

## AERODYNAMIC ANALYSIS OF SMALL SCALE CROSS AXIS WIND TURBINE

Afief Adiguna Naim \*, Shabudin Mat

Faculty of Mechanical Engineering, Universiti Teknologi Malaysia,  
81310 UTM Johor Bahru, Johor, Malaysia.

\* Corresponding author: afief@graduate.utm.my, shabudin@utm.my

### ABSTRACT

This study investigates the effect of blade thickness on the aerodynamic performance of small-scale CAWTs, focusing on torque generation and power coefficient ( $C_p$ ). Two blade configurations, with thicknesses of 2 mm and 6 mm and a  $180^\circ$  twist angle, were tested in the UTM Aerolab wind tunnel at wind speeds of 8–10 m/s. Torque was measured using a JR3 six-axis transducer, and rotor speed was captured by a microprocessor tachometer to calculate power and  $C_p$ . Results indicate that the thicker blade generated higher starting torque, aiding self-starting, while the thinner blade achieved higher maximum rotational speed and  $C_p$ , demonstrating superior aerodynamic efficiency. This analysis quantifies the trade-offs in blade thickness for small-scale CAWT design.

### KEYWORD

Cross axis wind turbine, blade thickness, aerodynamic performance, power coefficient, torque and wind tunnel testing.

### INTRODUCTION

Wind energy is a clean and renewable energy. Cross Axis Wind Turbine (CAWTs), a type of Vertical Axis Wind Turbine (VAWTs), characterized by integration of vertical and horizontal blades for capturing wind from multiple directions, offer advantages such as compact design, omnidirectional wind capture, and ease of maintenance (Chong et al., 2017). However, CAWTs generally have lower aerodynamic efficiency, and one of the key factors affecting their performance is the blade design, especially the shape and thickness. This study investigates how variation of blade thickness influences the torque and power coefficient output of a small scale CAWT through wind tunnel testing and aerodynamic analysis.

### MATERIAL AND METHODOLOGY

The wind turbine model used in this study is a scaled down version of a helical Savonius wind turbine design developed by Jeon et al., (2015). To accommodate the spatial constraints of the UTM Aerolab wind tunnel, the original dimensions (700mm height and 350mm diameter) were reduced by a factor 0.3. As a result, the final model features a rotor diameter of 105 mm and height 210 mm, excluding the thickness of the blade. Both turbine variants were fabricated with identical outer geometries but different in blade thickness, 2 mm and 6 mm. The  $180^\circ$  twist angle used in the blades from the original design, as it has been shown to promote smoother torque output and improved self-starting capability.

The wind speeds in wind tunnels varied from 8m/s to 10m/s with 1m/s increments, simulating low to moderate wind speeds environments like real world urban conditions. Figure 1 shows the wind tunnel used in this project. The models used in this project were printed using 3D printing with PLA materials.



Figure 1: UTM Aerolab wind tunnel.

The data collected in these experiments will be analyzed and calculated to get the  $C_p$  and the torque of the wind turbine, and the equation used to process the data in these experiments are,

$$P_{turbine} = T\omega \quad P_{wind} = \frac{1}{2}\rho AV^3 \quad C_p = \frac{P_{turbine}}{P_{wind}} \quad \omega = \frac{2\pi(rpm)}{60} \quad TSR = \frac{\omega R}{V}$$

$T$  = Blade torque (Nm)  
 $\rho$  = Density of air ( $kg/m^3$ )  
 $A$  = Area of rotor ( $m^2$ )  
 $\omega$  = Angular velocity (rad/s)  
 $V$  = Wind speed (m/s)

Torque was measured using the JR3 six axis force and torque sensor and the rotational speed was measured with microprocessor based optical tachometer, which recorded the rotor's rpm once steady state rotation was achieved at each wind speed. Figure 3 shows the setup of wind turbines for both thicknesses inside the wind tunnel.

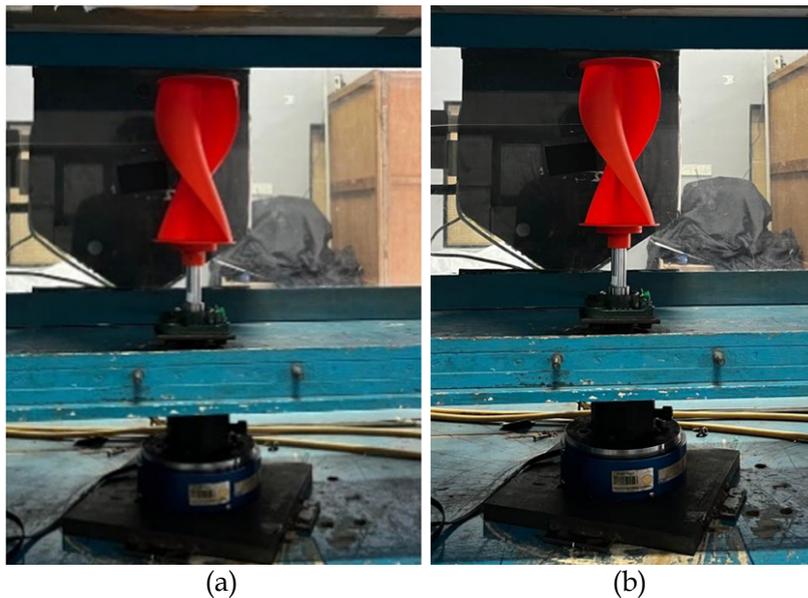


Figure 2: The setup of wind turbines inside the wind tunnel, (a) 2 mm blade thickness, (b) 6 mm blade thickness.

## RESULT AND DISCUSSION

The aerodynamic torque produced by the cross-axis wind turbine was evaluated (Figure 3). The 2 mm blade demonstrated higher torque at 8 and 9 m/s, indicating superior self-starting capability due to lower rotational inertia. In contrast, the 6 mm blade produced minimal torque at these speeds. At 10 m/s, the torque relationship reversed, with the 6 mm blade exceeding the 2 mm blade's output, illustrating a fundamental design trade-off.

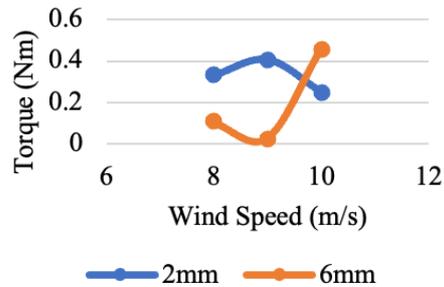


Figure 3: Torque vs wind speed of 2 mm and 6 mm.

Figure 4 shows torque versus rpm. The 2 mm blade reached 333 rpm at 10 m/s, while the 6 mm blade reached 148 rpm but with significantly higher torque. The 2 mm blade produced higher power at 8 and 9 m/s (5.02 W and 7.76 W, respectively) due to its higher rotational speed (Figure 5). At 10 m/s, the 2 mm blade generated 8.87 W, while the 6 mm blade increased significantly to 7.09 W, as shown in Figure 5.

Figure 6 shows  $C_p$  vs TSR. The 2 mm blade achieved higher  $C_p$  values, peaking at 0.70 at TSR = 0.10, and operates efficiently over a wider TSR range. The 6 mm blade exhibited very low efficiency at low TSR but increased sharply to 0.49 at TSR = 0.09, indicating a narrow effective operational window dominated by drag.

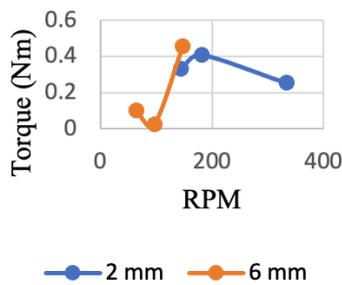


Figure 4: Torque vs rpm.

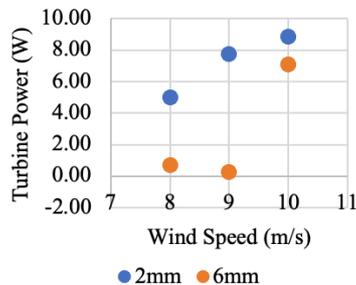


Figure 5: Turbine power vs wind speed.

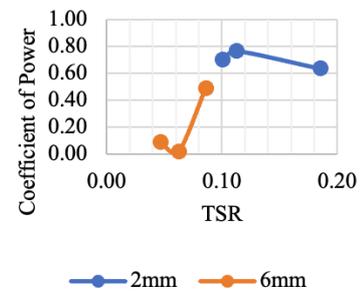


Figure 6: Coefficient power vs TSR.

## CONCLUSION

This study experimentally investigated the effect of blade thickness on the performance of a cross-axis wind turbine. Two blade configurations, 2 mm and 6 mm thickness, were tested at wind speeds of 8, 9, and 10 m/s. The results demonstrate a clear trade-off. The 2 mm blade exhibited better self-starting capability and higher efficiency at lower wind speeds, while the 6 mm blade showed improved performance (torque) at 10 m/s. The thinner blades are more suitable for low to medium wind speed applications, whereas thicker blades may benefit higher wind speed environments. Future work should investigate additional blade thickness variations, improved torque loss compensation, and extended wind speed testing to enhance performance evaluation.

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