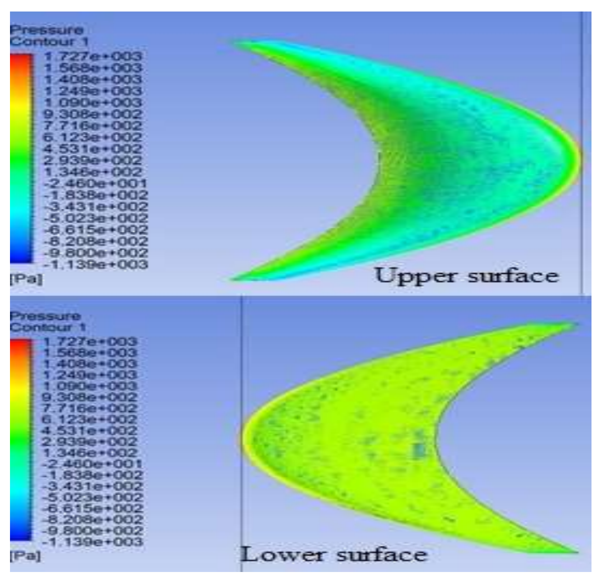

Plate V: Pressure contours for FT blade

Plate V above shows that the pressure at the lower surface of the FT blade is higher than that of the upper surface which indicate a significant lift generation

4.3 Comparison of Aerodynamic Parameters

The effect of angle of attack on the lift coefficient, drag coefficient and the lift-to-drag ratio are graphically compared in figure 1, 2 and 3 respectively

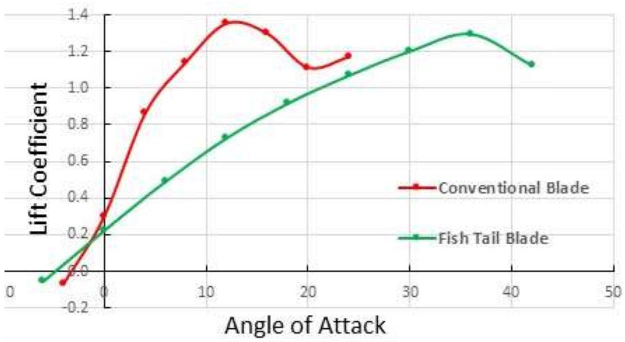

Figure 1: Effect of angle of attack on Lift coefficient

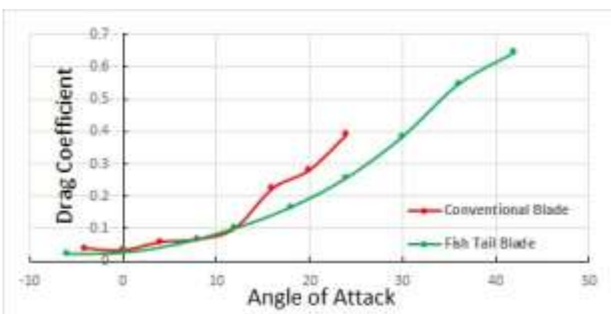

Figure 2: Effect of angle of attack on Drag coefficient

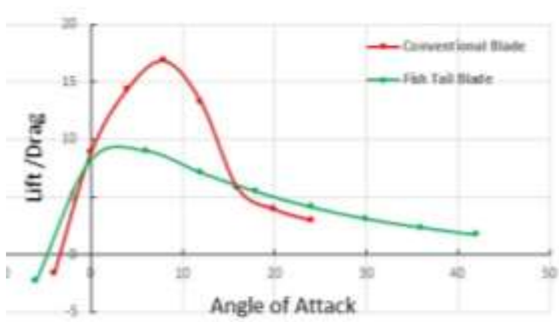

Figure 3: Effect of angle of attack on Lift-to-Drag ratio

The drag coefficients in both Conventional NACA 4415 and NACA 4415 FT blade increases at the same rate up to 12° angle of attack after which the rate of increase in drag is higher in the conventional blade.

The lift-to-drag ratio is maximum at 8° angle of attack for the Conventional NACA 4415 while for NACA 4415 FT blade is 6o angle of attack.

5.0 CONCLUSION

The study numerically investigated and compared the effect of angle of attack on lift coefficient, drag coefficient and lift-to-drag ratio for conventional NACA 4415 airfoil blades and the NACA 4415 FT blade. The conclusion are as follows:

Lift and drag coefficient increased with increasing angle of attack.

It is observed that the conventional NACA 4415 stalls at 13° angle of attack while the NACA 4415 FT blade stalls at 36° angle of attack.

The drag coefficients in both conventional NACA 4415 and NACA 4415 FT blade increases at the same rate up to 12° angle of attack after which the rate of increase in drag is higher in the conventional blade.

The lift-to-drag ratio is maximum at 8° angle of attack for the Conventional NACA 4415 while for NACA 4415 FT blade is 6° angle of attack.

REFERENCES

[1] UIUC, (2015). UIUC Airfoil data (Department of Aerospace Engineering, University of Illinois at Urbana-Champaign (UIUC)) Retrieved from http://m-selig.ae.illinois.edu/ads/coord_database.htm

[2] Şahin, İ. and Acir, A. (2015). Numerical and Experimental Investigations of Lift and Drag Performances of NACA 0015 Wind Turbine Airfoil, International Journal of Materials, Mechanics and Manufacturing, Vol. 3, No. 1, February 2015.

[3] J. Yao, W. Yuan, J. Wang, J. Xie, H. Zhou, M. Peng, and Y. Sun, "Numerical simulation of aerodynamics performance for two-dimensional wind turbine airfoils," Procedia Engineering, vol. 31, pp. 80-86, 2011.

[4] L. B. Li, Y. W. Ma, and L. Liu, "Numerical simulation on aerodynamics performance of wind turbine airfoil," in Proc. World Automation Congress (WAC), 2012, pp. 1-4.

[5] H. C. Ravi, N. Madhukeshwara, and S. Kumarappa, "Numerical investigation of flow transition for NACA-4412 airfoil using computational fluid dynamics," International Journal of Innovative Research in Science Engineering and Technology, vol. 2, issue 7, pp. 2778-2785, July 2013.

[6] Morshed, M., Bin Sayeed, S., Al Mamun, S. A. and Alam, GM. J. (2014); Investigation of Drag Analysis of Four Different Profiles Tested at Subsonic Wind Tunnel, Journal of Modern Science and Technology, Vol. 2, No. 2, September Issue. Pp.113-126.

[7] Amer, and Sahin M.(2014) Structural Analysis of Composite Wind Turbine Blade. World Academy of Science, Engineering and Technology,International Journal of Mechanical, Aerospace, Industrial and Mechanics Engineering Vol;8 (7).

[8] Peter J Schubel and Richard J.Crossley (2012). Wind turbine Blade design: Faculty Of Engineering, Division of materials, mechanics and structure, University of Nottingham, University park, Nottingham NG 72RD,UK