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Research Article

Numerical analysis of the effects of Vorticity and flow separation on the Aerodynamic performance of NACA 4415 Fish Tail Airfoil Blade compared with Conventional NACA 4415 Airfoil using computational fluid dynamics

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Abstract

In this work, numerical and experimental analysis of the effect of vorticity and flow separation on the performances of NACA 4415 Fish Tail airfoil were studied at different attack angle at low Reynolds number (Re) by measuring the forces at interval of 6° from -6° to 42°.The experiment was conducted in low-speed wind tunnel, and the numerical analysis was performed using CFD program ANSYS-FLUENT. The results obtained from experiment and numerical were compared. The study determined the stall angle and angle corresponding to the maximum lift-to-drag ratio.

Keywords: *Angle of attack, CFD, NACA 4415, Airfoil, wind tunnel.*

I. INTRODUCTION

Energy is very important for human life. It is well-known that, energy produced from fossil fuels, have two problems of resources depletion and environmental pollution. For this reason, renewable energy as alternative resource is emerged necessary. One of the reliable forms of renewable energy is wind energy. Wind turbines use wind to convert kinetic energy of the air into electrical energy. But wind turbines have very poor efficiency. Because of that, a number of researches were conducted to investigate wind turbines blades and their aerodynamic parameters. One of the most important parameters of wind turbines is wing (which is the blade) because wind hits to the wings and energy of wind is transformed into the mechanical energy by wings. In the literature, wings profiles are referred to as airfoils. Airfoil profile is the important parameter for wing design because wing efficiency increases depending on the airfoil profile, so there are a lot of numerical and experimental studies on the airfoil profiles as in the literature. Experimental investigations are very important due to accuracy. However, they take much time and it is costly. But whenever we want to change a parameter about our study, it is very difficult because of time and economic. Fortunately, investigation and the study will be very fast and easy with computational fluid dynamics (CFD) programs. These programs can give as correct results as experimental methods. Also, CFD programs can be contributed as regards time and faster according 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 airfoil profiles coordinate (Cartesian) data which can be obtained from online resources. [1]. *Şahin and Acir,* performed a numerical and experimentally analysis of the lift and drag performances of NACA 0015 airfoil at different attack angle at low Reynold 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

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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]. Srinivosan *et al.*, studied on evaluation of turbulence models for unsteady flows of an oscillating airfoil. They studied on NACA 0015 airfoil by using five different turbulence model. They saw that Spalart Allmaras turbulence model had good agreement with experimental results for lift, drag and moment coefficient [7].

In the present work, the lift and drag performances of NACA 2415 wind turbine airfoil were investigated numerically and experimentally. K-epsilon model of ANSYS-FLUENT was used. The obtained numerical results were compared with experimental results.

II. EXPERIMENTAL SET UP

The experiments were conducted in an open wind tunnel at the fluid Mechanics laboratory of Bayero University Kano, Faculty of Engineering. This tunnel test section is about 0.4m long and flow cross-section is approximately 0.3m×0.3m, interval of wind velocity is from 3.1 to 28 ms^{-1}. Fig. Plate I.

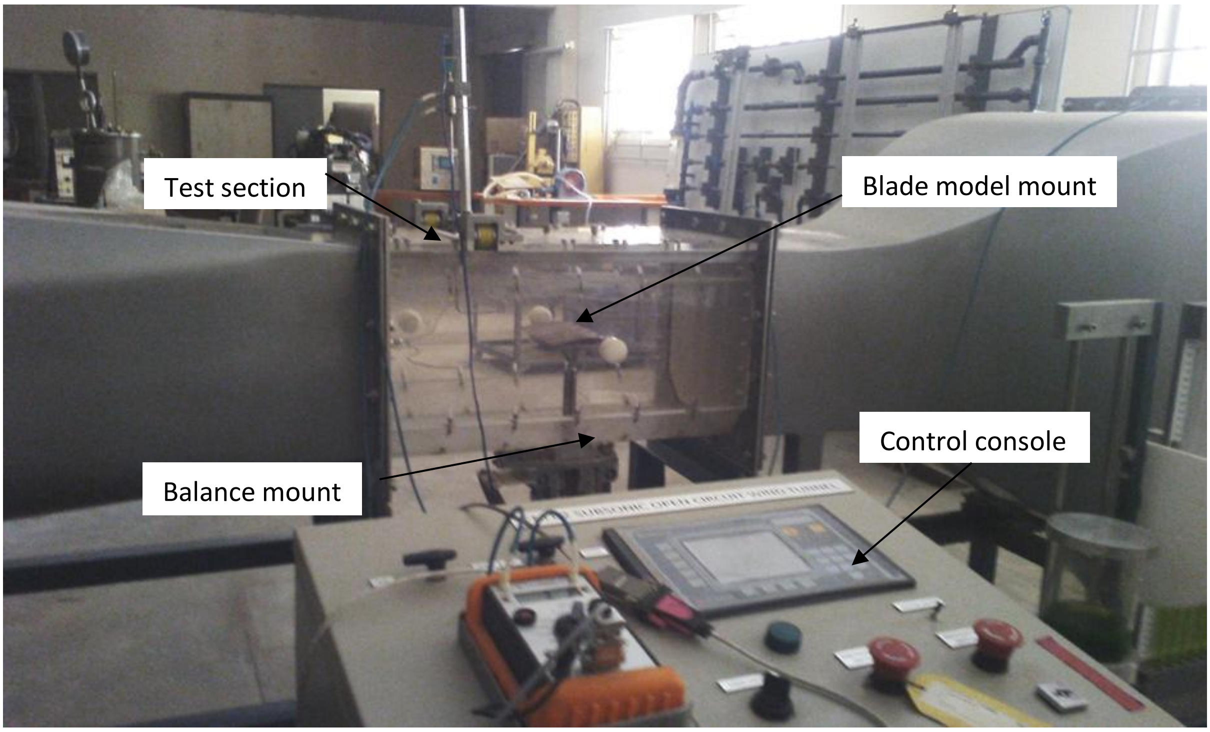


Plate 1: Wind tunnel set up

The Fish Tail blade used was developed from NACA 2415 airfoil profile. The curves of the leading and trailing edges of the fish tail are parabolic from equations (1) and (2) for leading and trailing edge respectively.

$$x^2 = 46.875y \quad (1)$$

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

The blade profile was developed with a CATIA part design and the experimental model made of wood was produced with CNC milling machine. The Experimental and the CFD model are shown in plate II below.


Experimental Model CFD Model

(a) Plan Views


Experimental Model CFD Model

(b) Side Views

Plate II: Experimental CFD FT blade Models.

The experiments were conducted at 15 m/s wind velocity (v) in Wind tunnel which is corresponding to 6.16E+04 Reynolds number (Re). The Lift and drag coefficient of NACA 4415 FT airfoil at different attack angle between -6° to 42° were measured. Also, the lift and drag coefficient were obtained as numerical with ANSYS-FLUENT programs for the same conditions.

III. RESULTS AND DISCUSSIONS

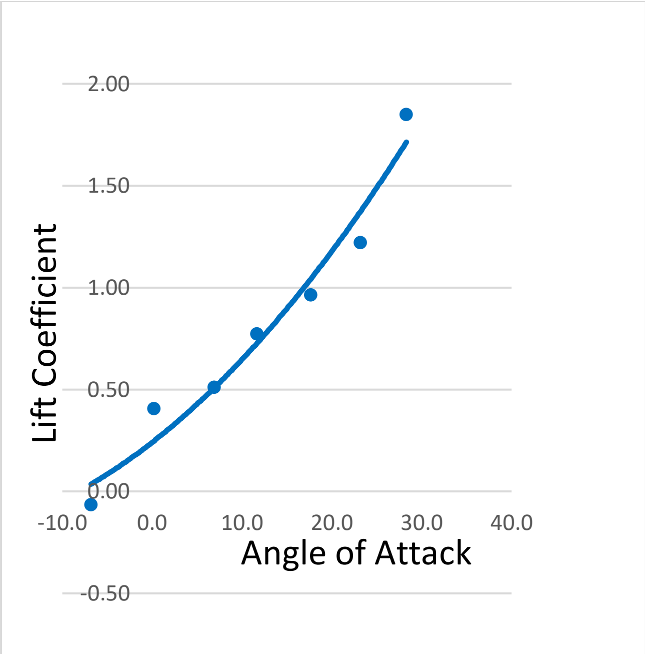
The lift and drag forces obtained from experiment were used to determine the lift and drag coefficients using equation (3) and (4) below.

Lift force, L = $C_L(\frac{1}{2})\rho V^2 C$ (3)

Drag force, D = $C_d(\frac{1}{2})\rho V^2 C$ (4)

where *L* and *D* are lift and drag force respectively, *Cl* and *Cd* are lift and drag coefficients of airfoil respectively, *C* is airfoil cord length, *V* is velocity of wind, *ρ* is density of air.

The lift-to-drag ratio was also evaluated. The effect of angle of attack on the lift coefficient, drag coefficient and the lift-to-drag are graphically presented in figure 1-a, 1-b and 1-c respectively



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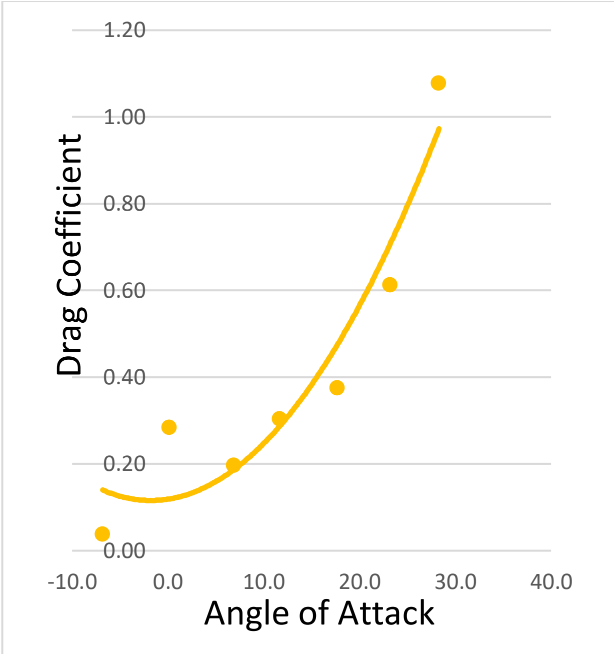

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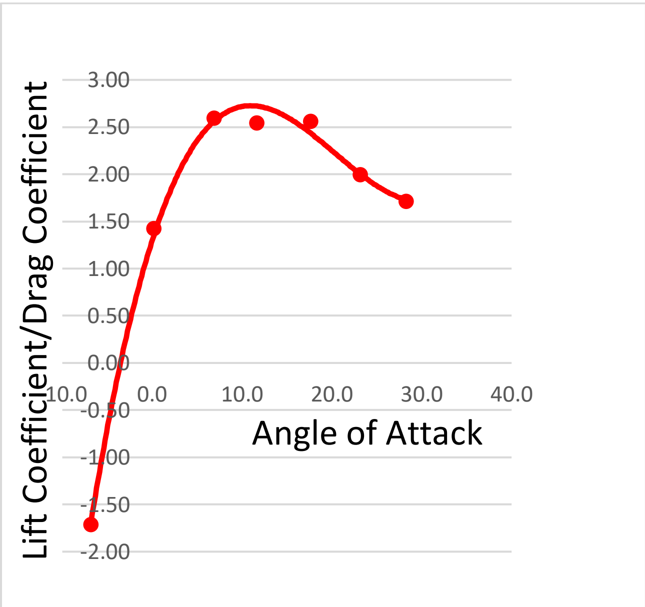

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Fig. 1: Experimental results showing graphically the effect of angle of attack on **(a)** Lift coefficient **(b)** Drag coefficient and **(c)** Lift-to-Drag ratio at velocity of 15ms^{-1}

The lift and drag coefficient was primarily affected by attack angle. Both the lift and drag coefficients increases with increase in angle of attack. The lift-to-drag is maximum at about 10° angle of attack

Also, the lift and drag coefficient were computed with CFD analysis using K-epsilon. Plate III below shows the mesh around the FT airfoil blade

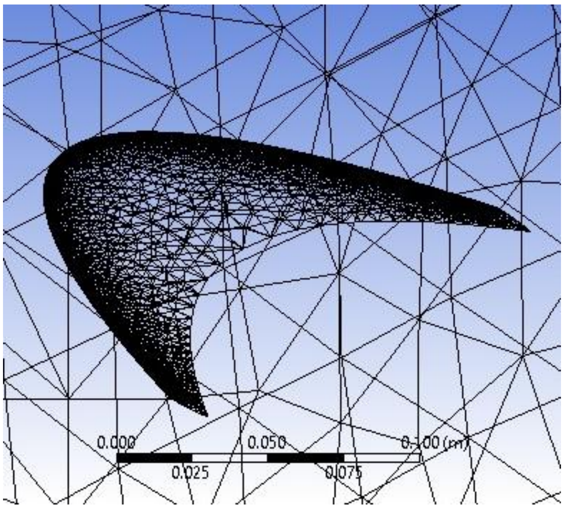
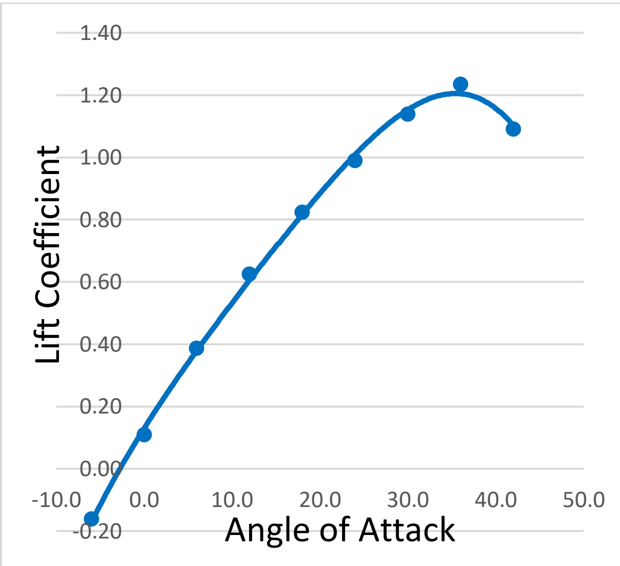


Plate IV: Mesh around the FT airfoil blade

The lift coefficient, drag coefficient and the lift-to-drag are graphically presented in figure 2-a, 2-b and 2-c respectively.



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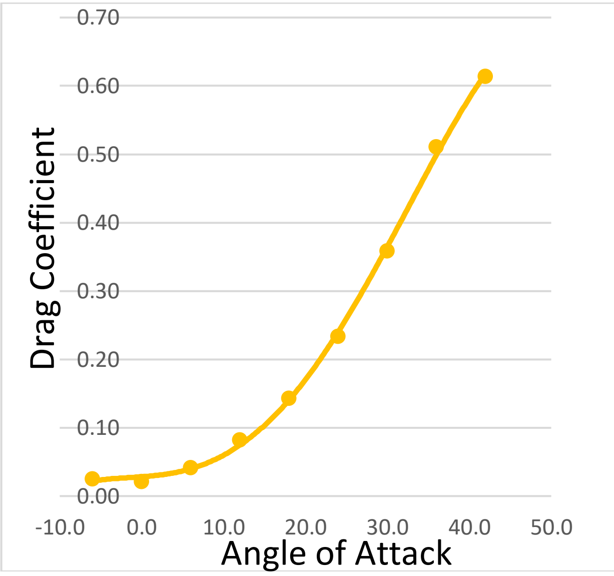

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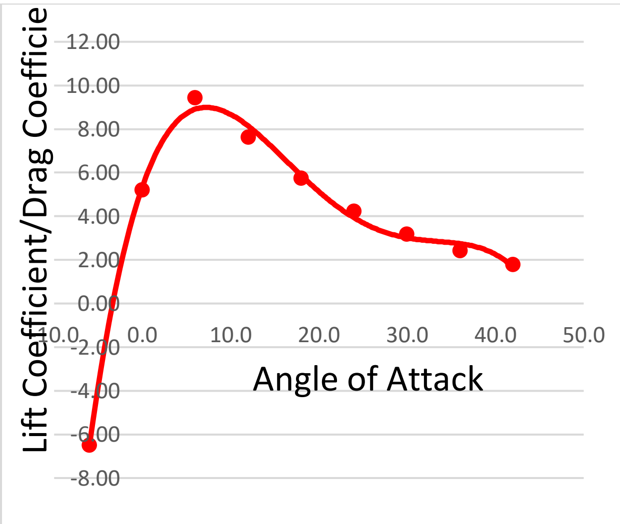

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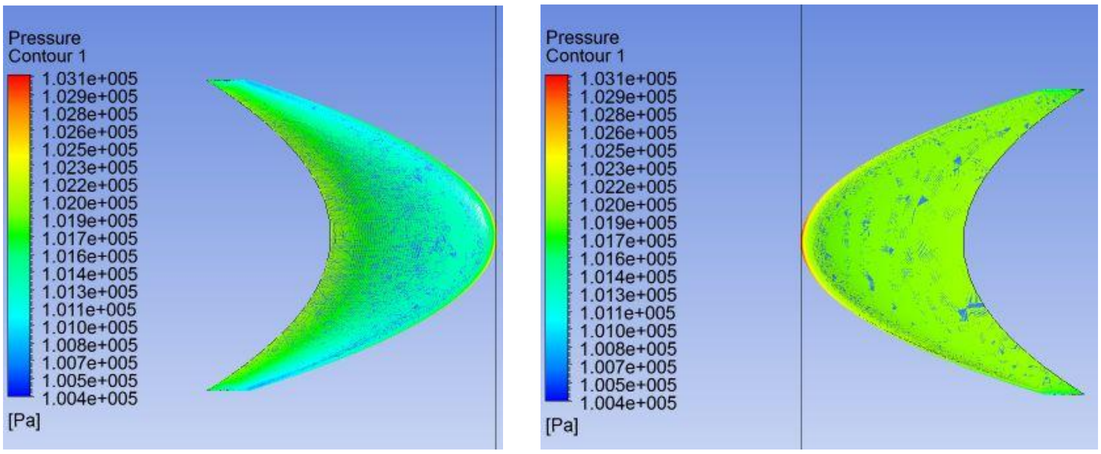
Fig. 2: CFD results showing the effect of angle of attack on **(a)** Lift coefficient **(b)** Drag coefficient and **(c)** Lift-to-Drag ratio velocity of 15ms^{-1}

The lift and drag coefficient was primarily effected by attack angle. Both the lift and drag coefficients increases with increase in angle of attack. The maximum lift and drag coefficient were found as 1.2 and 0.51 for 36 ° stall angle. The lift-to-drag is maximum at about 10° angle of attack.

The pressure contour for the upper and lower surfaces are shown in plate IV below.



Upper surface Lower surface

Plate IV: Pressure Contours for NACA 4415 airfoil FT blade

The pressure contours show higher pressure at the lower surface than that of the upper surface of the blade. This indicates existence of lift.

The experimental and numerical result were compared in figure 3. The graph indicated validation of numerical result with the experimental result.

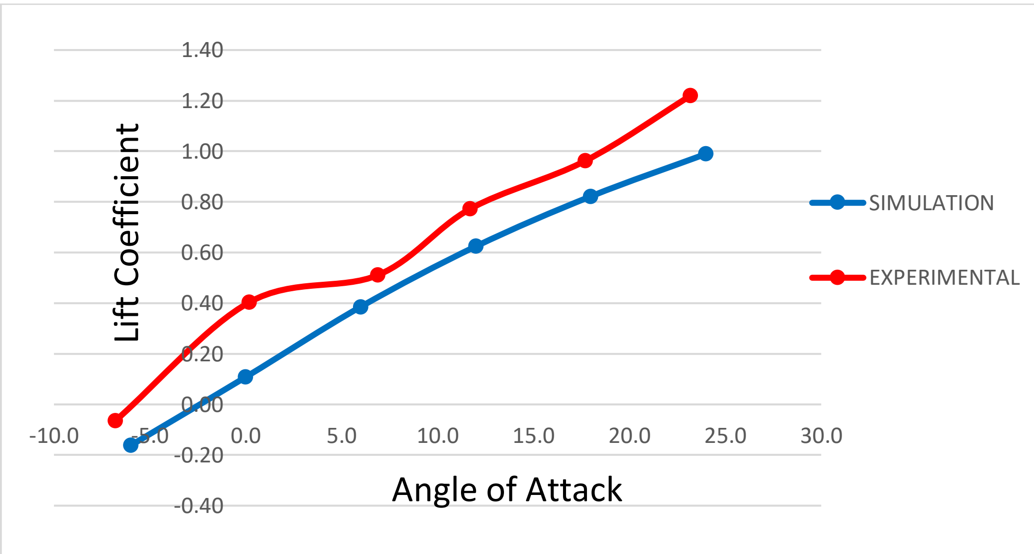


Fig. 3: Validation of numerical result with experimental

IV. CONCLUSIONS

In this study the effect of angle of attack on lift, drag and moments coefficients were investigated experimentally and numerically for NACA 4415 Fish tail airfoil. Numerical and experimental results were compared. The following conclusion were drawn:
Lift, drag and moments coefficients increased with increasing angle of attack.
There was no stall up to 30° attack angle.
The optimum lift-to-drag ratio was attained at 10° which signifies the optimum airfoil performance.
Experimental and numerical analysis shows similarity.

Sponsor

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