

Numerical Simulation of a Bionic Blade on Small-Scale Wind Turbine

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Abstract. This study presents the aerodynamic characteristics of a small-scale horizontal axis wind turbine (HAWT) with bionic blade contours. Taiwan incense cedar was chosen as imitations. On account of the contour of the winged disseminules and the ANSYS FLUENT 14, we designed the bionic blades to process the computations of aerodynamic characteristics of the bionic wind turbine blades. The aerodynamic characteristics and the wind/electricity power transform efficiency of the turbines were examined in a wind tunnel. The wind tunnel experimental outcomes showed that the wind/electricity transformation efficiency of the wind turbine setup could reach to 37%, and it is benefit environment and global energy management.

1. Introduction

The world seek to provide stable and sufficient quantity energy which is a important energy industry. Fossil oils was the primary energy source, but air pollution did harmful influences on people and environment through exhaust emissions. Green technologies developed progressively to energy management. The sources of wind energy is clean and inexhaustible which makes wind power a promising green power resources. The wind turbine is a key component in wind power facilities, either in vertical or horizontal configurations. A large-scale wind turbines are more available in areas with abundant wind resource[1]. But inferences of a large-scale wind turbine farm on the local climate in rising the local surface temperature and causing a larger rate of precipitation was dominated.[2-4] Hence, Tummala *et al.*[1]recommended a small-scale wind turbines installed of the decentralized grid system. The small-scale wind turbines can guarantee a better aerodynamic execution at poor wind resource areas with a lower wind velocity. Thus, the subject of the blade designs for a small HAWT is important. Blade designs will strongly influence the turbine performance and the wind/electricity transformation efficiency for electrical power generator.

The active blade design constantly referred to the NACA [7-9] or animals airfoils [10-11] for increasing the wind turbine efficiency in the wind/electricity power transformation. Based on the theoretical aerodynamic analysis[5-6], the same aerodynamic characteristics are presented with either an object moving with steady speed in stationary air or a fixed object in a uniform air with steady velocity under the steady air speed or a moving object. The equivalent law of aerodynamics such as birds, bats, and insects are furnished with wings, which provides energy to drive the air and produces the aerodynamic force needed for flight. Active wing configurations inspired engineers design and manufacture turbine blades of propeller or aircraft. Some researchers draw their attention on the maple samaras kinematic characteristics. Varshney *et al.*[11] experimentally revealed the dynamic characteristics of a dropping down maple samaras.



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In this research, the aerodynamic characteristics of the bionic passive wing lift-driven (PWLD) blades are surveyed. The winged disseminules of the Taiwan incense cedar is chosen as the shape of bionic PWLD blades from the *Calocedrus formosana*[12]. The blade contour is mimicked and designed by using the seed wings contours, and examined methodically by ANSYS FLUENT 14 to obtain the essential aerodynamic characteristics. The wind tunnel experimentally tested the HAWT to show the relation between the efficiency of wind/electricity power transformation and aerodynamic characteristics.

2. Numerical Model Constructions

The wind will spread away the winged seeds when the Taiwan incense cedar cones are burst and rotational split. Figure 1 present the contours of the winged-like appendages sketched by an optical microscope. Then, the Creo software process the data to build the contour bionic blades models. IGES files reserved those models and fax the information into ANSYS FLUENT 14 to analog those aerodynamic properties. And, the bionic blades sample were put in the rectangular experimental tunnel with the size of 30 mm×40 mm×70 mm to process the numerical simulations. The tetrahedral meshes were generated by ANSYS FLUENT 14 automatically. Aluminum material are used in the simulation bionic blades. Turbulent air is trusted as the working fluid. The k- ϵ model is used to describe the turbulent flow. The inlet boundary condition and the atmospheric pressure is the outlet and lateral surface boundary conditions. The wall function of the ANSYS FLUENT 14 is used to process to kinematic properties of the bionic blade near-wall region. The convergence criterion will reach 10^{-6} after approximately 400 iterations.

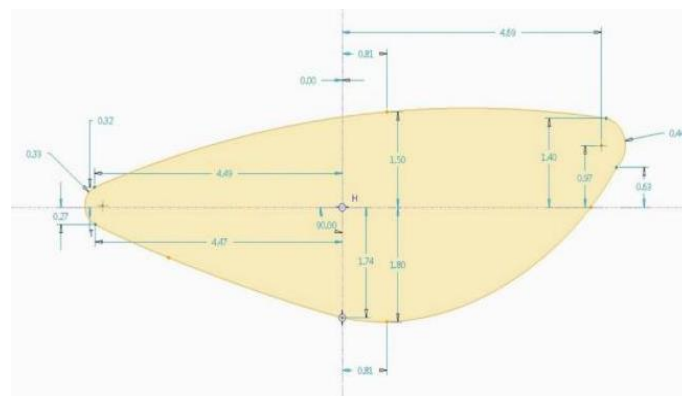


Figure 1. The winged seed shape of Taiwan incense cedar as original bionic blade contour

3. Wind Tunnel Experiment: Set Up and Results

For experimental testing, Taiwan incense cedar blades fabricate a small-scale HAWT based on the enlarged winged disseminule sketch. Each enlarged bionic blade was formed by a 0.3 mm thick aluminum plate and the enlarged blade span is 235 mm. A wood stick with 5 mm × 10 mm cross-sectional area was adhered to the rear blade surface to strengthen the bionic blade stiffness.

The three bionic blade and five bionic blade of the HAWT model were formed and investigated in a wind tunnel to explore the correspondence relationship between the driving wind speed and the wind/electricity power transformation efficiency. The schematic diagram of the wind tunnel is shown in Figure 2. The cross-sectional area of the test section is 800 mm × 800 mm. The examining wind velocity is set to be 3, 4, 5, and 6 m/sec respectively because of the average wind speed per year is 5 m/sec in Taiwan. The local pitch angle of the blades is 15°, 20°, 25°, and 30° respectively. The repeatability of the test results for HAWT model was confirmed by three times under the testing wind speed and pitch angle conditions.

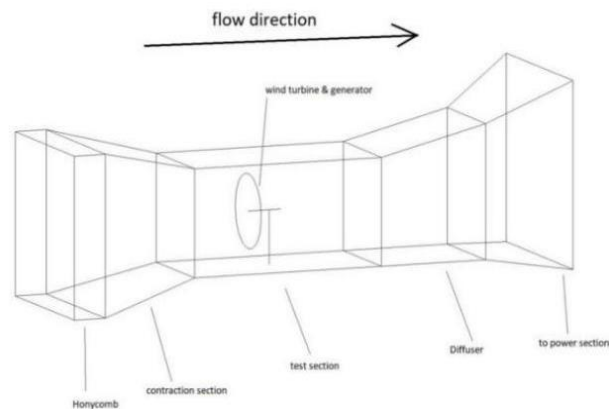


Figure 2. The wind tunnel diagram for testing HAWT model

Figure 3 depicts the relationship between the wind speed and the rotor power coefficient of the five-blade Taiwan incense cedar HAWT model. One can reveal that a maximum rotor power transformation efficiency is reached 37% while the pitch angle is 15° and the wind speed 4 m/sec. But, rotor power transformation efficiency decreases under 5 m/sec wind speed except the 20° pitch angle case. All the wind/electricity efficiency increase monotonically with wind velocity when the wind speed is below 4 m/sec. The results of a small-scale wind turbines presents a better aerodynamic execution at poor wind resource areas with a lower wind velocity.

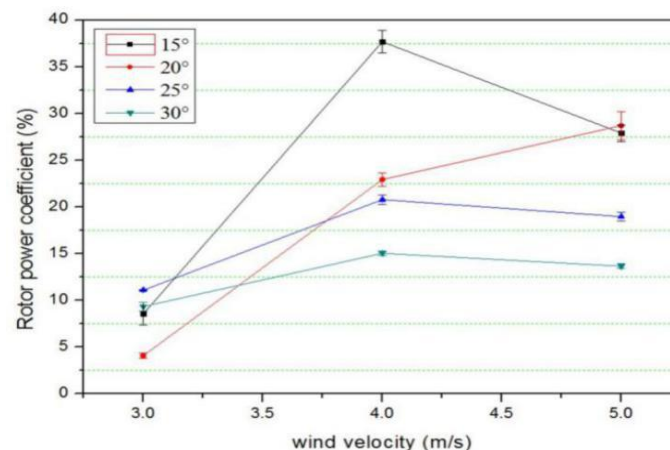


Figure 3. Relationship between the rotor power coefficient and wind speed

The tip speed ratio connect the relations of the pitch angles and wind/electricity efficiency of HAWT models. The corresponding relation between the tip speed ratios and the rotor power transform efficiency of the three bionic blade and five bionic blade of HAWT model is shown in Figure 4. For both three bionic blade or five bionic blade HAWT model, the values of the rotor power transformation efficiency is located from 25% to 37% as the tip speed ratio is within 2.5 to 3.5 and the pitch angle 15° or 20° . These results demonstrate excellent bionic blade aerodynamic properties. However, the wind/electricity power transformation efficiency of the five-blade HAWT model is higher than that of three-blade one.

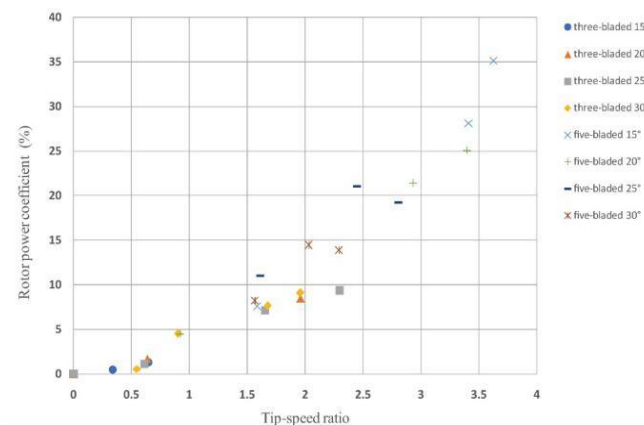


Figure 4. Relationship between the rotor power coefficient and tip-speed ratio of Taiwan incense cedar blades HAWT model

The bionic blades aerodynamic performances are depicted as following. Firstly, a constant wind speed of 3 m/sec is set. Although the wind speed per year is 5 m/sec in Taiwan, while a good weather often accompanies with a 3 m/sec wind speed. It is important that a small-scale HAWT can operate steadily in such a low wind speed. Based on the contour characteristics of the Taiwan incense cedar, figure 5 showed the variation of the lift and drag coefficients relating to the bionic blade angles of attack (AOA). As bionic blade AOA varied from 10° to 60° , the range of drag coefficient of the bionic blade is within 0.8 to 1.16. In general, active airfoils or blades with NACA have a narrow range of AOA. Figure 5 also indicated that a maximal lift coefficient value 0.2 was reached when its AOA is 10° in the case of Taiwan incense cedar bionic blades.

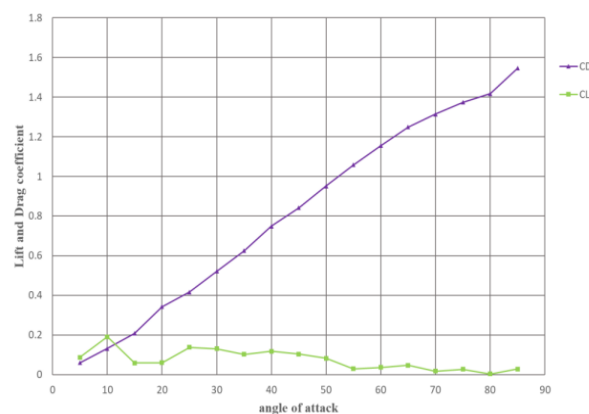


Figure 5. Changes between the angle of attack and the lift and drag coefficients

Under a driving wind speed is 3 m/sec, the corresponding relation of the lift-drag coefficient with the AOA of the bionic blades are showed. The maximal lift-drag ratio value of the bionic blade achieved at a smaller angle of attack. The maximal lift-drag ratio value is 1.5 of the Taiwan incense cedar bionic blades at AOA 5° . The spin mechanism of the winged disseminule might be related to the phenomenon. Based on the above numerical and experimental outcomes, one could reason out that the bionic blade aerodynamic performance is confident enough to guarantee a higher wind/electricity power transformation efficiency. The numerical results obtained from ANSYS FLUENT 14 also confirm the wind tunnel experimental results of the bionic blade lift/drag ratio under the same testing conditions.

4. Conclusions

Adapted the passive wing design turbine blade, one could match the requirement of the driven mechanism for wind turbine under unsteady flows. The imitated objects is the shapes of the winged disseminules of the Taiwan incense cedar, the designed bionic blades were based on their contours and analyzed the aerodynamic characteristics. The research and design of three bionic blade or five bionic blade configuration of wind turbine are carried out. In the wind tunnel experiment, a five bionic blade HWAT model with Taiwan incense cedar can generates the highest wind/electricity power transformation efficiency.

5. Acknowledgement

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6. References

- [1] Tummala A, Velamati RK, Sinka DK, Indraj V, Krishna VH. A review on small scale wind turbines. *Renew. Sust. Energ. Rev.* 2016; 56: 1351-1371.
- [2] Wang C, Prinn RG. Potential climate impacts and reliability of very large-scale wind farms. *Atoms. Chem. Phys.* 2010; 10: 2053-2061.
- [3] Fiedler BH, Bukovsky MS. The effect of a giant wind farm on precipitation in a regional climate model. *Environ. Res. Lett.* 2011; 6: 045101.
- [4] Kirk-Davidoff DB, Keith DW. On the climate impact of surface roughness anomalies. *J. Atmos Sci.* 2008; **65**: 2215-2234
- [5] Karamcheti K. *Principles of ideal-fluid aerodynamics*. Reprint edition with corrections. Krieger: Florida, USA, 1980, pp. 278-311
- [6] Abbott IH, von Doenhoff AE. *Theory of wing sections - including a summary of airfoil data*. Dover Publications Inc.: New York, USA, 1959.
- [7] Karthikeyan N, Murugavel KK, Kumar SA, Rajakumar S. Review of aerodynamic development on small horizontal axis wind turbine blade. *Renew. Sust. Energ. Rev.* 2015; 42: 801-822.
- [8] Lissaman PBS. Low-Reynolds-number airfoils. *Annu. Rev. Fluid. Mech.* 1983; 15: 223-239.
- [9] Giguere P, Selig MS. Low Reynolds number airfoils for small horizontal axis wind turbines. *Wind Eng.* 1977; 21: 367-380.
- [10] Singh RK, Ahmed MR, Zullah MA, Lee Y-H. Design of a low Reynolds number airfoil for small horizontal axis wind turbines. *Renew. Energ.* 2012; 42: 66-76.
- [11] Song Q, Lubitz WD. Design and testing of a new small wind turbine blade. *J. Sol. Energ. Eng.* 2014; 136: 034502.
- [12] Biodiversity Research Center, Academia Sinica ROC, Database of Native Plants in Taiwan, <http://www.hast.biodiv.tw/Announce/newsC.aspx> (accessed 15 February 2018).