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Comparative Performance of NACA 6409 9% and NACA 0012 Airfoils on Savonius Hydrokinetic Turbine Using CFD

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ABSTRACT

This study investigates the potential of river water energy in Magelang District as an alternative source of electricity. The research method includes measuring the river's width, depth, and flow velocity, followed by calculating the discharge. Computational Fluid Dynamics (CFD) simulations were used to evaluate the performance of a Savonius turbine with NACA 6409 9% and NACA 0012 blades. The novelty of this research lies in optimizing Savonius turbine efficiency by assessing the influence of different blade geometries on turbine performance in river applications. Simulation results show that blade geometry significantly affects water flow dynamics, causing velocity spikes at the blade tips and varying pressure distributions between the two profiles. Furthermore, the study highlights substantial turbulence downstream of the turbine. These findings provide critical insights for enhancing Savonius turbine design, improving river water energy utilization, and offering practical solutions for renewable power generation in Magelang District.

Keywords: Air foil, Coefficient of Pressure, Renewable Energy, Savonius Hydrokinetic Turbine.

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1. Introduction

For rural communities, electrical energy plays a very important role in meeting daily needs. Electrical energy can help in efforts to improve the quality of life and economic growth in rural areas (Ikhsan and Amri, 2022). In helping to meet the needs of electrical energy in rural areas, the solution that can be used is the use of renewable energy. One of the renewable energies that has good potential to be applied in rural areas is water energy. Later, it will utilize the potential of river water flow as renewable energy in providing alternative electrical energy (Ridgill et al., 2022). The utilization of water energy as a renewable energy source is supported by its potential in Indonesia, which is estimated to reach 75,000 MW, but which has only been utilized around 10.1% or 7,572 MW (Sugiyono et al., 2014). Water energy is usually used by utilizing the high fall of water and large water discharge. The principle uses mechanical energy from water flow, which is a transformation of gravitational potential energy to drive a turbine or mill (Apriani et al., 2020). However, utilizing river water flow can also be applied if the speed is sufficient.

The river basin of Magelang Regency, Central Java, has the potential for water energy that can be utilized as a source of electrical energy. The river area, which is dominated by village settlements, is expected to be utilized to meet the electrical energy needs in the vicinity. Based on pre-experiment data conducted, the river has a width of about 5 meters with the deepest depth of about 94 cm, and the average velocity of river flow ranges from 0.55 - 0.92 m/s. Utilization of water energy potential in Magelang Regency as a power plant can be done by using Savonius-type turbine technology. Savonius-type turbines include vertical-axis turbines that can rotate at fairly low angular velocity conditions, can receive movement from all directions, and are cheap to manufacture (Djalal et al., 2023). In addition, Savonius-type turbines also have a relatively low tip speed ratio and power factor (Alit and Pamuji, 2016). Thus, Savonius-type turbines are suitable for small and simple purposes.

This research was conducted to determine the potential of river water flow in Magelang Regency for hydropower generation and to test the performance of Savonius-type turbines in the Magelang Regency River area on the electrical energy produced. By comparing experimental data from the water flow dynamics of the Magelang river using CFD methods with the NACA 6409 9% and NACA 0012 standards, we can verify and validate the CFD simulation results to ensure the accuracy of the flow model, assess the efficiency and performance of the Savonius turbine under real river flow conditions, and gain a deeper understanding of the flow characteristics in the Magelang river and their impact on turbine design. This comparison also allows for optimizing the turbine design to enhance its efficiency in generating electrical power from the river flow and ensures the relevance of the research to existing technologies, making it practically applicable to meet the electrical energy needs in rural areas. The importance of this comparison lies in ensuring that the proposed solution, the use of Savonius turbines, operates optimally and is well-suited to the specific flow conditions of the Magelang river.

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2. Literature Review

2.1 Hydrokinetic Energy Potential in Rivers and Its Application in Savonius Turbines

Hydrokinetic energy, which utilizes energy from water flow in rivers, has become a focus of research for the efficient and environmentally friendly utilization of renewable energy. Indonesia, with its many rivers spread across the country, has great potential to develop hydrokinetic energy as an alternative source of electricity. Ridgill et al. (2022) emphasize that hydrokinetic energy can be optimally utilized in areas with sufficient river flow, providing an efficient energy solution for remote regions in Indonesia.

The Savonius turbine, a vertical-axis turbine, is known for its ability to operate at low wind speeds or flow rates, making it suitable for application in rivers with varying flow speeds. Djalal et al. (2023) noted that Savonius turbines have advantages in terms of design simplicity and low production costs, making them an ideal choice for small-scale applications in rural areas. Additionally, hydrokinetic turbine technology like Savonius enables the effective and sustainable utilization of river flow energy.

2.2 Blade Design and Geometry in Savonius Turbines

Blade geometry design is a critical factor in the performance of Savonius turbines, directly influencing the energy efficiency produced. Various blade designs, such as half-circular blades or more advanced airfoil-based blades, have been tested to enhance turbine performance. Chaudhari and Shah (2023) in their study used the NACA 6409 blade profile and demonstrated that this blade provides greater torque, contributing to higher turbine efficiency compared to traditional blade designs.

Additionally, research by Napitupulu et al. (2014) showed that blades with a NACA 0012 profile can improve turbine performance, as their design is more flexible to variations in pitch angle, allowing the turbine to adapt to different water flow conditions. The success of this design in hydrokinetic turbine applications emphasizes the importance of selecting blade geometry that is suitable for local river conditions.

2.3 Application of Computational Fluid Dynamics (CFD) for Savonius Turbine Optimization

Computational Fluid Dynamics (CFD) methods are increasingly used to simulate fluid flow around hydrokinetic turbines, including Savonius turbines. The use of CFD allows researchers to explore and optimize various blade geometry designs without having to build physical prototypes. Research by Hamada and Fürth (2023) tested various turbulence models using CFD to analyze flow around Savonius turbines. The results of this study provide insights into the influence of design on pressure distribution and turbulence, which are crucial in determining energy conversion efficiency.

In another study, Irunokhai (2019) used CFD to analyze a Savonius turbine with NACA 0012 blade design and found that CFD simulations provided results consistent with physical testing, as well as a more detailed understanding of the interaction between fluid flow and turbine components. This demonstrates that CFD not only accelerates the design process but also enables more precise optimization of turbine performance.

2.4 Latest Innovations in the Development of Savonius Hydrokinetic Turbines

With technological advances and design innovations, Savonius hydrokinetic turbines are now more efficient and effective in converting energy from river flows. One of the latest innovations being tested is the use of deflectors to improve the performance of Savonius rotors. Patel et al. (2023) revealed that adding deflectors to the Savonius turbine design can improve power efficiency by reducing turbulence that occurs after the flow passes through the rotor.

This study shows that a better design, utilizing CFD technology, can significantly improve the performance of hydrokinetic turbines, even in locations with lower flow speeds.

2.5 Optimizing Energy Conversion in Savonius Turbines: Bernoulli's Principle and Kinetic Energy

The application of Bernoulli's Equation and the principles of kinetic energy conversion are integral to understanding the efficiency of Savonius turbines in fluid dynamics. Bernoulli's equation (1) describes the relationship between pressure, velocity, and potential energy in a fluid, stating that for incompressible and steady flow, the total energy remains constant. In the case of Savonius turbines, this principle explains how the kinetic energy of flowing water is converted into mechanical energy to drive the turbine. As the water flows, its kinetic energy, represented by

$$E_{kinetic} = \frac{1}{2}mv^2 \quad \text{.......................................} (1)$$

Where, m is the mass of the flowing fluid and v is the velocity of the fluid.

The turbine's efficiency is further influenced by the Tip Speed Ratio (TSR), which compares the tip speed of the turbine blade to the flow velocity. A low TSR is characteristic of Savonius turbines, and it is essential to account for the effects of high-flow conditions on energy conversion efficiency, with the equation 2 to determine how well the turbine performs in varying flow speeds.

$$TSR = \frac{v_{tip}}{v_{flow}} \quad \text{..................................} (2)$$

Where, v_{tip} is the tip speed of the turbine blade and v_{flow} is the velocity of the fluid flow.

The hypothesis of this study is that variations in the blade design of the Savonius turbine, specifically the NACA 6409 9% and NACA 0012 profiles, significantly impact the

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efficiency of energy conversion from river flow into electricity. The study aims to determine whether different blade geometries lead to substantial differences in turbine performance, with the expectation that the NACA 6409 9% profile will demonstrate higher efficiency in energy generation compared to the NACA 0012 profile.

3. Research Methodology

This research aims to assess the capabilities of a water turbine having diverse blade geometries, which is planned to be installed in a river. By examining various blade configurations, this research seeks to understand how blade geometry design affects turbine efficiency and overall functionality. It is expected that the findings obtained from this study will provide invaluable guidance for improving the efficiency and dependability of water turbines customized for implementation in rivers.

This research was conducted in the Ndas Gending river located in Gedongan Hamlet, Bondowoso Village, Mertoyudan District, Magelang Regency, Central Java. This location was chosen for the study because of its suitability for testing water turbines that have different blade geometries under conditions that reflect river conditions. Figure 1 and Figure 2 illustrate the research site which provides a visual representation of the river's placement within a broader geographical framework.

Figure 1. Research location of the Ndas Gending River

The measurement of the width and depth of the river is done by direct measurement in the field as shown in figure 2. The table 1 are the results of measuring the width and depth of the river. Figure 3 visually represents the cross-section of the Ndas Gending River, providing a detailed illustration of its width and depth measurements. This diagram is crucial for understanding the river's morphology, which directly impacts the potential for hydrokinetic energy generation. The cross-sectional view, derived from direct field measurements, helps in calculating the river's flow rate and subsequently in determining the suitability for installing Savonius hydrokinetic turbines. It highlights the varying depths across the river, essential data for the Computational Fluid Dynamics (CFD) simulations used in the study.

Figure 2. Width and Depth Measurement of Ndas Gending River

Based on the case study of river water flow shown in Table 1 and Figure 3.

Table 1. Width and Depth of Ndas Gending River

No	Measurement Points	Width (cm)	Depth (cm)	Segment Width (cm^2)
1	A-B	50	20-47	1675
2	B-C	50	47-81	3200
3	C-D	50	81-92.5	4337.5
4	D-E	50	92.5-94	4662.5
5	E-F	50	94-88	4550
6	F-G	50	88-89	4425
7	G-H	50	89-78	4175
8	H-I	50	78-79.5	3930
9	I-J	50	79.2-81	4005
10	J-K	50	81-69	3750
				38710

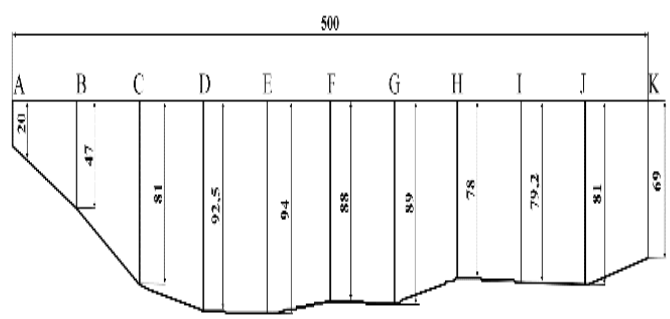

Figure 3. Cross-section of Ndas Gending River

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To measure the river flow velocity, a current meter was used. The results of the river flow velocity measurements are shown in Table 2 and Figure 4.

Table 2. Measurement of Flow Velocity of the Ndas Gending River

NO	Point	Distance (cm)	Round			Time (detik)		
			0,2 h	0,6 h	0,8 h	0,2 h	0,6 h	0,8 h
1	A	0	44	49	33	19.75	20.2	20.89
2	B	50	41	49	38	19.84	19.27	19.07
3	C	100	58	50	41	19.68	19.8	20
4	D	150	63	62	47	21.56	20.05	19.72
5	E	200	58	59	48	20.56	19.83	19.42
6	F	250	56	55	49	19.56	19.89	19.23
7	G	300	54	53	44	19.46	19.19	19.98
8	H	350	53	50	43	19.59	19.41	19.05
9	I	400	54	51	43	19.52	20.12	19.62
10	J	450	41	48	31	17.96	19.58	19.55
11	K	500	35	34	29	19.13	19.54	18.88

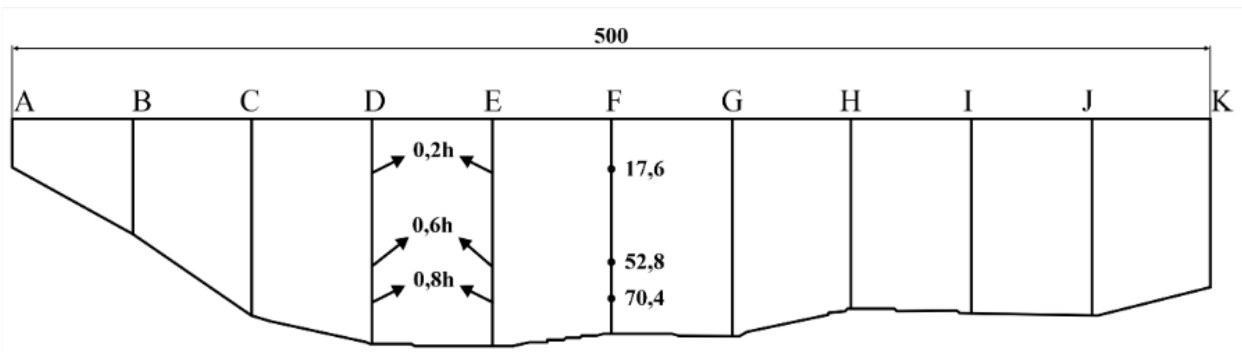

Figure 4. Speed Measurement Point of Ndas Gending River

Then the data obtained from the measurement of the flow velocity of the Ndas Gending river, then the calculation of the point velocity and average velocity is carried out using the equation below. The equation for finding then value is

$$n = \frac{round}{time} \quad \text{..(3)}$$

The equation for finding the point velocity value is

$$V = K \times n \times D \quad \text{……………………………………………..(4)}$$

Because 1,98 < n < 10,27

The equation for finding average velocity value is

$$V_r \left[\left(\frac{v_{0,2h} + v_{0,8h}}{2} \right) + v_{0,6h} \right] \times \frac{1}{2} \quad \text{..................................(5)}$$

The calculation is done by entering the data from the measurement of river flow velocity into the equation, then the average velocity data is obtained which can be seen in Table 3. To calculate the river flow discharge, data is needed from the measurement of the average velocity of each segment and measurement data of the flow segment area. The following equation is used to measure river flow discharge.

$$q_x = V_x a_x \quad \text{……………………………………………..(6)}$$

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Where, V is Flow velocity of each segment (m/s); a : Cross-sectional area of each segment (m^2).

So, with the above equation, the results of the calculation of river flow discharge can be seen in Table 4.

Table 3. Average Velocity of River Flow Calculation Results

NO	Point	n Value			v Value (m/s)			Average Velocity (m/s)
		0,2h	0,6h	0,8h	0,2h	0,6h	0,8h	
1	A	2.2278	2.4257	1.5797	0.7159	0.7794	0.5117	0.6966
2	B	2.0665	2.5428	1.9927	0.6642	0.8169	0.6405	0.7346
3	C	2.9472	2.5253	2.0500	0.9465	0.8112	0.6589	0.8070
4	D	2.9221	3.0923	2.3834	0.9384	0.9930	0.7658	0.9225
5	E	2.8210	2.9753	2.4717	0.9060	0.9555	0.7941	0.9028
6	F	2.8630	2.7652	2.5481	0.9195	0.8881	0.8186	0.8786
7	G	2.7749	2.7619	2.2022	0.8913	0.8871	0.7077	0.8433
8	H	2.7055	2.5760	2.2572	0.8690	0.8275	0.7253	0.8123
9	I	2.7664	2.5348	2.1916	0.8885	0.8143	0.7043	0.8054
10	J	2.2829	2.4515	1.5857	0.7336	0.7876	0.5136	0.7056
11	K	1.8296	1.7400	1.5360	0.5896	0.5617	0.4981	0.5527
River Average Velocity								**0.7874**

Table 4. River Flow Discharge Result

Point	Cross-Sectional Area (m^2)	Flow Velocity (m/s)	Debit Flow (m^3/s)
A-B	0.1675	0.7156	0.1199
B-C	0.3200	0.7708	0.2467
C-D	0.4338	0.8648	0.3751
D-E	0.4663	0.9127	0.4255
E-F	0.4550	0.8907	0.4053
F-G	0.4425	0.8610	0.3810
G-H	0.4175	0.8278	0.3456
H-I	0.3930	0.8089	0.3179
I-J	0.4005	0.7555	0.3026
J-K	0.3750	0.6292	0.2360
Total			**3,1555**

After obtaining the required data, the turbine specifications will be determined. The turbine used is the savonius type with 9% NACA 6409 blades and NACA 0012 blades instead of conventional semicircular blades as shown in Figure 5.

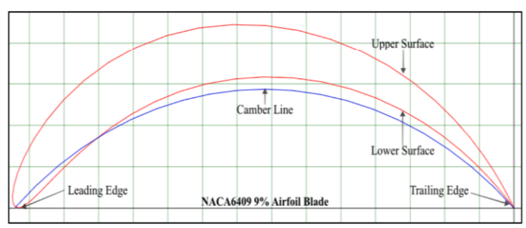

Figure 5. NACA 6409 9% NACA Blade Design
(Source: Chaudhari and Shah, 2023)

Based on research (Chaudhari and Shah, 2023b) the decision to use blades with NACA 6409 9% geometry was based on several important factors. First, this blade geometry presents a large torque generation capability, allowing the turbine to properly utilize the energy from the fluid flow. The uniform pressure distribution across the blade surface also plays an important role in improving the overall efficiency of the turbine. Considering these aspects collectively, using the NACA 6409 9% blade profile appears as a good step to improve the performance and efficiency of the savonius turbine in the context depicted in the journal.

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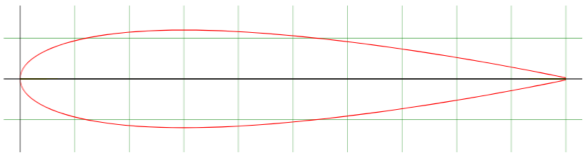

Figure 6. NACA 0012 Blade Design

According to (SAFI'I H'MIM, 2016), the NACA 0012 blade design is considered very advantageous due to its flexibility in accommodating a wide range of pitch angle variations. The results show that the NACA 0012 blade design produces considerable power output for the turbine, which exhibits a remarkable level of efficiency. Hence, the NACA 0012 blade design emerges as a viable option for turbine construction and optimization purposes. (Napitupulu Farel H. and Napitupulu Ekawira K., 2014) stated that NACA 0012 blades having three blades are considered more efficient in extracting the energy required to drive the turbine than turbines having four or five blades.

Furthermore, this research will be tested using the Computational Fluid Dynamic (CFD) method with ANSYS 2023 R2 software for the numerical calculation simulation process. The test results from this computation will later be compared between the NACA 6409 9% and NACA 0012 blades, the purpose of which is to determine the efficiency of applying blades to savonius type turbines in the Ndas Gending River, Magelang Regency.

4. Result and Discussion

Based on the simulation results of the performance analysis of the comparison of 9% NACA 6409 and NACA 0012 blades as a savonius type turbine blade with 3 blades. In the simulation analysis usually uses an endplate to cover the savonius turbine, but to clarify how the water flow passes through the turbine the endplate and turbine support shaft are removed.

4.1 Velocity Contour

In the analysis of velocity contours, it is carried out with a flow velocity of 1m/s. The velocity contours that occur in the flow after passing through the turbine can be seen in Figure 7 and Figure 8.

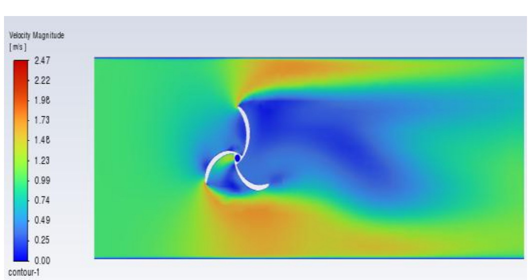

Figure 7. Velocity Contours at NACA 6409 9%

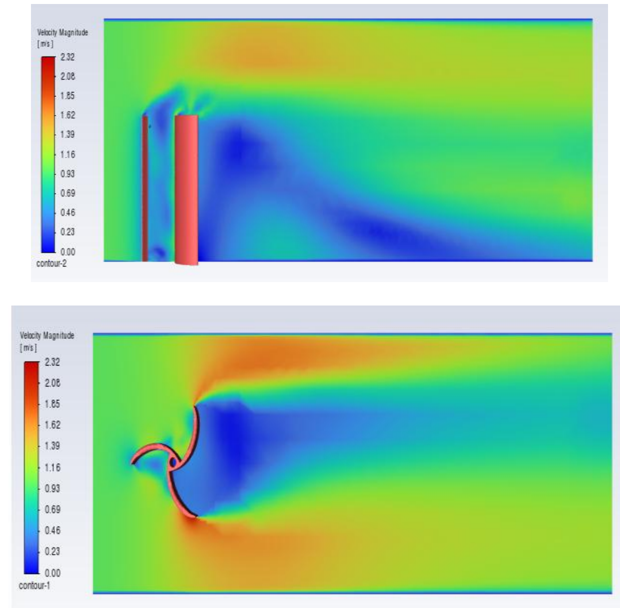

Figure 8. Velocity Contours at NACA 0012

In the velocity contour with a flow of 1 m/s, the NACA 6409 9% blade has the highest speed at the tip of the blade of 2.22 m/s. While on the NACA 0012 blade the highest speed occurs at the tip of the blade at 2.08 m/s.

In the analysis of velocity contours in water flow with an inlet velocity of 1 m/s, the prominent result on the NACA 6409 9% blade is that the maximum velocity reaches 2.22 m/s at the blade tip. While on the NACA 0012 blades, the prominent result is that the maximum speed reaches 2.08 m/s. This change in speed shows the influence of the geometric design for the turbine, which can be analyzed further. With an initial flow of 1 m/s, the velocity contour analysis shows a significant increase in the velocity at the blade tip. These results highlight that small changes in design can have a significant impact on water flow performance.

By carefully designing the blades, the flow velocity of 1 m/s can be optimized so that it reaches the maximum velocity at the blade tip. This emphasizes the importance of a holistic design approach to achieve optimal efficiency and performance in applications related to water flow. Through velocity contour analysis, it was found that a flow with an initial velocity of 1 m/s can be significantly increased at the blade tip. This highlights the crucial role of turbine blade design in improving performance for savonius-type turbines.

4.2 Turbulence Contours

The turbulence contour analysis was carried out with a flow velocity of 1m/s. Turbulence that occurs in the flow after passing through the turbine can be seen in Figure 9 and Figure 10.

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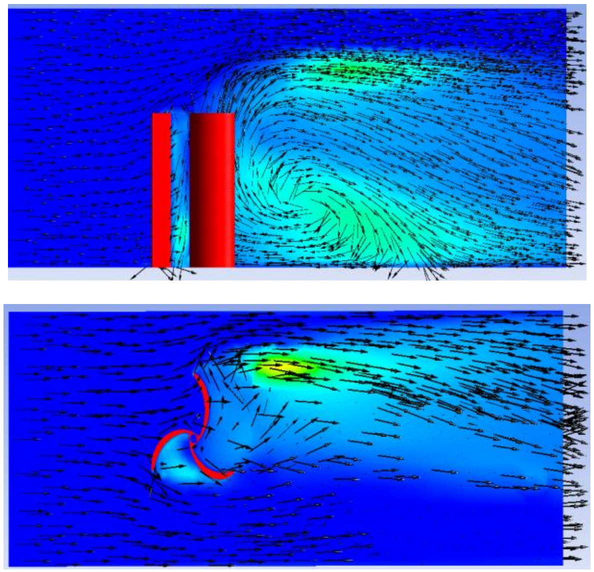

Figure 9. Turbulence contours at NACA 6409 9%

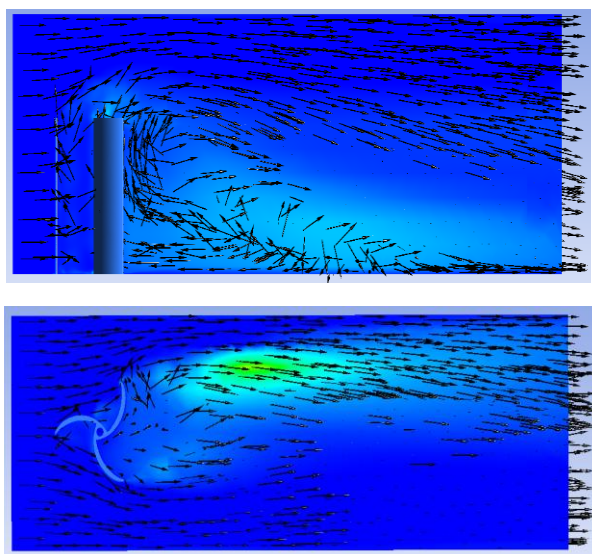

Figure 10. Turbulence contours at NACA 0012

The findings regarding turbulence patterns highlight the prominent turbulence levels after the water flow passes through the turbine. Through this analysis, it becomes clear that the water flow undergoes significant changes, characterized by increased turbulence after passing through the turbine. This suggests that the interaction between the water flow and the turbine elements is significant in generating varying turbulence conditions. These turbulence contours offer additional insights to refine the turbine design and improve its efficiency, aiming to design a more efficient design that reduces the impact of turbulence on the turbine.

Turbulence generated from the flow hitting the NACA 0012 turbine is low, while in the NACA 6409 9% turbulence flow occurs more as shown in Figure 9. So that low turbulence in the flow will be good for water turbines because regular flow and with low turbulence will help optimize turbine performance, minimize energy losses, and extend the life of turbine components As explained by Gong, Z. (2025) and Iqbal, M. R., & Marryam, S. (2025).

4.3 Pressure Coefficient

Pressure coefficient measurements provide deep insight into the efficiency of pressure management in a system, with a focus on optimal pressure distribution. In addition, the motion of pressure coefficient dynamics is also important, as it considers pressure changes in a moving or dynamically changing system.

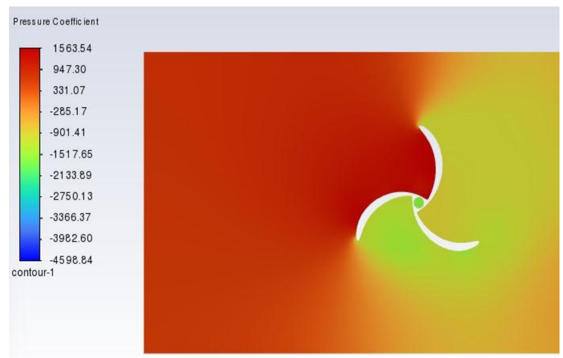

Figure 11. Pressure Coefficient Contour at NACA 6409 9%

This analysis includes the study of how changes in system parameters can affect the pressure coefficient and attempts to optimize the pressure distribution As has been discussed by related researchers (Kinast, D., et al. 2025; Qureshi, W. A., et al. 2025). The contour analysis of the pressure coefficient can be seen in Figures 11 and 12.

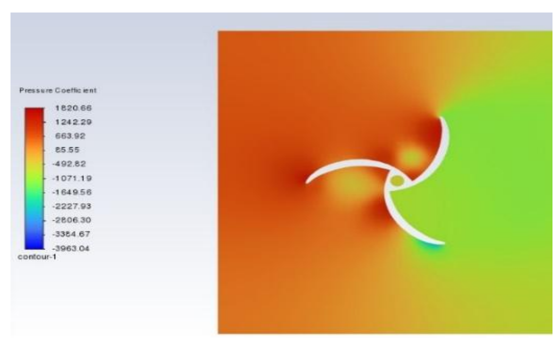

Figure 12. Pressure Coefficient Contour at NACA 0012

The observed differences in turbulence between the NACA 6409 9% and NACA 0012 blade profiles can be theoretically attributed to their distinct aerodynamic shapes and how these shapes interact with the fluid flow. The NACA 6409 9% profile, designed for higher lift and torque generation, likely creates a more complex flow separation and reattachment pattern, leading to increased wake turbulence. Its

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specific curvature and thickness can induce stronger shear layers and vortices downstream, resulting in higher turbulence levels compared to the NACA 0012. The NACA 0012, being a symmetrical airfoil, generally promotes a smoother flow with less aggressive flow separation, thus generating lower turbulence. This is crucial because lower turbulence in the flow is beneficial for water turbines, as it optimizes performance by minimizing energy losses and extending the lifespan of turbine components due to reduced dynamic stresses as explain by Durmuş, S., & Ulutaş, A. (2023).

In the contour of the pressure coefficient of NACA 0012, it can be seen that the pressure coefficient value is at the highest point of 1820.66 which hits the inside of the turbine blade. While in NACA 6409 9% the highest pressure coefficient value is at 1563.54 which is the same as in NACA 0012 which is most affected by the inside of the turbine.

A comparison of the pressure coefficient contour results between the NACA 0012 and NACA 6409 9% profiles underscores the variation in pressure distribution along the two different geometry shapes. In the pressure coefficient contour of the NACA 0012 profile, the pressure coefficient peak reaches 1820.66, concentrated within the inner region of the turbine blade. In contrast, in the case of the NACA 6409 9% profile, the highest pressure coefficient value recorded was 1563.54, mirroring the peak observed in NACA 0012, also located within the inner region of the turbine. This comparison shows that despite the differences in shape and geometric characteristics, the maximum pressure point shows relative consistency in both profiles, especially in the interior of the turbine as discussed by Tokul, A., & Kurt, Ü. (2023).

This indicates that considerable stresses occur inside the turbine on both profiles, potentially affecting the overall performance or design of the turbine. Therefore, understanding the pressure distribution within these profiles can help in optimizing turbine designs or conducting performance assessments for turbines and other related applications.

Table 5. Comparison of Speed Contours of NACA 0012 and NACA 6409 9%

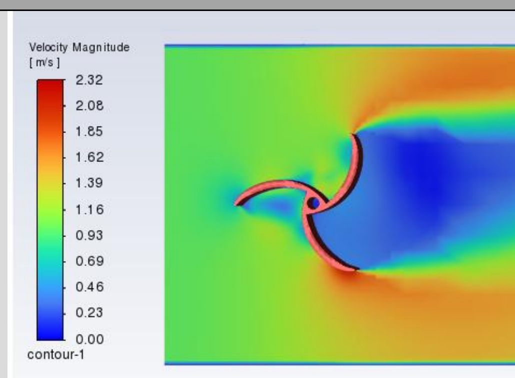
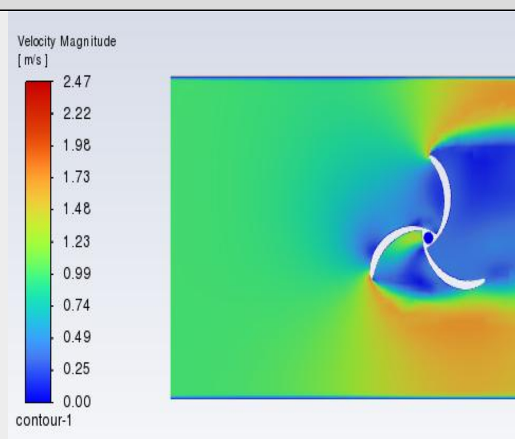
Blade Type	**Figure**	**Velocity Max (m/s)**	**Velocity Min (m/s)**
NACA 0012		2,32	0,23
NACA 6409 9%		2,22	0,25

Table 6. Perbandingan Kontur Turbulensi NACA 0012 dan NACA 6409 9%

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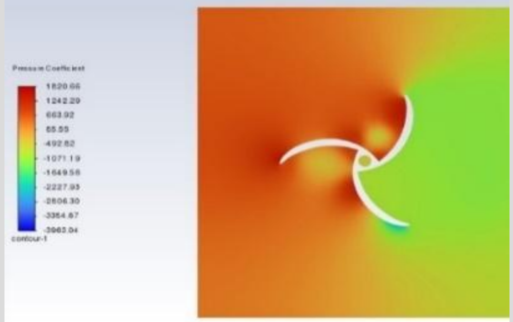
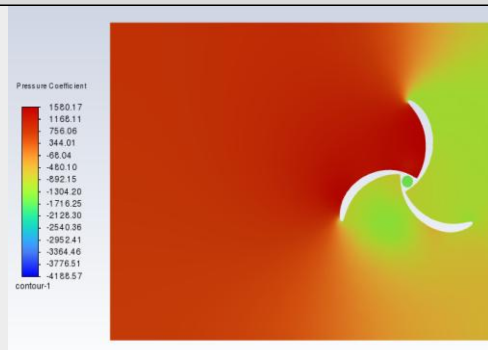
Available online at: http://tljes.org/index.php/tljes/data

Blade Type	Figure	Pressure Coefficient Max	Pressure Coefficient Min
NACA 0012		1820,66	492,82
NACA 6409 9%		1563,54	480,10

5. Conclusion

The study concludes that small changes in turbine blade geometry can significantly affect water flow performance, as evidenced by the velocity contours and turbulence levels observed in the NACA 0012 and NACA 6409 9% blades. These changes notably impact the flow velocity, especially at the blade tip, highlighting the importance of a detailed design approach for optimizing efficiency. The turbulence contours further emphasize the interaction between water flow and turbine components, offering opportunities for design improvements to enhance turbine performance. Pressure coefficient analysis reveals that, despite geometric differences, the pressure distributions in both blade profiles remain relatively consistent, particularly within the turbine's inner region. Notably, the NACA 0012 blades show higher pressure coefficients, suggesting greater potential for performance but also indicating higher stress concentrations that could affect structural stability. Understanding these pressure distributions is essential for optimizing blade design, material selection, and ensuring the long-term durability of turbines. Overall, the findings from the CFD simulations provide valuable insights into fluid flow behavior and the water-turbine interaction, contributing to the development of more efficient and reliable turbine systems.

The novelty of this research lies in its comprehensive optimization of Savonius turbine efficiency by comparing two distinct blade geometries (NACA 6409 9% and NACA 0012) for river applications. Unlike previous studies focused on individual blade designs or CFD simulations, this work combines field measurements of river flow dynamics with advanced CFD simulations to validate turbine performance under real-world conditions. Additionally, it offers a detailed analysis of turbulence generation and pressure distribution, highlighting their impact on structural stability. This integrated approach provides valuable insights for improving Savonius turbine design and optimizing renewable energy generation in specific regions, such as Magelang District.

6. Recommendation and Limitation

The main limitation of this study is the reliance on CFD simulations without field validation, which may not fully capture real river complexities like flow variations and sedimentation. This affects the accuracy of performance, efficiency, and structural stability predictions. Future research should prioritize field testing with Savonius turbine prototypes in actual river environments, including long-term monitoring to assess durability. Additionally, exploring alternative materials and conducting social and economic impact assessments are important for developing sustainable turbine designs. These recommendations are especially relevant for countries like Timor Leste, where renewable energy solutions can significantly benefit rural communities.

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