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Numerical Study of a Wind Turbine Blade Modification Using 30° Angle Winglet on Clark Y Foil

Nu Rhahida Arini[1], Gilang Muhammad[1], Joke Pratilastiarso[1], Setyo Nugroho[1,2]

[1]Power Plant Engineering Study Program, Politeknik Elektronika Negeri Surabaya, Surabaya, Indonesia
[2]Scholl of Mechanical Engineering, The University of Adelaide, Australia
Correspondence Author: arini@pens.ac.id

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Abstract

The depletion of fossil fuels and the worsening environment motivate engineers and researchers to explore renewable energy resources. One of the promising renewable energy is wind energy. The wind turbine extracts wind energy to generate electricity. This study aims to modify a wind turbine blade using Clark Y foil to improve the lift force. The modification is employed by forming a winglet profile with a 30° angle on the foils tip. The result shows that the 30° winglet enlarges the lift coefficient to 1.3253 from 1.2795 of the original blade lift coefficient.

Keywords: Winglet, Wind Turbine Blade, CFD, OpenFOAM

1. INTRODUCTION

The depletion of fossil fuels becomes crucial and motivates researchers to explore renewable energy resources intensively. There are several studies to extract renewable energy resources, and one of the promising energy resources to extract is wind energy [1-2]. Wind energy has become alternative energy to generate electricity by utilizing wind turbines. Researchers developed wind turbines over two decades to harness energy from the wind to rotate electricity generators. Since then, they have also modified turbine blades to improve turbine performance.

There are several parameters considered as performance indicators, and the one which is commonly used is the lift force, as investigated by Arini [3], Ponwin [4], and Udalov et al. [5]. Lift force is generated when the air is in contact with turbine blades and induces pressure difference as it moves along different paths length on the upper and lower surfaces. This induces an upward force on the lower surface and rotates the blades. The higher the lift force is generated, the higher the wind energy can be converted [6]. One way to enhance wind energy extraction is to modify turbine blades. Thus, this paper aims to numerically investigate wind turbine blades with winglet modifications to improve the wind turbine performance using the

Computational Fluid Dynamic (CFD) method. In this paper, the wind turbine's performance is indicated by the lift coefficient obtained from lift force during a turbine's operation. The higher the lift force is generated, thus the higher the lift coefficient, and the more power from the turbine rotor can be produced [7]. In this case, the wind turbine has better performance.

2. RELATED WORKS

Improving turbine performance can be satisfactorily predicted using the CFD method. The CFD can precisely predict fluid behaviour and the interaction between fluid and structure [8]. The additional winglet profile on the wind turbine operation can also be predicted using CFD, as studied by Nugroho [9], Khalafallah [10], and Mourad et al. [11]. The CFD simulation can obtain valid results and thus has become a powerful tool in the area of fluid mechanics, as studied by Gaur [12], Sayed [13], and Rezaeiha [14]. The CFD analysis is performed in OpenFOAM, an open-source CFD software that can handle fluid mechanics problems with precise solutions. More researchers use OpenFOAM in CFD across the university and industries nowadays. They develop more solvers to estimate various cases. Lablebici [15], Quan [16], and Daniele [17]. Developed wind turbine blade models in OpenFOAM. Their results showed valid predictions. OpenFOAM is selected for the ability to provide accurate results and straightforward processes, thus producing much cheaper investment.

3. ORIGINALITY

This section explains the method of modification taken in this research and how the modification affects a turbines performance improvement. Several methods have been invented and proven to be applied on turbine blades. Modifications are applied to the original turbine blade profile, and the lift force is evaluated to confirm the enhancement. In this research, the blade originates from The Clark-Y profile and is modified with two procedures.

The original Clark-Y is twisted with simultaneous angles along the spanwise, and the winglet profile is additionally employed on the original foil tip. Some researchers conducted both modifications, but the lack of results explained the turbine performance when those two modifications were applied. Lee [18] researched to study numerically and experimentally the influence of twist angle on a vertical turbine performance (coefficient of performance, Cp). He found that Cp is strongly affected by twisted angles. Alkhabbaz [19] suggested twist angle distribution for a 10 kW horizontal axis wind turbine to increase the performance. The twisted angle can also be optimized to confirm the improvement of a renewable energy turbine, such as research was done by Abdessalam [20], Liu [21], and Nejadkhaki et al. [22].

4. SYSTEM DESIGN

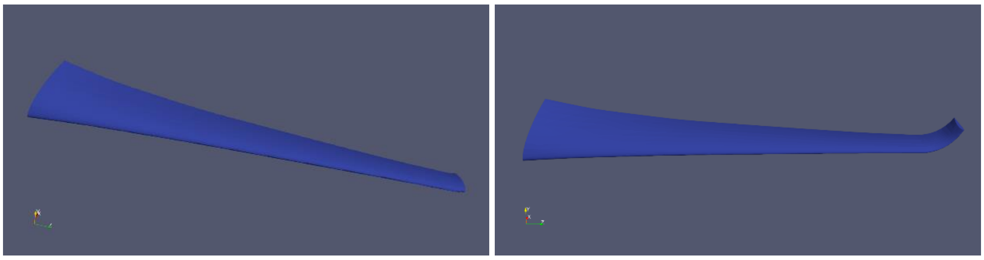
In this paper, the 3D CFD model of the wind turbine blade is developed and simulated using OpenFOAM 8 [23]. The solver of wingMotion in OpenFOAM 8 is employed. The solver is also utilized by Arini et al. [24] to predict the fluid-structure interaction in a vertical-axis tidal turbine blade. Their result shows that the solver provided a good prediction of the interaction and used it in this study. The investigation is applied in a single blade to confirm the improvement of the single foil before a wind turbine assembly. However, the wind turbines performance with the blades arrangements is beyond the scope of the paper. The blade foils original profiles properties can be seen in Table 1. The distribution of twisted angle employed on the original Clark-Y foil is shown in Table 2. The twisted angle is assigned on the foil parts, which is expressed in percentage of the spanwise length. The winglet tip modifies the original profile and forms a 30° angle on the foil tip. The original and modified Clark-Y foils are shown in Figure 1.

Table 1. Blade geometry parameter.

Parameter	Value
Foil	Clark Y
Spanwise length	2.4 m
Winglet angle	30°
Chord length at hub	0.445 m
Chord length at tip	0.15 m

Table 2. Twisted angle in accordance with foil position.

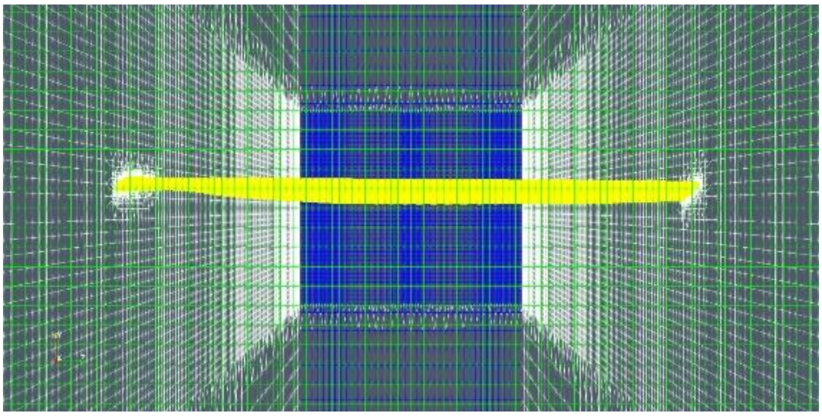
Radial position from hub (%)	Chord length (%)	Twisted angle (deg)
0,15	1,00	28,13
0,21	0,96	22,06
0,27	0,93	17,53
0,32	0,89	14,11
0,38	0,85	11,46
0,44	0,82	9,35
4,92	0,78	7,63
0,55	0,75	6,21
0,61	0,71	5,02
0,66	0,67	4,00
0,72	0,64	3,12
0,77	0,60	2,36
0,83	0,56	1,70
0,89	0,53	1,08
0,92	0,49	0,88
1,00	0,45	0,63



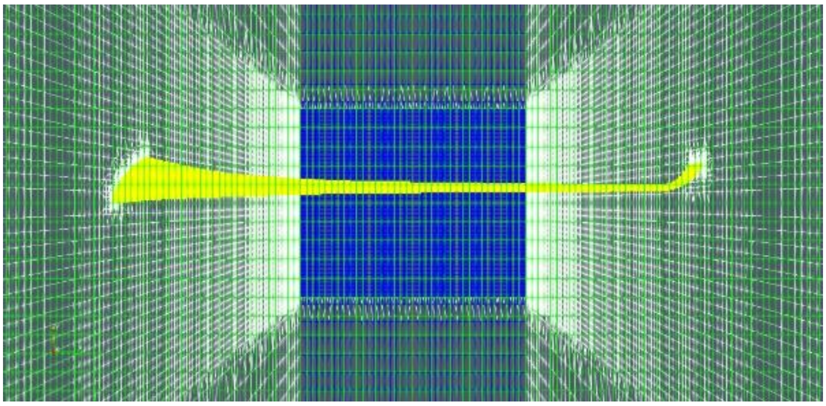
(a) (b)

Figure 1. (a) Original Clark Y foil, (b) Modified Clark Y foil with 30° winglet

The 3D CFD preprocessing utilizes blockMesh and snappyHexMesh features. The domain, which is set in the blockMeshDict, is a rectangular block using structured mesh. Original foil has 1,865,194 cells with simple grading (constant cell size) in all directions. The spacing in all directions is maintained to be constant for both models. The grid of both models is shown in Figure 2.



(a)



(b)

Figure 2. (a) Original Clark Y foil grid, (b) Modified Clark Y foil grid

The result of mesh statistics and mesh checking from OpenFOAM are shown in Table 3.

Table 3. Twisted angle in accordance with foil position.

Parameter	Value
Cells	1865194
Max aspect ratio	11.6589
Mesh non-orthogonality max	62.0293
Mesh non-orthogonality average	6.1472
Max skewness	53.045
Average skewness	4.342

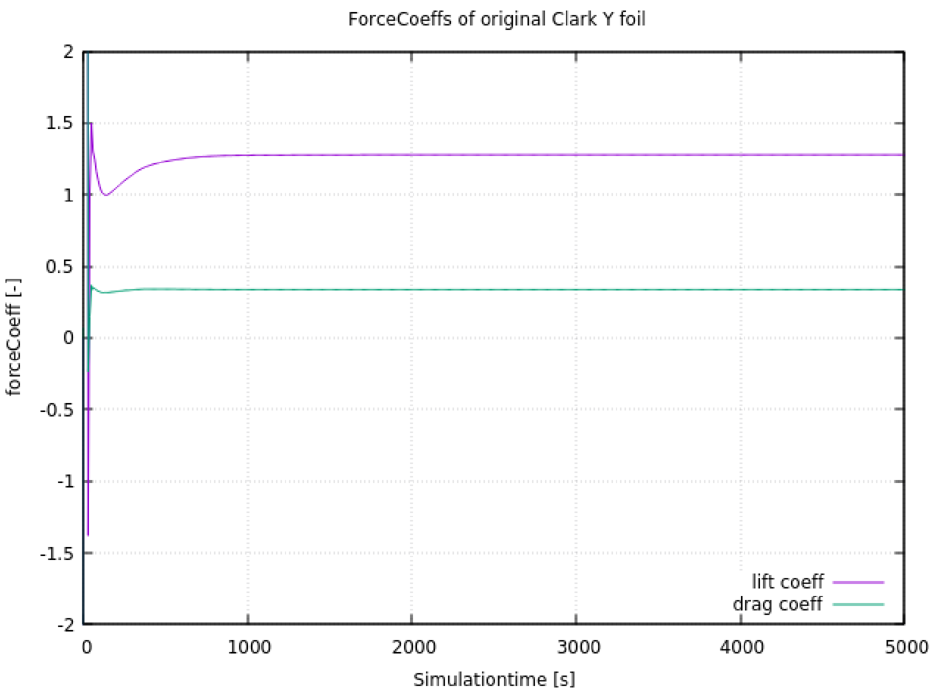
This simulation uses air as a working fluid, for the fluid properties are shown in Table 1. The simulation in this research is performed under steady conditions, the turbulence model uses k-ω, and for the algorithm using SIMPLE with linear interpolation as suggested by [25], the residual for all parameters is 10^{-5}.

Table 4. Fluid properties

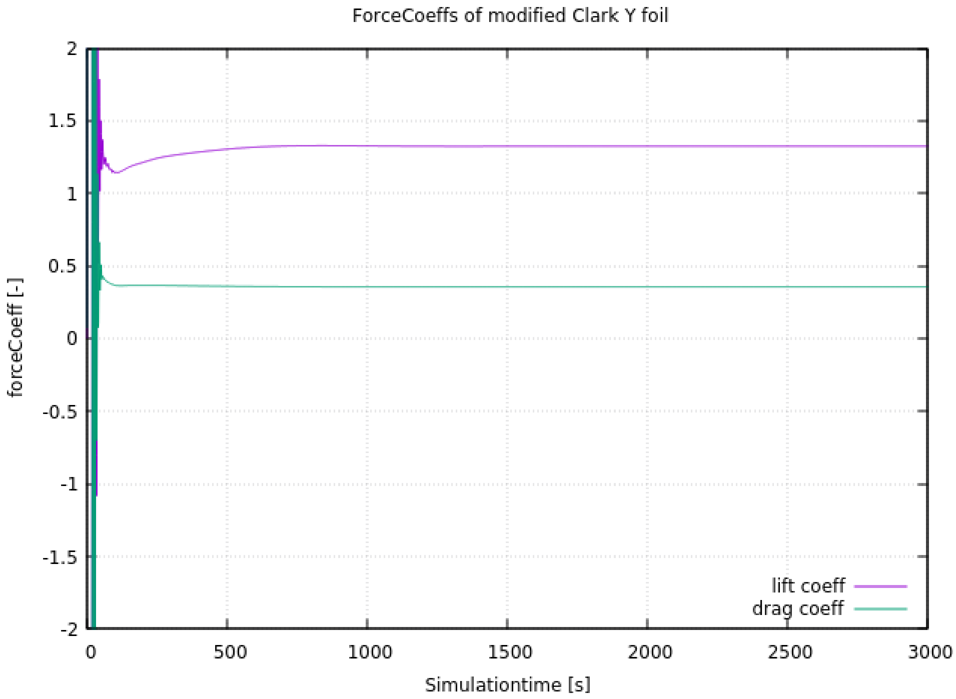
Parameter	Value
Density	1.225 kg/m^3
Velocity	12.5 m/s
Reynold Number	0.32 x 10^6
Kinematic Viscosity	1.562 x 10^{-3}

5. EXPERIMENT AND ANALYSIS

Force coefficients are considered the performance indicators in this study. Lift and drag coefficients are recorded during the simulation and plot to confirm the steadiness of the result. The lift and drag coefficients are recorded during the simulation, as shown in Figure 3.



(a)



(b)

Figure 3. Lift and drag coefficients plot: (a) original Clark Y foil, (b) modified Clark Y foil.

Figure 3 shows that unsteadiness is found at the beginning of the iteration before it reaches 500 iterations. After 500 iterations, the coefficients of both foils are becoming relatively constant. However, at the beginning of the original case, the coefficients are likely to have more fluctuations than the modified one. This may indicate that the simulation of the modified foil is more stable.

Figure 3 also reveals that the lift coefficient of the modified foil is higher than the original Clark Y foil. The original and modified foils have lift coefficients of 1.2795 and 1.3253, respectively. The winglet, added in the Clark Y profile used for a wind turbine blade, increases lift force to 3.5%. The overall performance of three-bladed wind turbines is required to be studied further to confirm the turbine improvement compared to the use of the original Clark Y.

Similar to the lift coefficient, the drag coefficient value of modified foil has a higher magnitude than the original one. The drag coefficient of the original foil is 0.336, whereas the modified foil has 0.355. The higher drag coefficient should be taken into consideration as this might give another effect on the turbine performance; thus, as mentioned earlier, the overall performance of the three-bladed horizontal axis wind turbine needs to be evaluated rigorously to confirm the enhancement as the result of the winglet profile.

6. Conclusion

This paper investigated the effect of the winglet profile added at the tip of a wind turbine blade using the Clark Y profile. The investigation is performed by developing a 3D CFD model in OpenFOAM 8 using wingMotion solver. From the result, it can be concluded as follow:

1. The additional winglet profile enhances the lift coefficient by 3.5% thus likely will improve wind turbine performance.
2. The additional winglet profile also affect of increasing the drag coefficient to 0.355.
3. Further research is needed regarding the appropriate shape of the winglet profile to produce the minimum possible drag coefficient with the maximum possible lift coefficient.

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