Journal of Applied Science, Engineering and Technology
e-ISSN: 2722-8363 p-ISSN: 2722-8371
DOI: https://doi.org/10.47355/jaset.v5i2.90

J. ASET

Integrated of Aerodinamics Tip and Hub of Wind Turbine on Composite Materials

Akhmad Riszal*, Agus Sugiri, Irza Sukmana, Martinus, Ahmad Yonanda, Rizal Adi N

Department of Mechanical Engineering, Faculty of Engineering, Universitas Lampung, Gedung H Lt. 2, Jl. Prof. Soemnantri Brojonegoro No. 1, Bandar Lampung 35143, Indonesia

*Corresponding Author: akhmad.riszal@eng.unila.ac.id

Received: 23.10.2025; Accepted: 02.11.2025; Published: 26.12.2025

Abstract: Global energy consumption is increasing, this is because human needs are dependent on electricity. However, many power plants still depend on fossil fuels, so the impact on the environment is getting bigger as energy consumption increases. It is necessary to develop renewable energy sources, to reduce the use of fossil fuels. One of them is using renewable energy from wind sources. The purpose of this research is to conduct simulations to analyze the aerodynamics and pressure distribution in the tip and hub areas of a wind turbine using QBlade, then conduct experiments in making composite specimens that will later be applied to wind turbines according to the design. This research shows that the highest pressure occurs at the tip and hub of the blade, so it is necessary to improve strong and lightweight materials by using bamboo fiber composites.

Keywords: Aerodinamics, QBlade, tip and hub, composites.

1. Introduction

Fossil fuels have a significant impact on the environment and climate change worldwide. With the advancement of technology, people's electricity consumption has skyrocketed. Undeniably, electricity is now considered a primary need, as many people rely on it for their daily lives. Energy issues are complex due to the imbalance between energy demand and supply. Fossil fuels can be diverted to renewable energy sources. One renewable energy source that can be utilized is wind energy, through wind turbine technology. Wind turbines convert mechanical energy into electrical energy. The conversion process produces output, or power, based on the wind flow phenomenon passing through the wind turbine rotor. The magnitude of the wind gusts passing through the rotor is directly proportional to the amount of power converted by the wind turbine. However, many factors can increase output power beyond wind speed, such as blade diameter, number of blades, generator used, and so on. Power output varies significantly with wind speed, due to the highly fluctuating nature of wind speed. So it is necessary to develop wind turbines with specifications that can be used at low wind speeds and at high wind speeds.

Wind turbine development can be done by simulating aerodynamics, in parts that are critical to wind speed and developing composite materials to obtain the strength and reliability of the wind turbine at low or high wind speeds. The influence of wind speed and variations in the number of blades on turbine performance if the number of blades and wind speed have a significant influence on the power generated [1]. Analysis with the NACA 4415 airfoil type with aerodynamic characteristics that the Tip Speed Ratio (TSR) from 0 to 7 Power Coefficient increases and high Power Coefficient decreases [2]. Then in the design and simulation of small wind turbine blades using Qblade, this design uses the NACA 0018 airfoil type which can improve the performance of wind turbines at low wind speeds [3]. Design research using flat-shaped blades with variations in the ratio of Top and Button blades with the highest efficiency of 9.6% at a speed of 5 m/s with a blade angle of 300 with a ratio of 4:5 [4]. To convert mechanical energy into electrical energy, a generator is needed. A generator is a medium that plays a crucial role in converting kinetic energy into electrical energi [5]. Rapid technological advancements have resulted in a variety of generator types with the latest innovations and technologies for use in small- and large-scale wind power plants (PLTB). Research into Permanent Magnet Generators (PMGs) offers the advantage of producing electricity at low rotations per minute (RPM) speeds, allowing them to generate electricity even in low wind speeds. [6]. This turbine design comes in a variety of variations, from one blade, two blades, three blades, to six blades. Each rotor design has its own advantages and disadvantages. The advantages of this type of turbine include high efficiency and low cut-in wind speed. The disadvantages are that this type of turbine has a more complex design because the rotor can only capture wind from one direction, requiring a wind guide [7]. The increase in turbine efficiency is influenced by variations in the number of blades and the materials used. The use of epoxy resin can produce lighter blades, thereby increasing wind turbine performance. [8]. Research with a wind speed of 6 m/s and blade material using coconut fiber, pine wood, glass fiber, epoxy, comparison of the three materials, the highest output value is the use of coconut fiber at a rotation of 124.1 Rpm producing 3.6 Watts of power. The use of type E fiberglass with random length mixed with layered weave then hybridized with coconut fiber using 6 layers [9]. Research on the effect of hemp fiber length on the tensile strength of fiber metal laminate composites shows that the longer the fiber length, the higher the tensile stress.[10].

2. Materials and Methods

2.1. Blade Design

The design uses Qblade software and the blades are selected according to the type of airfoil used. Specifications can be seen in Table 1.

Tabel 1. Parameter Turbin

Airfoil Type	NACA 4412
Blade Diameter	1.2 m
Number of Blades	5
Wind velocity	7 m/s
Density	1.22 kg/m³

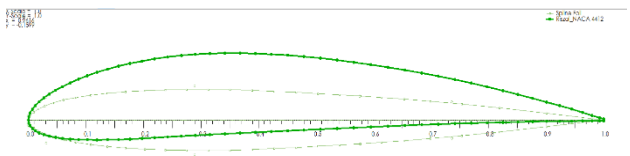


Figure 1. Naca 4412 Airfoil

2.3. Composite

In the initial research, an experiment was conducted in making specimens for composites. The composite used was Bamboo Fiber with NaOH treatment for 3 hours at a volumetric reaction of 30% and a mixture of materials, namely epoxy resin. The initial research was conducted to determine the manufacture of composite specimens. The formation of composite specimens by preparing bamboo fibers and cutting the fibers and making molds in the manufacture of initial specimens in order to determine the solidity of bamboo fibers against volumetric reaction.

3. Results and Discustion

3.1. Design Analysis

The research results were used to design and simulate a wind turbine with appropriate parameters. The design and simulation were performed using QBlade software. The airfoil type used was NACA 4412. The blade profile was then constructed using 13 airfoil segments from the hub to the tip.

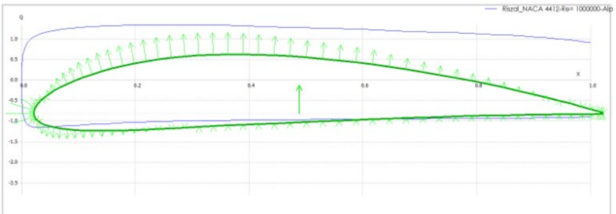


Figure 2. NACA 4412 pressure distribution

Figure 2 shows the pressure distribution along the airfoil surface and the direction of the pressure force. Pressure occurs around the leading edge of the airfoil (upper surface).

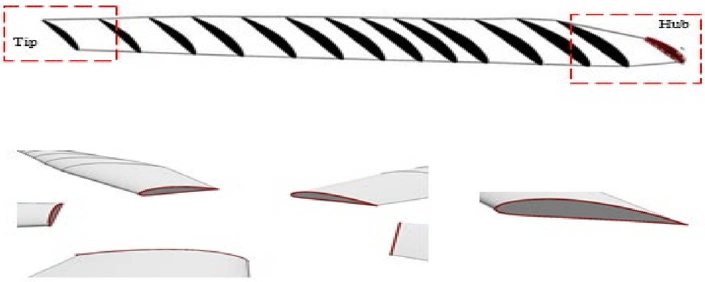


Figure 3. Airfoil contours and segments

Figure 3 shows a cross-section along the blade (span). Along the blade from the hub to the tip. The hub section and the application of the twist angle to adjust the angle of attack in the adian position, which is used to maintain optimal lift distribution along the span and produce uniform torque to avoid stall.

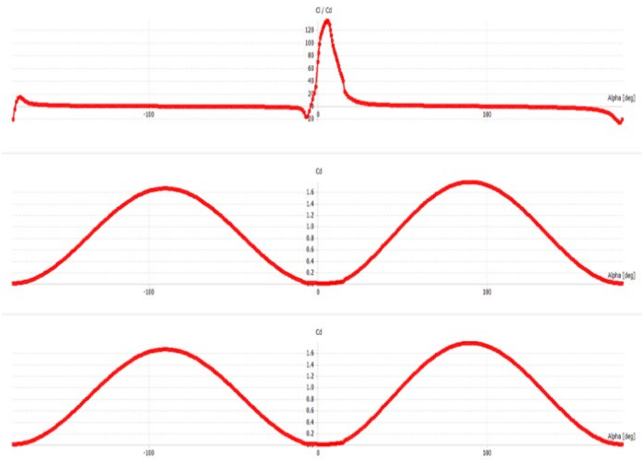


Figure 4. Polar Analysis of the NACA 4412 360^0 Airfoil

Figure 4 shows the aerodynamic efficiency ratio Cl/Cd, drag coefficient Cd and lift coefficient Cl. The highest Cl/Cd value is obtained at a small angle of attack of 5^0-10^0 indicating optimal efficiency with maximum lift can be achieved with minimum drag. Then the Cd value reaches a minimum around a= 0^0 and increases sharply when the angle of attack approaches 90^0, this indicates the presence of pressure drag. Then Cl increases linearly until the stall point and reverses to a negative angle, illustrating a change in the direction of lift according to the orientation of the airflow towards the NACA 4412 airfoil.

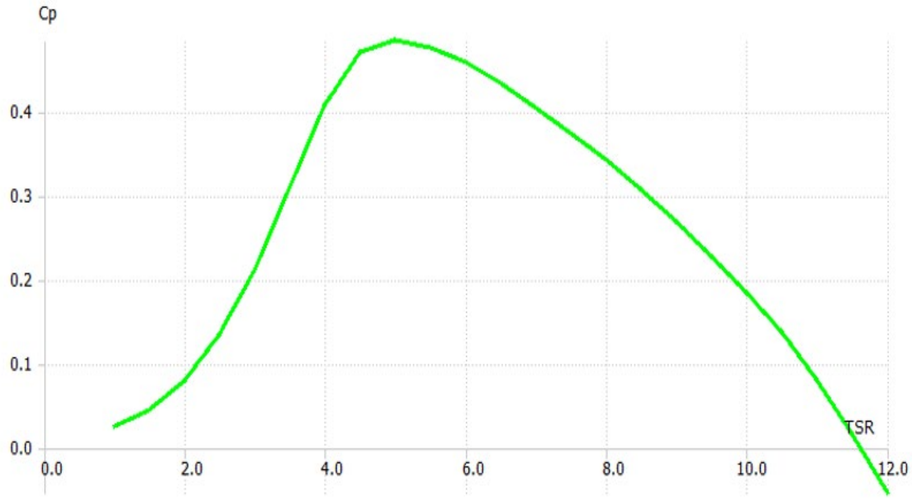
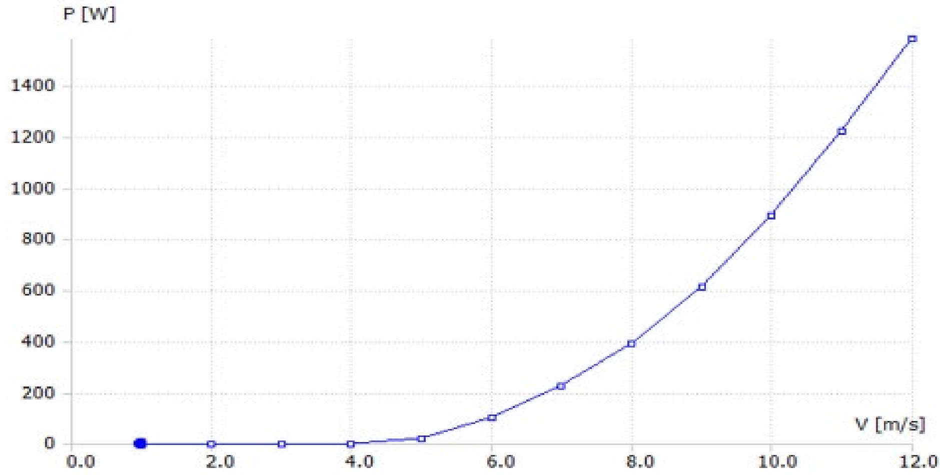


Figure 5. Power Coefficient (Cp) on TSR

Figure 5 shows the graph showing the relationship between the power coefficient (Cp) and the tip speed ratio (TSR) of a wind turbine. The Cp value indicates the efficiency of converting wind kinetic energy into mechanical energy in the rotor, while the TSR describes the ratio of the linear speed of the blade tip to the free wind speed. From the graph, it can be seen that Cp increases as the TSR increases until it reaches a peak value of around TSR=5,which indicates the most efficient operating condition for the turbine. At this point, the blade produces maximum lift with relatively little resistance, so that the power generated reaches its optimum value.

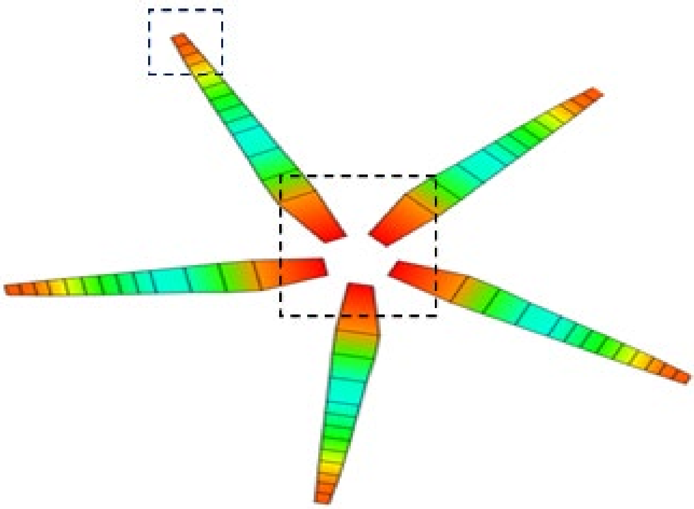
After passing the optimum TSR, the Cp value decreases significantly. This is caused by increased aerodynamic drag and reduced lift effectiveness when the blades rotate too fast, causing the airflow around the airfoil to become turbulent. This decrease also indicates that at high TSR, most of the wind energy cannot be captured efficiently by the blades. Therefore, the peak point on the Cp versus TSR graph is an important reference in the design and operation of wind turbines to determine the ideal rotor rotation speed to achieve maximum efficiency



under various wind speed conditions.

Figure 6. Relationship between P (Turbine Power) and Wind Speed (V).

Figure 6 shows that power increases exponentially with increasing wind speed, in accordance with the principle that wind power is directly proportional to wind speed. At low speeds (<4 m/s), the power generated is very small because the kinetic energy of the wind is not enough to overcome the inertia of the system and the mechanical resistance of the turbine. However, starting at around 6 m/s, the power increase becomes significant, reaching 149.2 W at 12 m/s. This curve shows the general characteristics of small to medium-scale wind turbines, where energy conversion efficiency increases sharply at medium wind speeds.



Gambar 7. Visualization fluid flow distribution

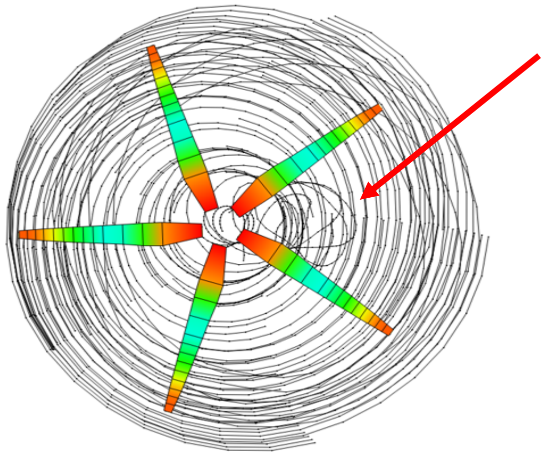


Figure 8. Fluid flow vortex

The focus of this research is to observe the characteristics of the hub and tip sections regarding fluid flow to enable the development of composite materials. Figure 7 displays the results of a five-blade wind turbine aerodynamic simulation using the Blade Element Momentum (BEM) method with visualization of force distribution and vortex wake at a wind speed of 7 m/s. In the first figure, the distribution of pressure and force coefficients along the turbine blade is shown. The red color indicates areas with high pressure which are generally located at the base of the blade (near the hub), while the green and blue colors indicate lower pressures found at the tip of the blade. This color distribution indicates that the greatest lift force is generated in the middle to the tip of the blade, while the tip tends to experience dominant drag due to interaction with the hub. Under these conditions, the power generated is approximately 0.182 kW with a power efficiency of Cp = 0.263 indicating quite good energy conversion performance at moderate wind speeds.

Figure 8 shows the vortex flow pattern or vortex structure behind the rotor, illustrating the wake phenomenon caused by blade rotation. The black circular lines indicate the direction and intensity of the air vortices formed at the blade tips. The denser the vortex pattern, the greater the induction effect and energy loss due to turbulence. This phenomenon is important in analyzing the spacing between turbines in a wind farm because the wake effect can reduce the efficiency of the turbine behind it. From the figure, it can be seen that the vortex distribution is relatively symmetrical and spreads in a stable spiral pattern, indicating a controlled flow without major turbulent disturbances around the rotor. These two results together provide a picture of the turbine's aerodynamic performance in capturing wind energy and converting it into mechanical power efficiently.

3.2. Composite starting material

In this study, the fiber used was bamboo fiber with NaOH treatment for 2 hours and the formation of volume fractions in the material mixture. After mixing the materials and treating the materials, the next step was to make a mold and mix the 30% Volume Fraction Variation to the epoxy mixture. Composite specimens were formed by preparing bamboo fibers and cutting and forming the fibers according to requirements.

Figure 9. Initial Cast of the Pra Specimen

Figure 9 shows the initial composite impression using 3D printing as a mold for the initial sample. PLA was used as the material due to its ease of printing and smooth surface. This mold was used for the flaking process of the composite material with an epoxy resin mixture.

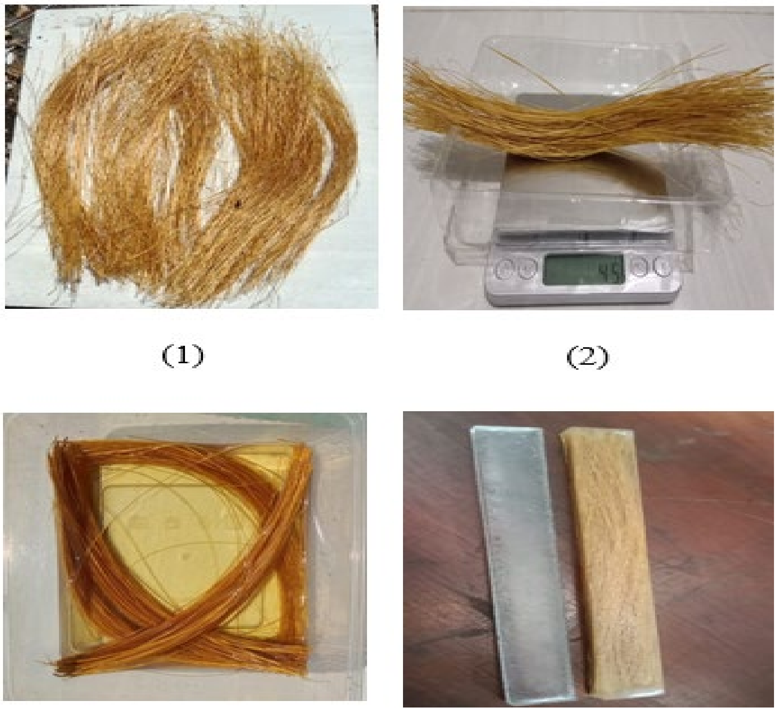


Figure 10. Initial formation of 30% ratio composite

Figure 10 explains the process of making bamboo fiber composites with alkali treatment (NaOH) and a fiber:resin volume ratio of 30%:70% (Vf = 0.30). The manufacturing process is carried out by molding epoxy resin hardener and making a composite mixture of bamboo fiber and hardener with a ratio of 30%. This process uses a gradual hand lay-up method to produce an initial composite that has no voids so that no air is trapped.

4. Conclusion

Analysis using the NACA 4412 airfoil type shows that the design at certain speeds shows that the pressure distribution on the hub and tip sections has a high load, which is shown in red so it is highly recommended if the use of composites can be applied as wind turbine materials. The tested material has no voids around the blade so that the pressure distribution can be evenly distributed on the surface around the blade.

Acknowledgement

The researcher would like to thank the University of Lampung through the DIPA BLU of the University of Lampung for providing research funding support through the Unila BASIC RESEARCH scheme based on the research contract number 666/UN26.21/PN/2025.

References

[1] Firman, A, dkk, (2013). Pengaruh Kecepatan Angin Dan Variasi Jumlah Sudu Terhadap Unjuk Kerja Turbin Angin Poros Horizontal, *Dinamika Teknik Mesin, Volume 3 No. 1.*

[2] Shailiendra, S dan Probhat, R. 2017. Analysis of NACA 4415 Blade Profile for Horizontal Axis Wind Turbine Using Various Aerodynamic Characteristics. *International Journal of Engineering and Technical Research (IJETR).* Volume-7, Issue-7.

[3] Veksha, R dan Anil, K. 2017. *Design and Simulation of Small Wind Turbine Blades in Q-Blade. International Journal of Engineering Development and Research (IJEDR).* Volume 5, Issue 4 .

[4] Herlambang, YD, dkk. (2018). Rancang Bangun Turbin Angin Poros Horizontal 9 Sudu Flat Dengan Variasi Rasio Lebar Sudu Top Dan Bottom Untuk Meningkatkan Kinerja PLTB. *Jurnal Eksergi*, Vol 14. 53-58.

[5] Anagha R. Tiwari, (2014). Comparison of various Wind Turbine Generators. *Multidisciplinary Journal of Research in Engineering and Technology (MJRET),* 1 (2), Page.129-135.

[6] Hasyim Asy'ari. (2012). Desain Generator Magnet Permanen Kecepatan Rendah Untuk Pembangkit Listrik Tenaga Angin Atau Bayu (PLTB), *Seminar Nasional Aplikasi Teknologi Informasi.*

[7] Yusuf Ismail Nakhoda. (2015). Rancang Bangun Kincir Angin Sumbu Vertikal Pembangkit Tenaga Listrik Portabel, *Seminar Nasional Sains dan Teknologi Terapan (ITATS)*, 978-602-98569-1-0.

[8] Hau, Erich. (2005) *Wind Turbines Fundamentals, Technologies, Application, Economics*. 2nd Edition. Springer. Verlag Berlin Heidelberg, Germany.

[9] Mawardi, I. and Hanif, H. 2018. Sifat Mekanis Komposit Polimer Hibrid Diperkuat Serat Sabut Kelapa-E-Glass. ETHOS: *Jurnal Penelitian dan Pengabdian kepada Masyarakat*, 6(2), pp.297-304

[10] Wisnu, K., Dkk. 2022. Uji Performa Sudu Turbin Berbahan Polimer Serat Karbon. Jurnal Adimetrik; *Jurnal Ilmiah Rekayasa dan Inovasi*. Vol 4 No.1. Hal 43-52.

.