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Research Article

COMPARISON OF CFD AND XFOIL AIRFOIL ANALYSES FOR LOW REYNOLDS NUMBER

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Abstract

Blade Element Momentum (BEM) theory is generally used technique for calculation of aerodynamic performance of such turbine application. To obtain close results with blade element momentum theory, aerodynamic data of airfoil has to be as correct as possible. Nowadays, Computational Fluid Dynamics (CFD) is used for optimization and design of turbine application. Lift coefficient, drag coefficient and Lift coefficient over drag coefficient are significant parameters for turbine application. Panel method and an integral boundary layer formulation are combined in the XFOIL code for the analysis of potential flow around the airfoils. In this study, XFOIL code, Transition SST k-omega model was used to predict the aerodynamic performance at low Reynolds number ($Re=3x10^5$ and $4x10^5$). The results were compared and CFD results and XFOIL code result are compatible with each other until stall angle. Also, lift coefficient over drag coefficient was tried to optimize by changing the airfoil geometry.

Keywords- *Xfoil, Computational Fluid Dynamics (CFD), Transition SST k-omega model, low reynold number.*

1. Introduction

Airfoil is such an aerodynamic shape and it generates aerodynamic forces. The air passes above and below the wing. Due to the momentum conversation, the speed of air particles on wing's upper surface increases and also the pressure on the wing's upper surface decreases due to the energy conversation. Because of that the high air pressure moves toward low air pressure. Air pushes the wing so that the force known as lift force is generated [1].

The point at front of the airfoil is defined as the leading edge. Similarly, the point at behind of airfoil is defined as the trailing edge. The chord length is the characteristic dimension of airfoil section [1].

It is possible to predict aerodynamic performance airfoil by using experimental, Computational Fluid Dynamics (CFD) and a user friendly program such as 2d panel code XFOIL that combines a conformal-mapping method for the design of airfoils with prescribed pressure distributions, a panel method for the analysis of the potential flow about given airfoils, and an integral boundary-layer method [3]. Although experimental and Computational Fluid Dynamics (CFD) methods are more expensive and require longer time than panel method, XFOIL results have less accuracy than experimental and CFD methods due to some assumption.

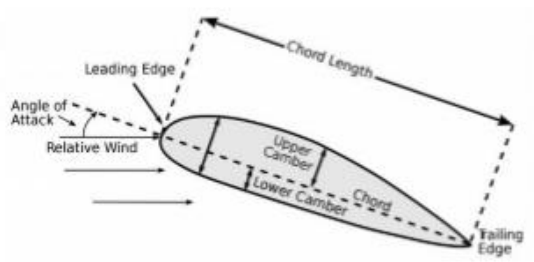

Fig. 1. Basic geometry of airfoil [2].

In this paper, the aerodynamic performance of low Reynolds airfoil SG6040 which is designed exclusively for horizontal wind turbines with small blades [4] is predicted by using XFOIL and ANSYS-FLUENT at two different Reynolds number (Re = 3x10^5, 4x10^5). Firstly, the 2D model of airfoil is

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generated by using airfoil coordinates. After that, aerodynamic performance of the airfoil is obtained by XFOIL software under General Public License. Domain construction and grid generation for calculating the 2D airfoil performance is described in CFD analysis. Then, the aerodynamic performance is calculated by using CFD methods (in Fluent commercial software). Finally, lift coefficient to angle of attack and drag coefficient to angle of attack of the airfoil obtained by the CFD results, are compared with XFOIL results and also literature.

2. XFOIL and CFD Analysis

SG6040 Airfoil

The low Reynold SG6040 airfoil, investigated in this study, has a maximum thickness of % 16, a camber of 2.5 %. The profile is shown in Fig. 2. This airfoil was designed exclusively for wind turbines with small blades (1-5 kW) [5].

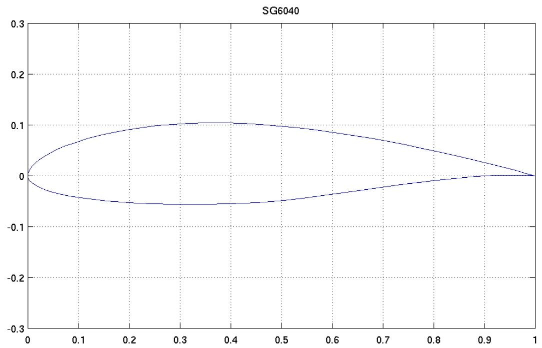


Fig.2. The Profile of SG6043.

XFOIL

The XFOIL [3] code combines a potential flow panel method and an integral boundary layer formulation for the analysis of the flow around airfoils. The code was developed to rapidly predict the airfoil performance at low Reynolds numbers and its convergence is achieved through the iteration between the outer and inner flow solutions on the boundary layer displacement thickness.

For calculating the airfoil performance in XFOIL coordinates of SG6040 airfoil was loaded to XFOIL. After loading airfoil coordinates, the number of point was defined as 250 point, and also number of iteration was defined as 100 iteration. Then, Reynolds number of the flow was set up as 3x10^5 and 4x10^5. The results were drawn as graph of the lift, drag coefficient versus angle of attack and also pressure distribution around the airfoil can be acquired.

CFD Analysis

CFD analysis for aerodynamic performance of SG6043 were carried out by using ANSY-FLUENT. The FLUENT code solves the RANS equations using finite volume discretization. Steady state solver, SIMPLE pressure based solver and Green-Gauss cell based discretization were used in the analysis. Also, second order scheme was used for the momentum and turbulence equations discretization. When applying the CFD analysis to airfoil at low Reynolds numbers, it is difficult to solve boundary layer elements with common turbulence methods. Because of that, more error has been obtained in calculation of drag force. To obtain more correct prediction of drag force, transition turbulence models are more suitable. With SST k-w turbulence transition model, the results were acquired. The convergence of the numerical solution was controlled by monitoring numerical error of the solution.

O-ring type domain structure was chosen. The external domain is a circle which has a diameter of 25 m. It was defined as a boundary condition of "Velocity Inlet". The airfoil bottom and top surfaces were defined as "Wall" boundary conditions. The domain which is defined as air which has a density (ρ) of 1.225 kg/m^3 and dynamic viscosity (μ) of 1.7894e-05 Pa s.

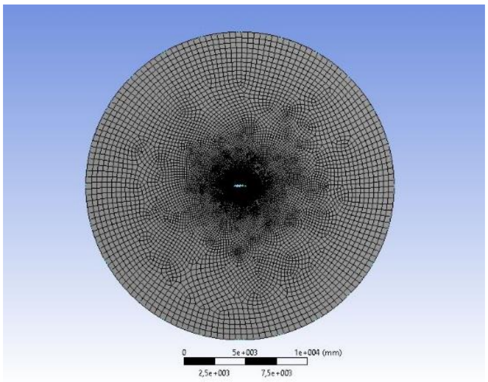


Fig. 3. The O-ring type domain structure with 25 m diameter for 2D analysis.

Circular domain was placed 12.5 times of the chord length away from the airfoil. The computational domain and mesh structure were shown in Fig. 3.

Different sizes of grids were used to ensure grid independency of the analysis results. This is achieved by obtaining solution with increasing number of grids nodes until a stage is reached where the solution exhibits negligible change with further increase in the number of nodes.

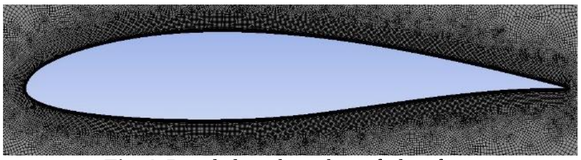
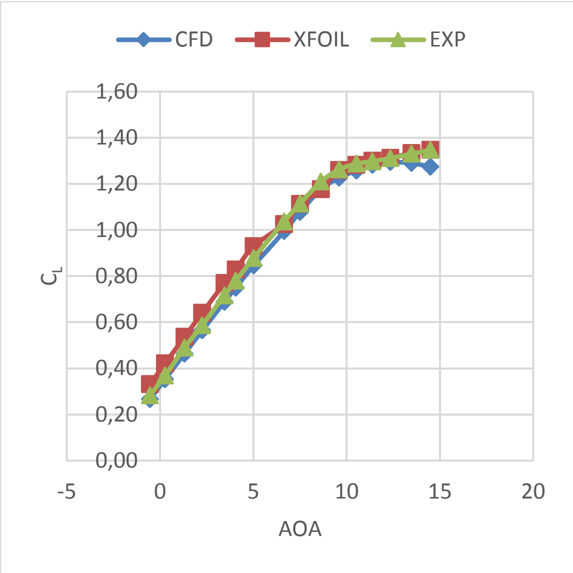


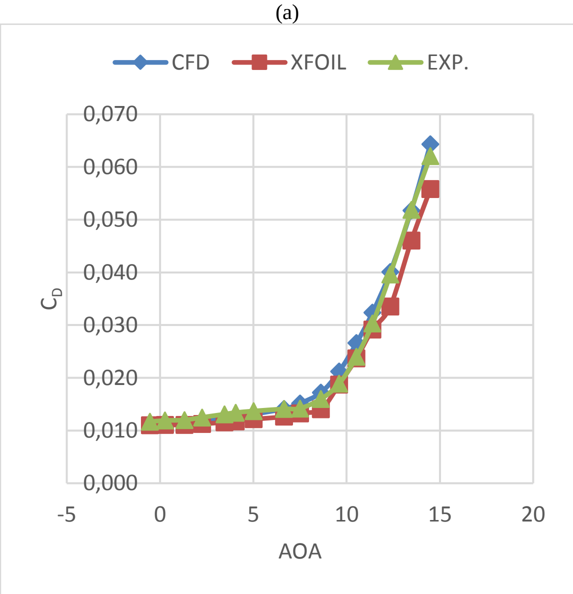
Fig. 4. Detailed mesh on the airfoil surface.

The convergence rate is monitored during the iteration process by means of the residuals of the dependent variables of the governing differential equation. Convergence is also checked using the relative differences between two successive iterations for each of the integrated force coefficients. In order to resolve the boundary layer, 42 layers in the boundary were introduced and first layer was located 0.005 mm from the wall. Hence, the first grid point of the wall in the normal direction was placed at a distance less than $y^+ = 1$ from the wall. The y^+ $\left(\rho U_f y/\mu\right)$ is defined as the non-dimensional wall distance for wall-bounded flow in a turbulent boundary layer analysis. To consider the viscous sub layer in the turbulent boundary layer, the value of the y+ has to be less than 10 [6, 7]. The detail of the mesh around the airfoil is shown in Fig. 4.

In Fig. 5 and Fig. 6, the comparison of the aerodynamic coefficients of SG6040 in CFD, XFOIL and experimental results [4] at different Reynolds number are shown.



(a)

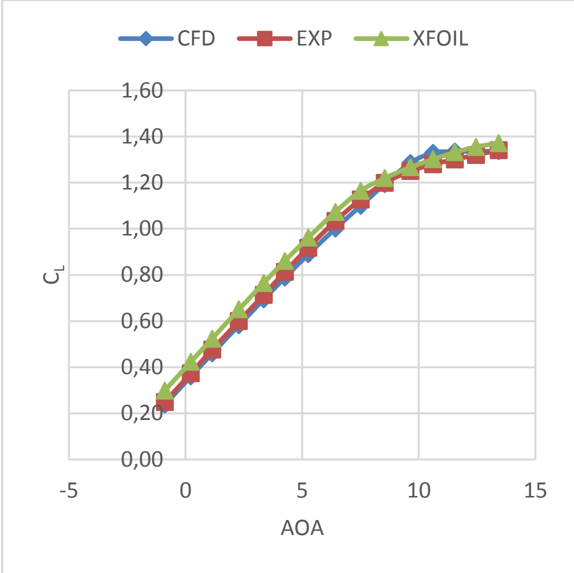


(b)

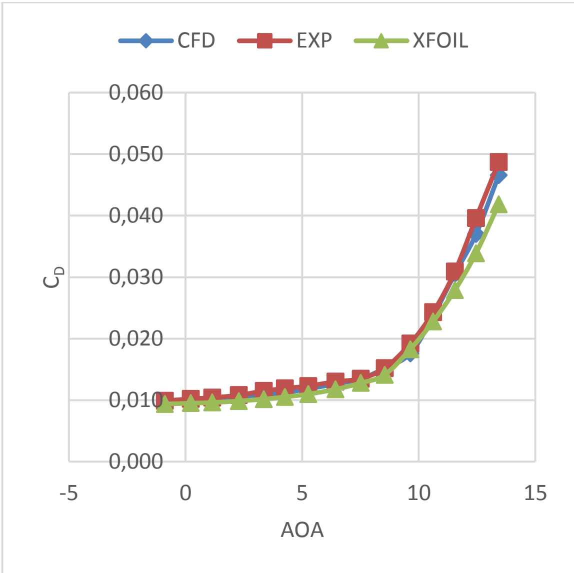
Fig. 5. Comparison of lift coefficient (a) and drag coefficient (b) between CFD, XFOIL and experiment at $3x10^5$ Reynolds number.

For the 0.27 of angle of attack degree at $3x10^5$ Reynolds number and 0.23 of angle of attack degree at $4x10^5$ Reynolds number, the contours of static pressure on SG6040 were obtained. As expected, the pressure on lower surface of airfoil is higher than upper surface, also negative pressure value was obtained on the lower surface.

Hence, the value of coefficient of lift and drag increases with increasing the angle of attack as expected.

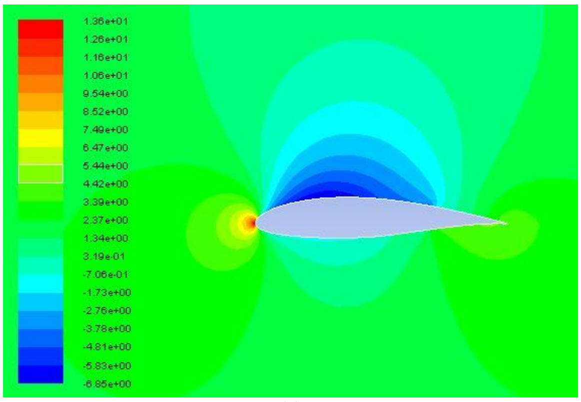


(a)

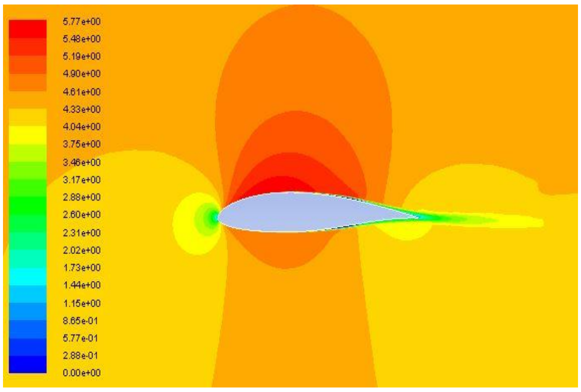


(b)

Fig. 6. Comparison of lift coefficient (a) and drag coefficient (b) between CFD, XFOIL and experiment at $4x10^5$ Reynolds number.

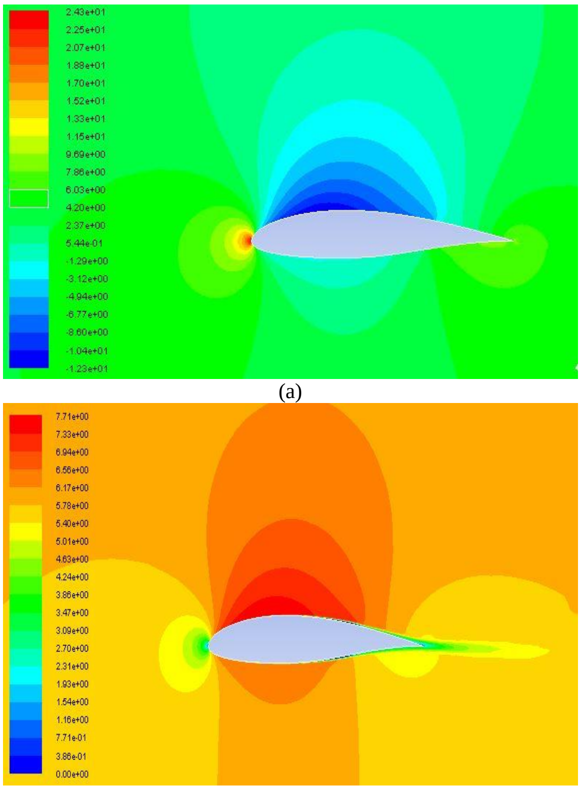


(a)



(b)

Fig. 7. (a) Contour of static pressure on SG6040 and (b) contour of velocity magnitude over SG6040 at 0.27 of AOA at $3x10^5$ Reynolds number.



(a)

(b)

Fig. 8. (a) Contour of static pressure on SG6040 and (b) contour of velocity magnitude over SG6040 at 0.23 of AOA at $4x10^5$ Reynolds number.

3. Conclusions

Flow performance characteristics of SG6040 has been computationally investigated at Reynolds number $3x10^5$ and $4x10^5$. The commercial code fluent with SST k-ω transition and general public license XFOIL, was used for numerical analysis.

The comparison between the experimental literature studies, CFD analysis and XFOIL analysis was analyzed. That the results of XFOIL analyses show as good as agreement with CFD analyses and experiment results, was observed. Although, SST k-ω transition model shows promising results to predict accurate aerodynamic coefficients such as lift (C_L) and drag (C_D) values, it is clear that XFOIL analysis tool can be used easily to predict aerodynamic performance of airfoils at low Reynolds number for the conceptual design in engineering.

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