CFD Study on The Influence of Gurney Flap Width to Wind Turbine Aerodynamics Performance of The Asymmetrical Airfoil

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Abstract. In a wind turbine, the blade is a key component that functions to cap-ture wind energy. Wind turbine blades have the ability to convert kinetic energy into force due to their curved shape, known as an airfoil. Design modifications, such as adding components like a gurney flap to the airfoil, can increase lift force and delay stall. The CFD study aimed to compare the influence of gurney flap width as the wind turbine application. The turbulence model applied in this simulation was the k-ω SST and scheme of solution methods was Coupled. The temperature used in this study was 288 K, with a Reynolds number of 600,000. The addition of the GF was set with a length of 1.25 percent-c and the position of 0 percent-c. The GF was installed at a 90-degree downward angle, as the goal was to achieve an increase in lift force (positive lift force value). The variation of the width were 0.75 percent-c, 1 percent-c, and 1.25 percent-c. The results showed that gurney flap affects the aerodynamics performance of airfoil by increasing the value of CL/CD. For wind turbine application (low velocity), gurney flap with 1%c width has the highest value of C_L/C_D.
Keywords: Airfoil, gurney flap, CFD, wind turbine, CL/CD

1 Introduction

One of the most promising alternative energy sources worldwide is wind energy. One of the devices used to convert wind energy into electricity is a wind turbine. In a wind turbine, the blade is a key component that functions to capture wind energy. Therefore, the blade has a significant impact on the aerodynamic performance of a wind turbine system [1]. Wind turbine blades have the ability to convert kinetic energy into force due to their curved shape, known as an airfoil. This force is generated by the pressure difference between the two surfaces of the airfoil (upper and lower). In designing an airfoil, it is important to focus on its ability to increase lift force, thereby enhancing the utilization of wind energy [2]. Moreover, design modifications, such as adding components like a gurney flap to the airfoil, can also increase lift force and delay stall [3]. A Gurney flap (GF) is a small plate added to the airfoil to improve its performance [4]. According to Aramendia et al. [5], the gurney flap (GF) is a propeller that is perpendicular to the airfoil surface, measuring between 0.1% and 3% of the airfoil's chord length. A comparison of airflow on airfoils with and without a GF can be seen in Fig. 1. Based on their research, Bianchini et al. concluded that to maximize the performance of an airfoil, the GF length should not exceed 2% of the chord length [3].

The utilization of wind energy as a power source in Indonesia is closely related to the available potential. Along the southern coast of Java, wind speeds range between 6-9 m/s, which is classified as low wind speed. This CFD study aimed to gather information on the effect of adding a gurney flap (GF) to the NACA 63-215 airfoil with varying width and angles of attack (AoA), in its application as a wind turbine. The results obtained were C_L/C_D of each variation. C_L is the ratio of the lift force produced by a surface to the dynamic pressure of the fluid and the reference area, while C_D is the ratio of the drag force to the dynamic pressure of the fluid and the reference area. Meanwhile C_L/C_D is the ratio to measure the aerodynamic efficiency of a shape or design.

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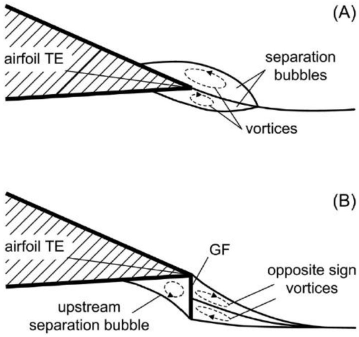


Fig. 1. (a) Flow on an airfoil, (b) Flow on an airfoil with a gurney flap [3]

2 Research Methods

2.1 Design

The airfoil used in this study was the NACA 63-215, as shown in Fig 2. This type of airfoil was asymmetrical, meaning the lengths of the upper and lower curves are different.

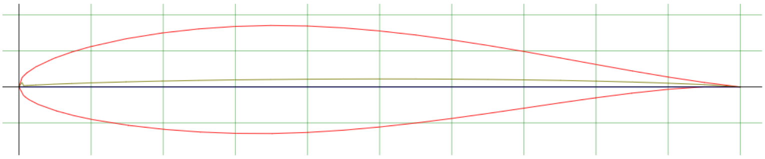


Fig. 2. Geometry of NACA 63-215 [6]

The addition of the GF was done based on previous research findings, with a length of 1.25%c [7], and the recommended position being 0%c, which is at the trailing edge [8]. The GF was installed at a 90-degree downward angle, as the goal was to achieve an increase in lift force (positive lift force value). The variation of the width were 0.75%c, 1%c, and 1.25%c. The installation of the GF on the NACA 63-215 airfoil is shown in Fig. 3.

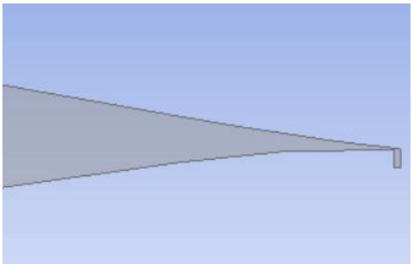


Fig. 3. The installation of the GF on the NACA 63-215 airfoil

2.2 Governing Equation

Conservation of mass

$$\frac{\partial \rho}{\partial t} + \nabla.[\rho \boldsymbol{V}] = 0 \tag{1}$$

Conservation of momentum

$$\frac{\partial(\rho \boldsymbol{V})}{\partial t} + \nabla.[\rho \boldsymbol{V}V] = -\nabla.P + \nabla.\tau \tag{2}$$

with ρ is gas density, V is velocity, and τ is shear stress.

Conservation of total energy

$$\frac{\partial(\rho E)}{\partial t} + \nabla.[\boldsymbol{V}(\rho E)] + \nabla.(\boldsymbol{V}P) + \nabla.(\tau.\boldsymbol{V}) + \nabla.q = 0 \tag{3}$$

with E is the total energy.

2.3 Simulation Setting

The simulation was conducted using Ansys Student version. The general steps of the simulation are as follows:

1) Geometry design
   In this study, the NACA 63-215 airfoil was imported from the website airfoiltools.com. The chord length used was 1 meter with the addition of a 1.25 cm GF. A C-shaped domain was applied. Fig. 4 provides a general view of the airfoil within the C-shaped domain.

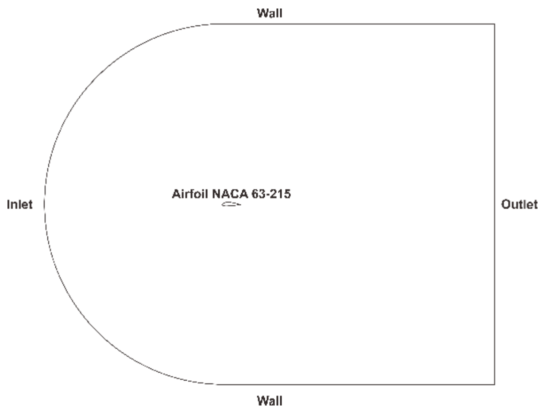


Fig. 4. Schematic of the NACA 63-215 in the C- shaped domain

2) Meshing
   In CFD, meshing is a critical process due to its significant impacts to the final results. In this study, the type of mesh used was quadrilaterals.
3) Setup
   The temperature used in this study was 288 K, with a Reynolds number of 600,000 (wind speed of 9 m/s), and airfoil position was set to unbound. The turbulence model applied in this simulation was the k-ω SST and scheme of solution methods was Coupled.

2.4 Validation

Validation is a crucial process in any simulation, as it relates to the reliability of the simulation data being studied. In this research, validation was carried out by comparing preliminary simulation results with experimental data from airfoiltools.com. The smaller the difference between the simulation results and the experimental data, the more accurate data. Therefore, if the simulation results closely match the experimental results (with minimal error), the simulation can proceed to data collection.

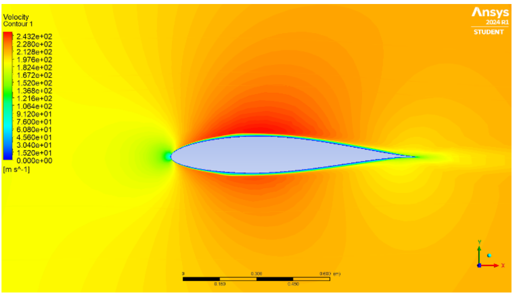
3 Results and Discussion

3.1 Validation

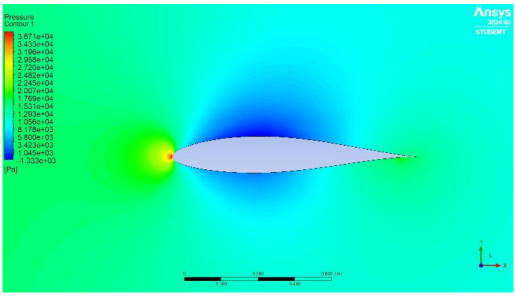
Table 1. Validation data

Elements Number	Nodes Number	C_L			C_D		
		CFD	Exp	Error	CFD	Exp	Error
224673	225493	0.1612	0.175	7.89%	0.007452	0.00626	19.04%

Table 1 shows the difference value of C_L (coefficient of lift) and C_D (coefficient of drag) between CFD and experimental study. Using elements number of 224673 and nodes number of 225493, the results show that error of C_L value is 7.89%, which is relatively small. Moreover, the difference between CFD and experimental study of C_D is also small, namely 19.04%. From the data above, it can be concluded that parameter used for the validation study, may be applied for the present numerical study. Fig. 5 presents the (a) velocity and (b) pressure distribution of NACA 63-215 with no GF on AoA 0°.



(a)



(b)

Fig. 5. Velocity (a) and pressure (b) distribution of NACA 63-215 with no GF on AoA 0°

3.2 Aerodynamics Performance of Airfoil 63-215

Aerodynamics performance studied in this simulation is C_L/C_D which represents the ratio of coefficient of lift and coefficient of drag. The higher C_L/C_D indicates the better aerodynamics performance of the airfoil. Theoretically, adding GF will affect the value of C_L and C_D.
Fig. 6 shows the C_L/C_D value of airfoil NACA 63-215 with and without GF. The diagram shows that the additional of GF increasing the value of C_L/C_D. The width variation of GF resulting the slightly difference value of C_L/C_D. As can be observed in the curve, the highest C_L/C_D experienced by GF width of 1%c.

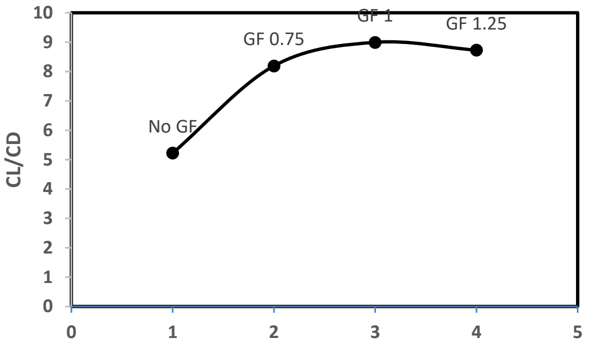


Fig. 6. C_L/C_D value of airfoil NACA 63-215 with and without gurney flap

Table 2 and 3 represent the velocity contour and streamline of airfoil NACA 63-215 with and without GF on AoA 0°. The contour shows that with no GF, the flow at the trailing edge is smooth without any disturbance. There is no additional generation observed at the trailing edge. Furthermore, with additional GF of 0.75%c, the flow at trailing edge shows the difference pattern. It indicates the flow disturbance due to the addition of GF. As can be observed under the GF, the blue colour, which represents the low velocity and surely the high pressure, appears. It indicates the higher lift of the airfoil. For GF 1 and 1.25%c, the similar pattern appears under the GF, which also represents the high lift of the airfoil. The same phenomenon observed in streamline, where velocity under the GF is lower, affects the pressure to be higher. It causes the C_L of airfoil increased.

Table 2. The velocity contour of NACA 63-215

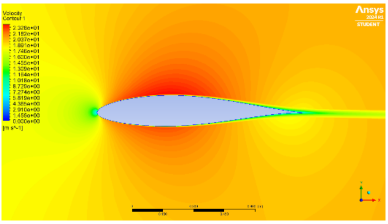
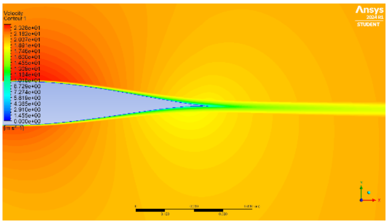
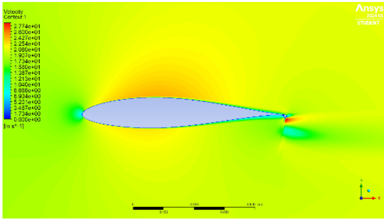
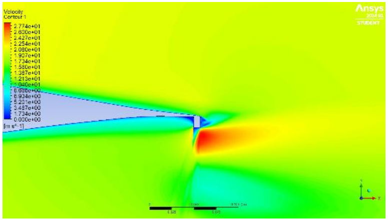
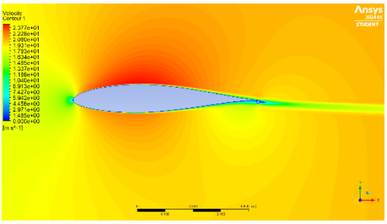
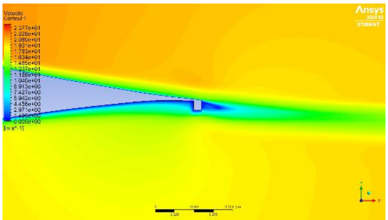
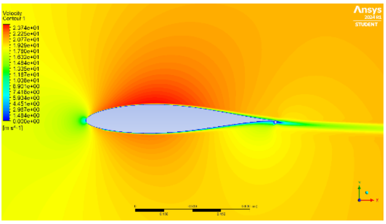
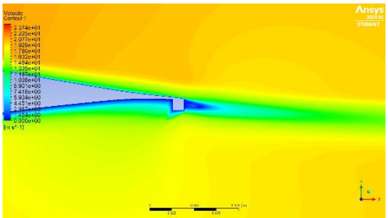
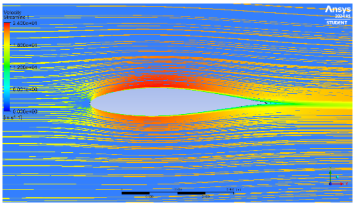
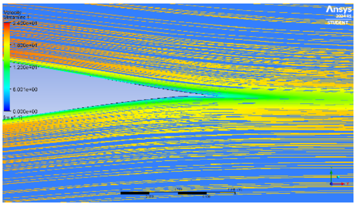
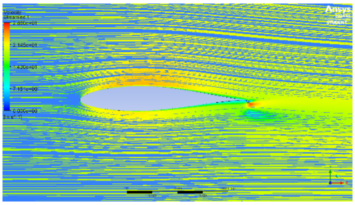
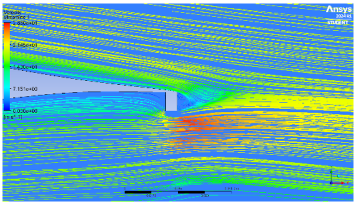
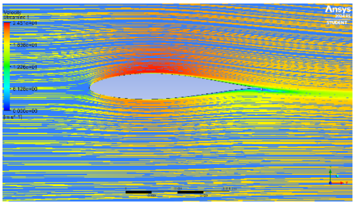
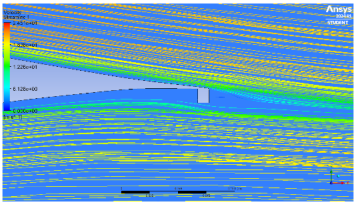
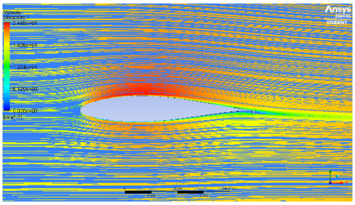
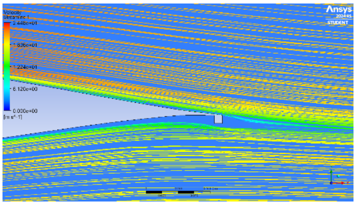
GF Width	Velocity contour of the airfoil	Velocity contour at the airfoil trailing edge
No GF		
0.75%c		
1%c		
1.25%c		

Table 3. The velocity streamline of NACA 63-215

GF Width	Velocity streamline of the airfoil	Velocity streamline at the airfoil trailing edge
No GF		
0.75%c		
1%c		
1.25%c		

4 Conclusion

The numerical study of NACA 63-215 with addition of gurney flap has been conducted. Velocity applied was 9 m/s as the application of this airfoil is for wind turbine. Based on the study conducted, there are some conclusions than can be drawn as follows:

1) Gurney flap affects the aerodynamics performance of airfoil by increasing the value of C_L/C_D.
2) For wind turbine application (low velocity), gurney flap with 1%c width has the highest value of C_L/C_D.

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