

Optimization of Propellerless Wind Power Potential Through Multidimensional Approach and Internet of Things

Samsul Ma'arip^{a,1}, Naufal Athiyya Hammam^{a,2}, Hasan Adi Nugraha^{a,3}, Nazwa Nurannisa P S^{a,4}, Riski Firnanda^{a,5}, Muhammad Aulia Rahman^{a,6*}

^a Universitas Gadjah mada, Yogyakarta, 55281, Indonesia

¹ samsulmaarip@mail.ugm.ac.id; ² naufalathiyahammam@mail.ugm.ac.id; ³ hasan.adi2002@mail.ugm.ac.id;

⁴ nazwa.nurannisa2804@mail.ugm.ac.id; ⁵ riskifirnanda@mail.ugm.ac.id; ⁶ muhammadaulia@ugm.ac.id*,

*corresponding author

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ABSTRACT

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This study optimizes propellerless wind power generation using a multidimensional approach and IoT technology. CFD simulations identified the S1210 airfoil as optimal due to its efficiency at low Reynolds numbers. The simulations revealed that a 9-degree angle of attack produced higher velocity and lower pressure, enhancing airflow and theoretical power output. Further simulations varying the distance between mirrored airfoils showed that an optimal distance exists for different wind speeds. An IoT system was then implemented to adjust this distance dynamically. Through in-depth analysis of airfoil design, material selection, and the application of IoT technology, this research pioneers a way to improve wind farm efficiency, overcome efficiency challenges at low wind speeds, and reduce maintenance costs. Its contribution is not only limited to the development of cleaner renewable energy technologies, but also opens the door to a deeper understanding of wind energy dynamics and its utilization on a large scale.

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I. Introduction

The challenge of emissions generated in an effort to fulfill electrical energy has an answer from the potential that Indonesia has. One of the great potentials that can answer these problems is wind energy [1]. According to the Handbook of Energy & Economic Statistics of Indonesia 2021, the installed capacity of wind power plants (PLTB) in Indonesia has only reached 157.41 megawatts (MW), with most of them connected to the national electricity grid (PLN) and a small portion outside the PLN network [2]. With 60 GW of wind energy potential, there is still a significant gap between the potential and utilization of wind energy in Indonesia. Currently, only 154 MW of wind power generation facilities have been installed [3].

Wind power plants in Indonesia currently use windmills and their large size requires large areas of land and difficult distribution process of turbine blades. The presence of turbines also endangers local fauna caused by the vibration generated, as well as potentially generating noise [4]. This research aims to address these challenges by optimizing an innovative solution using Aeromine Model Vortex Bladeless technology proposed by Sandia Laboratory and Texas University [5]. Through in-depth analysis of airfoil design and the application of IoT technology, this research pioneers a way to improve wind farm efficiency, overcome efficiency challenges at low wind speeds, and reduce maintenance costs [6]. Its contribution is not only limited to the development of cleaner renewable energy technologies, but also opens the door to a deeper understanding of wind energy and also opens the door to a deeper understanding of wind energy dynamics and its utilization on a large scale.

This research aim adopts the concept of a propellerless wind power plant that is free of noise pollution. With a compact and minimalist design, this tool does not require a large area for installation



so that it is possible to be applied in urban, residential, rural areas, especially tall buildings to deal with energy fulfillment problems by presenting environmentally friendly energy solutions.

The model wind power generation technology employs the use of mirrored airfoils to create low-pressure zones [7]. These zones are formed between two airfoils, which are equipped with suction holes that direct air from atmospheric pressure into the low-pressure zone. This airflow then passes through the turbine towards the low-pressure area.

To guarantee the suitability of the wind power plant model for Indonesian wind conditions, which typically exhibit lower speeds than those observed in the country of origin of previous research, further research is required on several pivotal variables. These variables encompass the type of airfoil, the angle of attack of the airfoil, the distance between the airfoils, and the optimal orifice configuration. This study will concentrate on determining these variables through engineering-based research.

II. Research Methods

This research began with reverse engineering previous studies to determine the most efficient airfoil type. The initial step involved selecting the appropriate airfoil type based on preliminary analysis. The optimal angle of attack was then determined using two-dimensional (2D) Computational Fluid Dynamics (CFD) simulations.

Upon identifying the optimal angle of attack from the 2D simulations, the study progressed to three-dimensional (3D) CFD simulations to obtain more accurate pressure contours. The 3D CFD simulations, as illustrated in Figure 1, used a model geometry which was reduced by half and then simulated using Ansys' symmetry feature, which resulted in a more efficient computational process. Furthermore, the CFD simulation is then validated by experiments using test specimen illustrated in Figure 2.

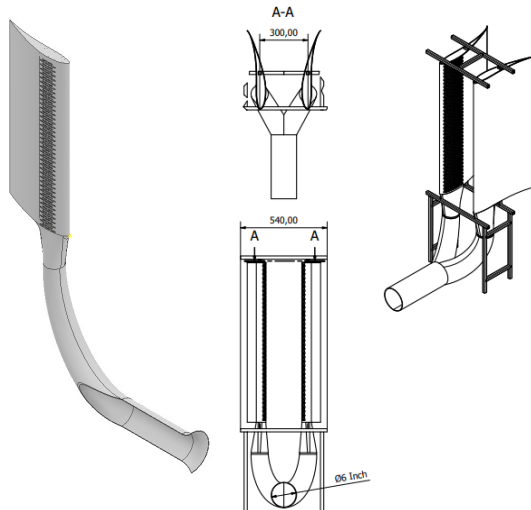


Fig. 1. The Geometry Model Used on CFD Simulation

All CFD simulations were conducted as single-phase simulations, using air as the working fluid. These simulations were crucial for accurately modeling the airflow behavior around the airfoil surfaces and within the overall system. The governing equations for these simulations are the continuity and momentum equations, which were solved for all computational cells to ensure a comprehensive understanding of the fluid dynamics involved [8]. The continuity equation, which ensures mass conservation, is expressed as:

$$\frac{\partial \rho}{\partial t} + \nabla \cdot (\rho \mathbf{U}) = 0$$

$$\frac{\partial (\rho \mathbf{U})}{\partial t} + \nabla \cdot (\rho \mathbf{U} \times \mathbf{U}) = -\nabla p + \nabla \cdot \boldsymbol{\tau} + \mathbf{S}_M$$

The Continuity and Momentum Equations

Where ρ represents air density, U is the velocity vector, t is time, p is pressure, τ is shear stress, and $S m$ is the momentum source. These simulations were performed under steady-state conditions, varying airspeed, angle of attack, and the distance between mirrored airfoils. A no-slip condition was applied to airfoil surfaces in contact with the fluid, ensuring no relative motion between the fluid and the wall. The SST $k - \omega$ model was employed, combining the strengths of the $k - \omega$ model near walls and the $k - \epsilon$ model in free-stream flow. This hybrid model excels at handling wall-bounded flows and sharp pressure gradients, providing accurate predictions of transition flows between laminar and turbulent states [9].

The optimal outlet hole position on the airfoil was determined. Proper hole placement is crucial to prevent ineffective flow distribution that could reduce system efficiency [10]. Initial simulations indicated that improper hole positioning led to uneven airflow and decreased theoretical power output. After identifying the optimal hole position, the theoretical power output or exergy was calculated [11]. Following the CFD analysis, the best design was prototyped and field-tested to compare CFD results with real-world performance under operational conditions. Field tests varied airspeeds, measuring key parameters such as flow velocity between the airfoils and inlet airflow velocity. This comparison between simulation and actual performance aimed to develop a more efficient propellerless power generation model, leveraging in-depth CFD analysis and comprehensive experimental validation.


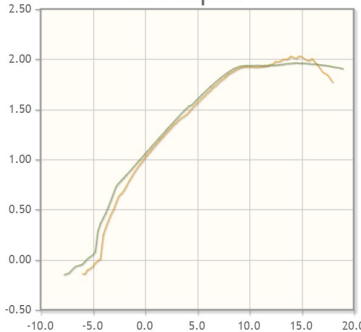
III. Results and Discussion

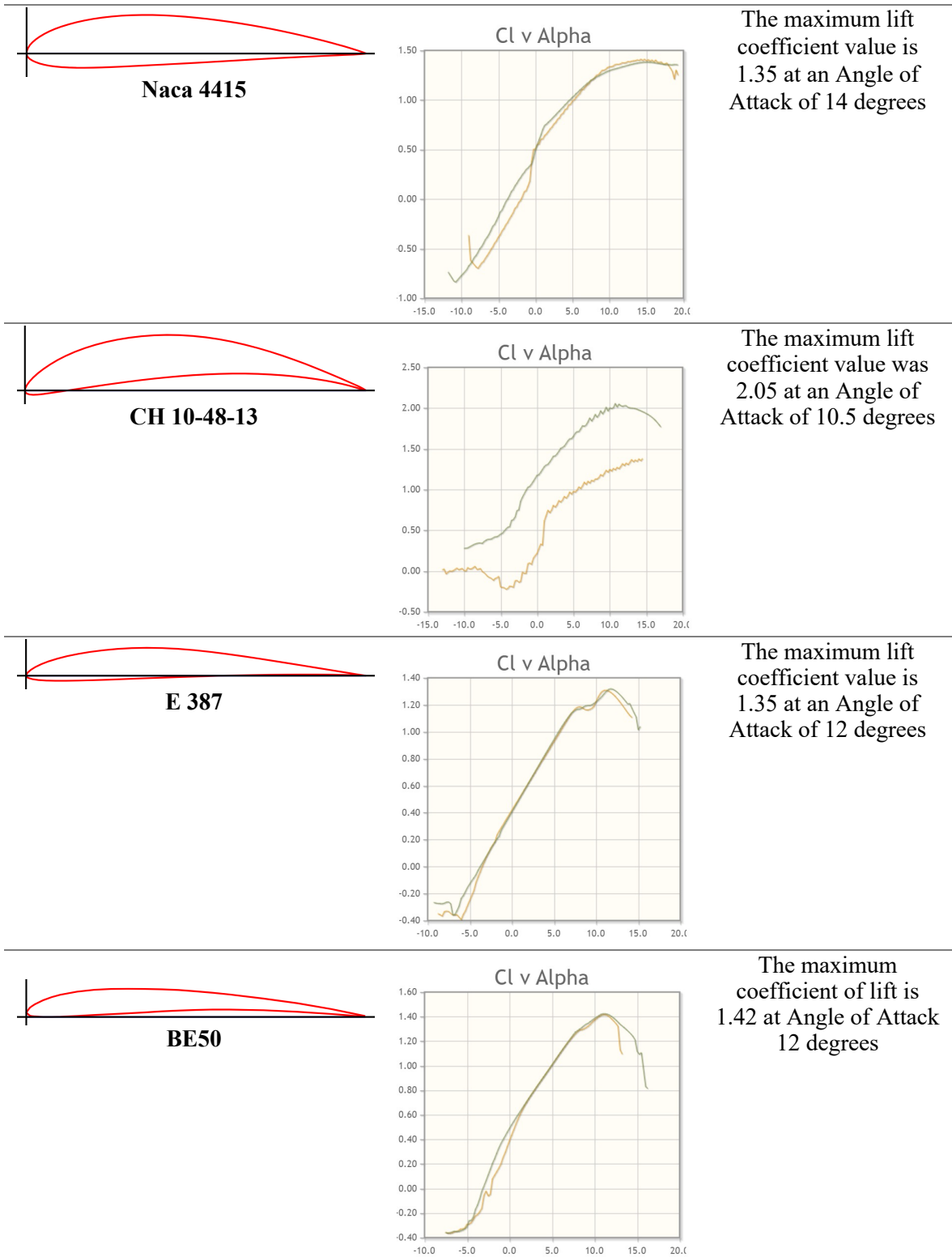
A. Analysis of Lift Coefficient and Angle of Attack on Airfoil

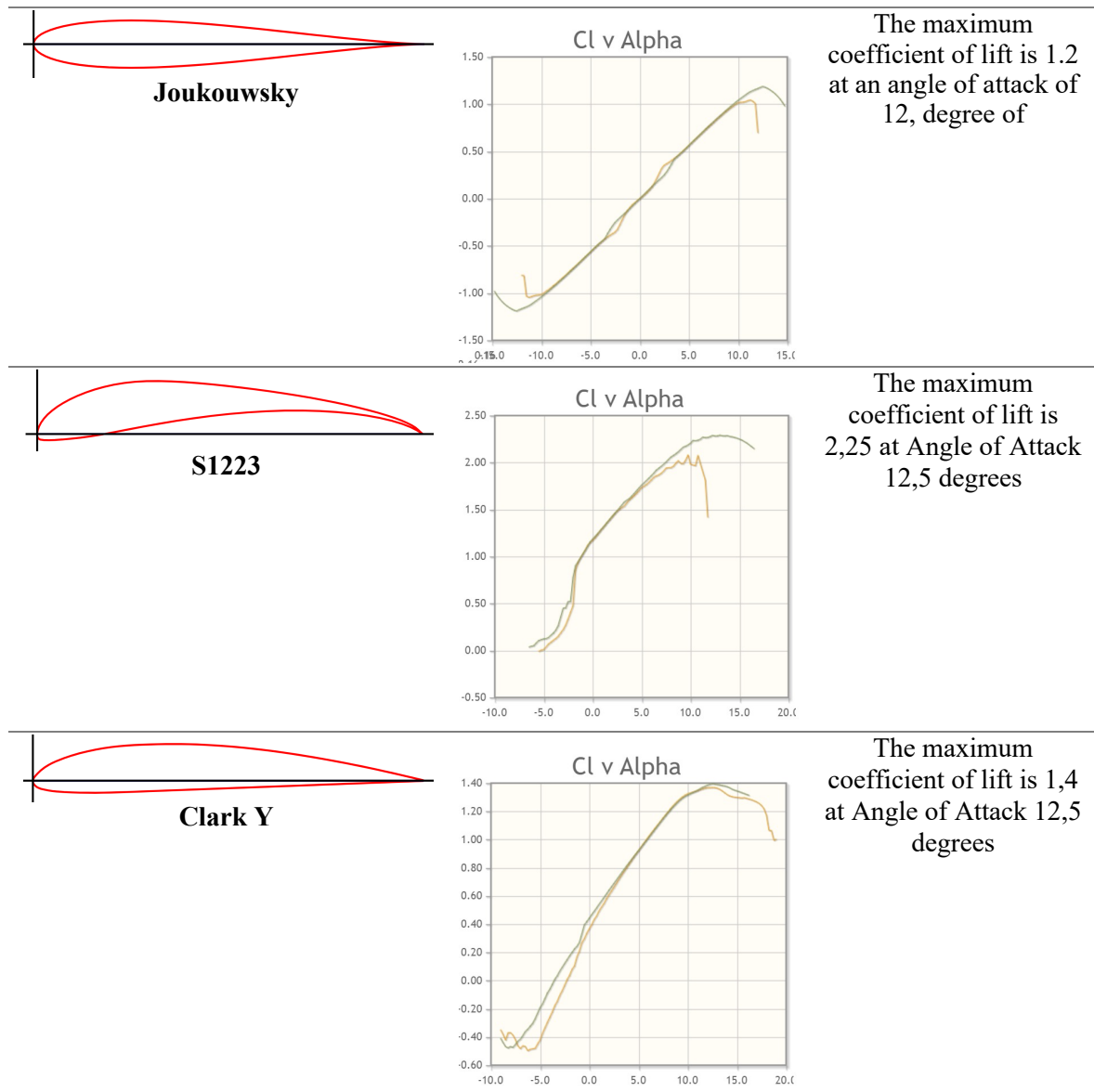
Various airfoil types were analyzed based on variations in angle of attack (AoA) and the resulting lift coefficient (Cl). The results indicated that the S1210 airfoil demonstrated a stable increase in Cl, reaching its maximum value without significant signs of stall. The green line in the graph represents the lift coefficient (Cl) versus angle of attack (AoA) at a Reynolds number (Re) of 200,000, while the yellow line shows the Cl versus AoA at a Reynolds number (Re) of 100,000.

This makes the S1210 ideal for conditions with low Reynolds numbers. In contrast, other airfoils like NACA 4415, S1223, Joukowsky, CH 10-48-13, E 374, BE50, and Clark Y exhibited unique aerodynamic characteristics but did not achieve Cl values as high as the S1210. The selection of the S1210 airfoil was based on its ability to generate high lift and maintain aerodynamic stability at low wind speeds, accelerating airflow and creating low pressure when two such airfoils are mirrored. Implementing the S1210 airfoil is expected to enhance the performance of the test setup by increasing the amount of airflow entering the inlet.

Table 1. Specimen Composition

Airfoil Names and Shapes	Cl vs AoA	Result
 <p data-bbox="424 1547 504 1576">S1210</p>		<p data-bbox="1118 1464 1385 1592">Maximum Coefficient lift value of 2 at 9 degrees Angle of Attack</p>





B. Velocity and Pressure Between Two Reflected S1210 Airfoils

The S1210 airfoil was chosen because it has the ability to generate a considerable pressure difference, which can be represented by the coefficient of lift (Cl), at low Reynolds numbers, making it ideal for the application. Variations in angle of attack (AoA) were tested using Computational Fluid Dynamics (CFD). The results show that at an angle of attack of 9 degrees, this airfoil produces the highest flow velocity and lowest pressure at the center of the test specimen, which then increases the airflow through the inlet hole, resulting in greater theoretical power. The average velocity in this test was about 4 m/s.

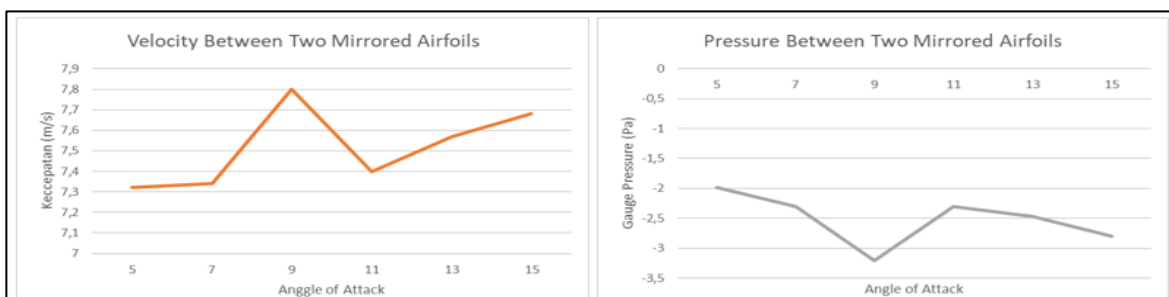


Fig. 2. Graphical Difference Between Pressure and Velocity

The analysis was performed under no-slip conditions and utilized meshing with inflation layers to ensure high accuracy in capturing flow details near the airfoil surface. The no-slip condition was critical in accurately modeling the behavior of the fluid in contact with the airfoil, ensuring that the simulated airflow closely mirrored real-world conditions. The inflation layers in the mesh were strategically designed to enhance resolution near the airfoil surface, capturing the subtle variations in velocity and pressure that are essential for precise aerodynamic analysis.

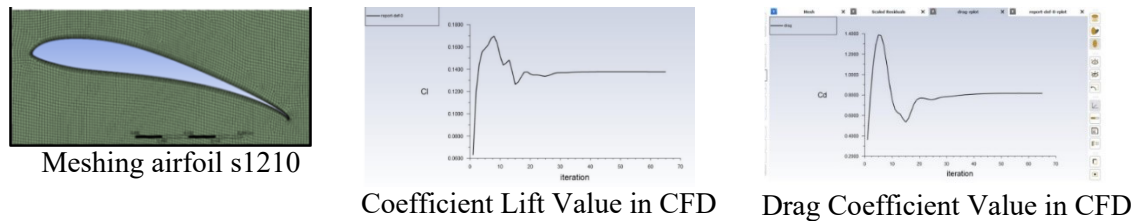


Fig 3. Specimen Composition

In the test, the C_l and C_d values were homogeneous at the 20th iteration, so the validity of the test can be accounted for. The graph shows that the higher the airflow velocity, the lower the pressure, in accordance with the principle of Bernoulli's law. The effect of the distance between the two mirrored airfoils also affects the pressure difference in accordance with the Venturi effect. The relationship between the pressure difference and the distance between the two airfoils is tested through 3D analysis.

C. Three-Dimensional Analysis through Multi-dimensional Approach

After determining the most optimal angle of attack in the 4 m/s velocity range, a more in-depth three-dimensional analysis was conducted to examine the effect of distance on the theoretical power generated. In the three-dimensional analysis, the intake manifold causes the inside flow pressure to be lower, thus increasing the airflow through the inlet hole. The lower pressure around the orifice causes airflow to flow through the inlet, which is then used as the basis for calculating theoretical power. A multidimensional approach was taken by varying the spacing between airfoils in the test scheme, so as to obtain the relationship between theoretical power and spacing. The test aims to evaluate how the variation in spacing affects the theoretical power generated by the system, as well as identify the optimum spacing that produces the maximum theoretical power.

The resulting graph illustrates the relationship between exergy (theoretical power output) and airspeed across various distances between two mirrored airfoils. The data indicate an optimal distance variation within the speed ranges of 2 m/s and 4 m/s. To optimize the generated power, an Internet of Things (IoT) based system was implemented, allowing for dynamic adjustment of the distance between the airfoils based on the surrounding airflow speed. This approach ensures optimal performance under diverse operational conditions.

D. Testing the effectiveness of the tool through the creation of airfoil manufacture

Testing was conducted by measuring the airspeed between two mirrored airfoils at the Faculty of Geography building, Universitas Gadjah Mada. In the mirrored airfoils, an increase in air volume causes a decrease in pressure, which ultimately enhances exergy power. This phenomenon occurs due to the increased mass flow rate resulting from the large amount of air being drawn through the inlet. The observed speed difference is primarily due to high-pressure drops and conventional manufacturing methods. This is evident from Figure 6, which shows a comparison of wind speeds between free air and the airflow around the airfoil.

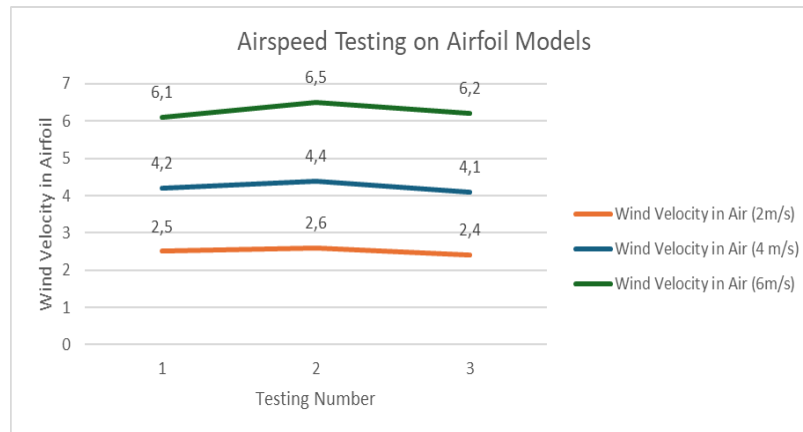


Fig. 4. The Ratio Between Wind Speed in Air and Airfoil

IV. Conclusion

CFD simulations in this study aimed to find the optimal model for a propellerless wind power generation system. The S1210 airfoil was chosen for its ability to enhance airflow at low Reynolds numbers. Simulations varying the angle of attack showed that a 9-degree angle produced higher velocity and lower pressure, improving airflow through the inlet and increasing theoretical power output. Further simulations identified optimal distances between two mirrored airfoils at various speeds. An IoT-based system was then implemented to dynamically adjust this distance based on airflow speed. The propellerless wind power system offers several advantages: reduced noise pollution, minimal risk to wildlife, lower maintenance costs, and longer operational lifespans. The IoT integration ensures real-time optimization, enhancing efficiency in varying wind conditions. This innovative approach not only improves renewable energy technology but also provides deeper insights into wind energy dynamics and its large-scale utilization.

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