Educational Administration: Theory and Practice
2024, 30(11), 1789-1795
ISSN: 2148-2403
https://kuey.net/
Research Article

Effect of Fins on the Power Performance of a Darrieus Wind Turbine

Rogelio C. Golez Jr[1]*, Elvene Raey N. Gargantos[1], Kenneth Norman O. Honculada[1], John Vincent E. Ostrea[1], Ruel Jeznar A. Cañeda[1], Karl Angelo C. Almueda[1]

[1]Mechanical Engineering Department, Xavier University – Ateneo de Cagayan, Cagayan de Oro City, Philippines

***Corresponding Author:** Rogelio C. Golez Jr
*Email: rgolez@xu.edu.ph

Citation: Rogelio C. Golez Jr et al. (2024), Effect of Fins on the Power Performance of a Darrieus Wind Turbine, *Educational Administration: Theory and Practice*, 30(11) 1789-1795
Doi: 10.53555/kuey.v30i11.9976

ARTICLE INFO

Received: October 1, 2024
Revised: October 17, 2024
Accepted: October 28, 2024

ABSTRACT

The development of the Darrieus wind turbine is useful in various applications, especially in increasing turbine efficiency. This study evaluates the power performance of a Globe-type Darrieus Wind Turbine using blades with helical fins at base angles ranging from zero to eighty-five degrees at fifteen-degree intervals, and no fins. The prototype design was 3D-printed at a scaled size fitted to the HM 280 equipment tube. The GUNT software program was used to control the radial fan at a fixed flow rate. The prototype turbine model is mounted on an acrylic plastic tube attached to the HM 280 instrument, having a 100mm diameter. The HM 280 is programmed to maintain a 6 m/s wind velocity and record power output at three-second intervals during each one-minute trial. Across three trials, the average recorded wind power input stands at 431.905 mW. Based on the results, the average power output of each turbine models are: at 0°, the power output is 33.21 mW, at 15° it's 4.94 mW, at 30° it's 8.83 mW, at 45° it's 25 mW, at 60° it's 81.32 mW, at 75° it's 28.27 mW, at 85° it's 53.16 mW, and at no fins, it's 14.3 mW. The turbine, having a 60° base angle model, produced the highest power output of 81.32 mW and turbine efficiency of 18.82%, while a no fin model has a 14.24 mW with 3.29% efficiency. Incorporating the helical fin into the Globe-type Darrieus wind turbine blade has resulted in a notable increase in turbine power output.

Keywords: Darrieus turbine, Efficiency, Helical fins, Wind power.

INTRODUCTION:

This project draws inspiration from the pioneering work of [1] France's great engineer, Georges Jean Marie Darrieus, for his development of a vertical-axis wind turbine in 1925 [2]. In the present studies, they are using simulation software to analyze the aerodynamic performance of a Darrieus turbine [3, 4, 5], the effects of blade height design [4], and achieve more optimal power and efficiency [6]. Wind turbines presently have studies focusing on blade shape [3], slotted blade [4], bio-inspired blade [8, 9], tip speed ratios [10], and number of blades [7]. It sparked our imagination to work on a more innovative way to improve the turbine's overall efficiency. Varying factors affect the Darrieus turbine power output, such as blade design, operational characteristics, and specific turbine design.

The design of wind turbine blades is being revolutionized through bio-inspired approaches, which look beyond mere energy generation to incorporate elements of energy storage [8, 9]. Omidvarnia et al. [8] made reviews on different cutting-edge sustainable energy techniques, such as drawing power from the kinetic movement of plants, insects, birds, fish, and whales. Their research review takes cues from the aerodynamic structures of several plants, including the lotus flower, the Borneo camphor seed, the seeds of Petrea volubilis and maple, as well as Epilobium hirsutum. They also consider the promising potential of mimicking the functionality of insect wings, the aerodynamic forms of birds, and fish to boost wind turbine blade efficiency by applying these biomimetic design principles. Reviews of different designs for vertical-axis and horizontal-axis wind turbines have resulted in the summarization of various blade structures that mimic important body parts, leading to the development of new, innovative, and aerodynamically efficient models [8].

The exploration of incorporating fin-like structures into wind turbine blades has led to significant advancements. Zhang et al. [11] further analyze the aerodynamic performance of the Whale-inspired wind turbine blade, studying the flow properties, lift and drag coefficients, and pressure distributions across the blade surface. Their study provides valuable insights for optimizing the design and operational parameters of the wind turbine blade for enhanced power output and efficiency. Also, Santoso et al. [12] studied the influence of high fins on NACA airfoil 0018 in an H-type Darrieus wind turbine. The study showed that adding fins to the turbine blades enhanced the performance of the wind turbine.

Additionally, Pamungkas et al. [13] analyzed the performance of an S-type Savonius wind turbine with varying fin additions on the blade. The research revealed that wind rotor blades with additional fins demonstrated an increase in power output as compared with rotor blades without fins. Inspired by the current studies, researchers identified the importance of developing and investigating the effects of the biomimetic structure of fish fins. This fish-fin structure is incorporated on the wind rotor blades of the Globe-type Darrieus wind turbine and evaluates its power performance and efficiency. The wind turbine rotor is inspired by these biomimetic fish fins and is named the Three-bladed Globe-type Darius wind turbine by the researchers.

STUDY OBJECTIVES:

This study aims to determine the effect of adding helical fish fins of different helix angles on the performance of Globe-type Darrieus wind turbines. The specific objectives are as follows:

1. 3D printing of a Globe-type Darrieus wind turbine with and without helical fins of different helix angles suitable for the HM 280 Instrument Capability.
2. Determine wind power input and power output for different models using the HM 280 Instrument for testing.
3. Determine the most efficient turbine models based on turbine efficiency.

METHODOLOGY

A. Instrumentation Set-up and its specifications

To facilitate the investigation of a biomimetic-inspired structure, a helical fish-fin on a Globe-type Darrius wind turbine blade, miniature 3D-printed blade models are utilized. These 3D-printed turbine blades are assembled and fit into the exit port of the HM 280 instrument. The HM 280 instrument is employed in the Mechanical Engineering laboratory for experimentation exercises that deal with investigating airflow characteristics, power output, and efficiency. The instrument is equipped with GUNT software that enables control of the radial fan speed, data acquisition, visualization, and operation which is beneficial to the mechanical engineering faculty and students' research activities.

With the instrument's capability, the researchers are keen to investigate the effect of helical-shaped fish fins on the turbine power output at different base angles. Fig. 1 below shows the experimental set-up of the HM 280 instrument with a desktop computer at the Mechanical Engineering research laboratory.

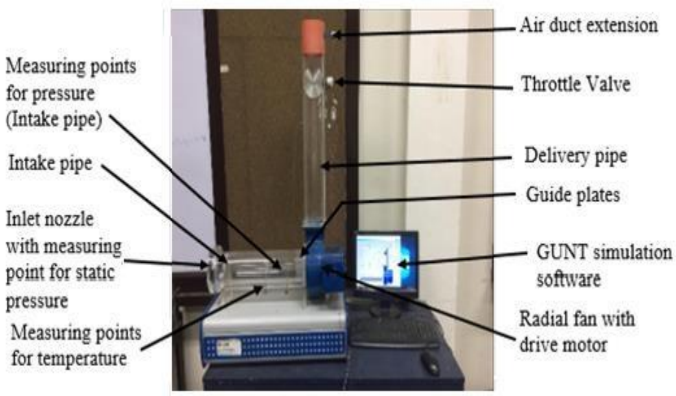


Fig. 1. HM 280 experimental set-up

The experimental unit is fitted with sensors for pressure and temperature. The airflow rate is determined via differential pressure measurement on the intake nozzle. The microprocessor-based measuring technique is well-protected in the housing. All the advantages of software-supported experiments and evaluation are offered by the GUNT software and the microprocessor. The connection to a PC is made through a USB. HM 280 features a radial fan with variable speed via a frequency converter, an intake pipe, and a delivery pipe. The transparent intake pipe is fitted with guide plates for flow guidance and with a flow straightener to calm the air. This enables precise measurements even with heavily reduced operation. The airflow is adjusted by a throttle valve at the end of the delivery pipe where the Darrieus wind turbine set-up is located (Fig. 2). Table I shows the specific technical details of the HM 280 instrument.

Fig. 2. Delivery pipe extension for Darrieus wind turbine set-up

For the fins, the design concept was inspired by mimicking the functionality of [8] fish fins. The design of the fins focused on the curved structure that is helical and incorporated into the blade surface. As shown in Fig. 3, the design of the fins has a helical angle of 180°, which shapes into a wave-like form. The helical-fin structure thickness is 2mm and has a radius of 70mm.

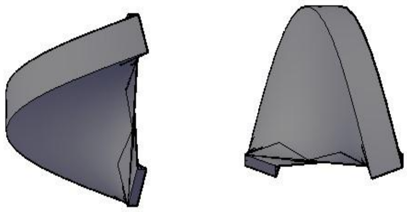


Fig. 3. Helical fish fin design model

Table 1 below presents the HM 280 Technical specifications based on the instrument's manual.

Table 1. HM 280 instrument technical specifications

HM 280 Technical Data	
Intake pipe:	Radial fan:
Inner diameter, D = 90 mm	Power consumption: 110 W
Length, L = 430 mm	Nominal Speed: 2800 rad/min
Delivery pipe:	Max. volumetric flowrate: 480 m^3/h
Inner Diameter, D = 100 mm	Maximum pressure difference: 300 Pa
Length, L = 530 mm	Dimensions and weight:
Measuring ranges:	L x W x H: 670 x 340 x 950 mm
Pressure: 0 – 1800 Pa	Weight: approx. 20 kg
Flow rate: 0 – 1000 m^3/h	Electrical operation requirements:
Temperature: 0 – 100°C	230V, 50/60 Hz, 1 phase
Required for Operation:	Software:
PC with Windows	GUNT software + USB cable

B. Parameters and Equations
B.1 Air Specifications:

Air Temperature = 27°C
Air Density = 1.183 kg/m^3
Wind Velocity = 6m/s

B.2 Theoretical Wind Power

$P_{wind} = \frac{1}{2}(pAV^3)$ Equation 1

where, P_{wind} = accessible wind power
p = air density (kg/m^3)
A = rotor swept area (m^2)

V = wind velocity (m/s)
B.3 Rotor Swept Area for Darrieus Turbine

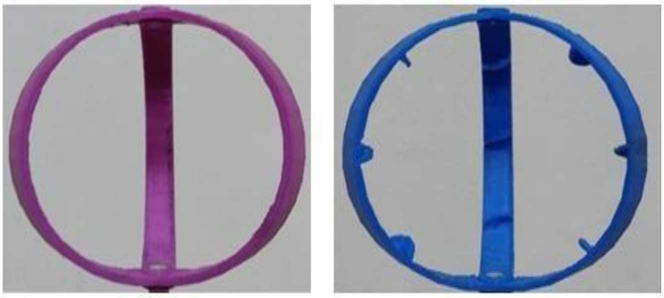
A = 0.65 (H) (D) Equation 2
where, A = rotor swept area (m^2)
H = blade height (m)
D = blade diameter (m)

B.4 Turbine efficiency is calculated through the equation

$$\eta_t = \frac{P_{output}}{P_{wind}} x100\% \qquad \text{Equation 3}$$

where, η_t = turbine efficiency in percent
P_{output} = actual power output, Watts
P_{wind} = input accessible wind power, Watts

Fig. 4 shows the 3D-printed Globe-type three-bladed Vertical-axis Darrieus wind turbine models are a reference point for the design model. Figure (a) represents without helical fins, and Figure (b) with helical fins.



(a) (b)
Fig. 4. 3D-printed Globe-type Darrieus wind turbine blade models

The 3D-printed prototype, as shown in Fig. 5, shows the helical fish fin's angle of inclination (base angle). These angles will be instrumental in assessing various aspects of power output and turbine efficiency. The experimental design incorporates base angles ranging from 0 to 85 degrees, facilitating comprehensive testing and evaluation.

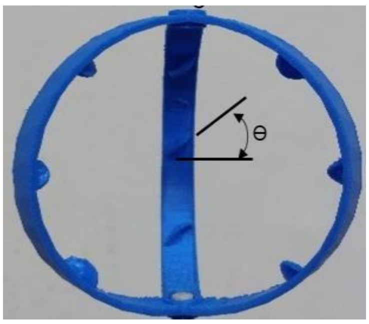


Fig. 5. Three-bladed Darrieus wind turbine with three fins per blade showing base angle θ

In Fig. 6, the Three-bladed Globe-type Darrieus wind turbine is enclosed within a 100-mm polyvinyl chloride (PVC) pipe, which is affixed to the end of the HM 280 delivery pipe. The PVC pipe measures 200mm in length, with the turbine positioned at its center. Table 2 presents the detailed design and material specifications of the Darrius wind turbine.

Fig. 6. Three-bladed Globe-type Darrieus wind turbine set-up

Table 2. Globe-type Darrieus Wind Turbine detailed specifications

Turbine design parameters and material specifications	
Rotor Radius, mm	41.50
Rotor Height, mm	90.00
Blade Cord Width, mm	70.00
Number of blades	3
Number of fins per blade	3
Material (Plastic)	PLA or Polylactic Acid
Number of 3D-printed Globe-type Three-bladed Darrieus Turbines	7 with fins 1 without fins

Experiments took place at Xavier University's Mechanical Engineering research laboratory located in the Annex building of the College of Engineering. The study involves designing, 3D-printing, testing, and analyzing the Three-bladed Globe-type Darrieus wind turbine within the laboratory.
The HM 280 instrument, along with the GUNT software was properly configured to adhere to the experimental criteria and standard, collect data at three-second intervals across three trials per turbine model, and evaluate the impact of varying base angles on turbine power performance and efficiency.

RESULTS AND DISCUSSIONS

Fig. 7 illustrates a 3D-printed Globe-type Darrieus wind turbine, showcasing both the corresponding fin base angles and a blade without fins. The figure showcases eight turbine models, numbered 1 through 8: turbine 1 represents the model without fins, while turbines 2 through 8 feature fins and their corresponding base angle as presented in Fig. 7. For detailed technical specifications of the turbine, please refer to Table 2.

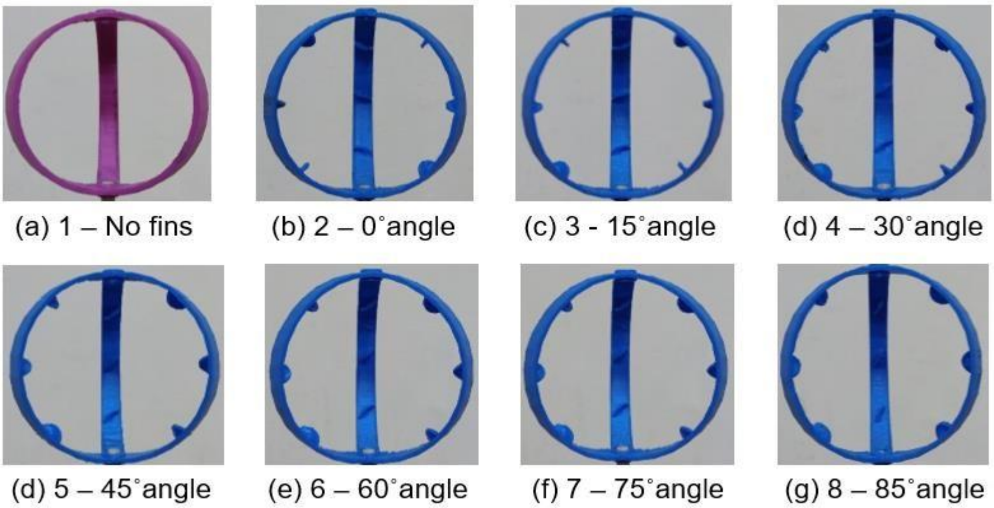


Fig. 7. 3D-printed Globe-type Darrieus wind turbine with fins demonstrated by different models

The data was then analyzed and presented in Fig. 8 and Table 3 to evaluate the average power output and turbine efficiency. The main objective is to determine the highest power output and efficiency. Based on Fig. 8, it is shown that the Three-bladed Globe-type Darrieus wind turbine with the fin-based angle of 60 deg. (model 6) has the highest power output as compared to the rest of the models, followed by models 8, 2, and 7. The average input power recorded at a 6 m/s wind velocity setup is 431.905 mW.

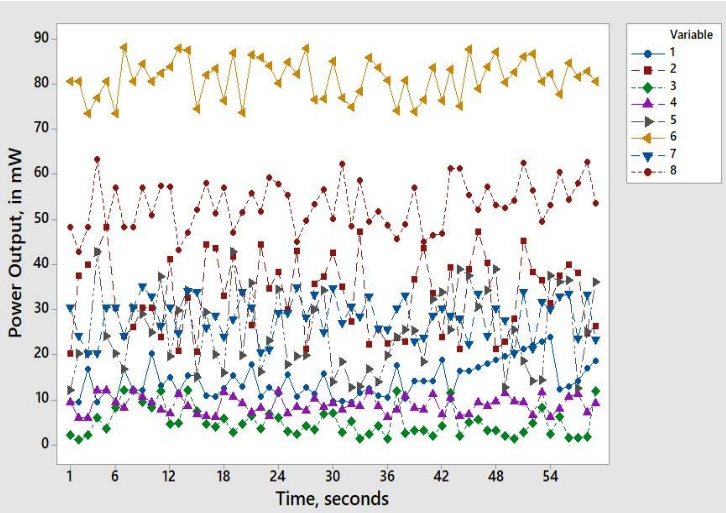


Fig. 8. Graph of power output at mW with fins at varying models

Table 3 shows the wind power, average power output, and the percentage turbine efficiency of all models. It presented that the Three-bladed Globe-type Darrieus turbine without fins (model 1) has a wind power of 431.84232 mW, a power output of 14.24 mW, and an efficiency of 3.29%. In comparison, model 6 obtained the highest power output of 81.32 mW and 18.82% turbine efficiency.

Table 3. Turbine Performance at different models

Model	Wind Power, mW	Average Actual Power Output, mW	Percent Efficiency, %
1 – No Fin	431.84232	14.24	3.29
2 – 0 degree	431.87972	33.21	7.69
3 – 15 degrees	431.88812	4.94	1.14
4 – 30 degrees	431.90414	8.83	2.04
5 – 45 degrees	431.93482	25.00	5.78
6 – 60 degrees	431.93157	81.32	18.82
7 – 75 degrees	431.93682	28.27	6.54
8 – 85 degrees	431.95482	53.16	12.30

Five (models 2, 5, 6, 7, 8) out of seven models produce higher turbine performance when varying their base angle. Models 3 (15 degrees) and 4 (30 degrees) have a lower power performance of 4.94 mW and 8.83 mW, while their efficiencies are 1.14 % and 2.04%, respectively, as compared to model 1 (no fins).

Fig. 9 shows a three-dimensional graph showing the overall effects of varying base angles of helical fish fins onboard the turbine blades on the power performance and turbine efficiency. The 3D surface plot presents the behavior of this varying model, which proves the importance of biomimetic structures in the design of turbine blades.

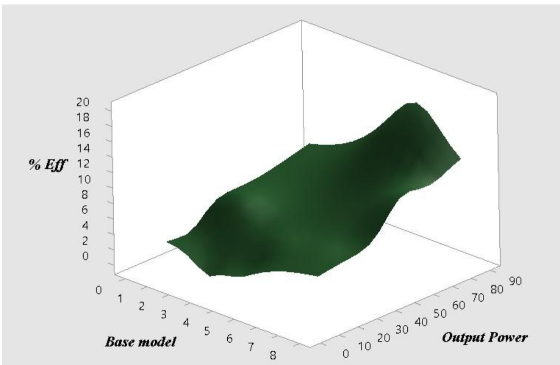


Fig. 9 Surface plot: x – Base Model, y – Output Power in mW, and z – % efficiency

CONCLUSION

This study investigates the impact of helical fish fins, a biomimetic structure integrated into the Three-bladed Globe-type Darrieus wind turbine, with variations in fin base angles ranging from 0 to 85 degrees. The results indicate that the inclusion of these fins significantly influences turbine performance compared to conventional wind turbines. The incorporation of helical fish fins on the turbine blades has led to a remarkable increase in efficiency, with a difference of 15.53%, and a significant enhancement in the power output of 67.08 mW, observed between Model 1 and Model 6.

ACKNOWLEDGMENT

The authors would like to extend their gratitude to the Mechanical Engineering Department of Xavier University for generously providing access to the HM 280 instrument and the 3D printer, which were instrumental in the successful completion of this research study.

REFERENCES

1. E.B. Dollera, R.C. Golez, S.D.R.C. Ty, J.P.F.S. Gaston, and J.V. Balo (2019). Development of XU Plastic Shredder for Cost-Effective Means of Minimizing Polyethylene Terephthalate Plastic Waste Volume. *International Journal of Innovative Technology and Exploring Engineering*. ISSN: 2278-3075, Vol **8**(12), October 2019
2. P. Gipe and E. Möllerström (2022). An overview of the history of wind turbine development: Part I – The early wind turbines until the 1960s. *Wind Engineering*, **46**(6) 1973 – 2004, DOI: 10.1177/ 0309524X221117825
3. R. A. Ghazalla, M.H. Mohamad, and A.A. Hafiz (2019). Synergistic analysis of a Darrieus wind turbine using computational fluid dynamics. *Energy 2019*, **189**, 15 https://doi.org/10.1016/j.energy.2019.116214
4. A. Abdolahifar and S.M.H. Karimian (2022). A comprehensive three-dimensional study on Darrieus vertical axis wind turbine with a slotted blade to reduce flow separation. *Energy 2022*, Vol. **248**, 1 June 2022, 123632. https://doi.org/10.1016/j.energy.2022.123632
5. F. Balduzzi, J. Drofelnik, A. Bianchini, G. Ferrara, L. Ferrari and M.S. Campobasso (2017). Darrieus wind turbine blade unsteady aerodynamics: a three-dimensional Navier-Stokes CFD assessment. *Energy 2017*, Volume **128**, 1 June 2017, pages 550-563. https://doi.org/10.1016/j.energy.2017.04.017
6. S.D. Boedi, J. Sundah, M. Kawulur and F. Bawano (2022). Design and Construction of Kinetic Turbine External Hinged Blade as A Picohydro Scale Power Plant. Vol. **12**, Issue 1, December 2022. ISSN: 2278-3075 (Online)
7. M. Asadbeigi, F. Ghafoorian, S. Chegini and A. Jarrahian (2023). A 3D Study of the Darrieus Wind Turbine with Auxiliary Blades and Economic Analysis Based on an Optimal Design from a Parametric Investigation. Sustainability 2023, **15**(5), 4684. https://doi.org/10.3390/su15054684
8. F. Omidvarnia and A. Sarhadi (2024). Nature-Inspired Designs in Wind Energy: A review. *Biometrics 2024*, 9(2), 90. https://doi.org/10.3390/biomimetrics9020090
9. J.B. Damota, J.D.R. Garcia, A.C. Casanova, J.T. Miranda, C.G. Caccia, and M.I.L. Galdo (2022). Analysis of a Nature-Inspired Shape for a Vertical Axis Wind Turbine. *Applied Science 2022*, **12**(14), 7018. https://doi.org/10.3390/app12147018
10. M. Shaheen and S. Abdallah (2017). Efficient clusters and patterned farms for Darrieus wind turbines. Sustainable Energy Technologies and Assessments. Vol **19**, Feb 2017, pages 125 – 135; https://doi.org/10.1016/j.seta.2017.01.007
11. R. Zhang, J. Wu and S. Chen (2012). A New Active Control Strategy for Wind-Turbine Blades Under Off-Design Conditions. *International Journal of Modern Physics: Conference Series*. Vol **19**(2012), 283 – 292. DOI: 10.1142/S2010194512008872
12. E. Santoso, I.S. Awika, and N. Ariwiyono (2023). Experimental Study Influence of High Fin on NACA Airfoil 0018 On Performance Of H-Type Darrieus Wind Turbine. *International Conference on Maritime Technology and Its Application 2022. IOP Conf. Series*: *Earth and Environmental Science* 1265 (2023) 012010. DOI:10.1088/1755-1315/1265/1/012010
13. S.F. Pamungkas, D.S. Wijayanto, H. Saputro, and I. Widiastuti (2018). Performance "S" Type Savonius Wind Turbine with Variation of Fin Addition on Blade. *The 2nd Annual Applied Science and Engineering Conference. IOP Conf. Series: Materials Science and Technology*, **288**(2018) 012132. DOI:10.1088/1757-899X/288/1/012132