OPTIMIZATION OF THE HELICAL TURBINE

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PRESENTATION OUTLINE

- Introduction
- Aim & Objectives
- Simulation Setup
- Demonstration
- Results
- Conclusion

INTRODUCTION

- During our last presentation, we focused on design concepts for each turbine type in order to avoid failure due to high wind loads.

- The focus was on the static stress on the turbine blades.

- This week, the Helical/H-Darrieus turbine were optimized using Computational Fluid Dynamics (CFD) simulation.

- The results of these simulations will be presented, along with their analysis.

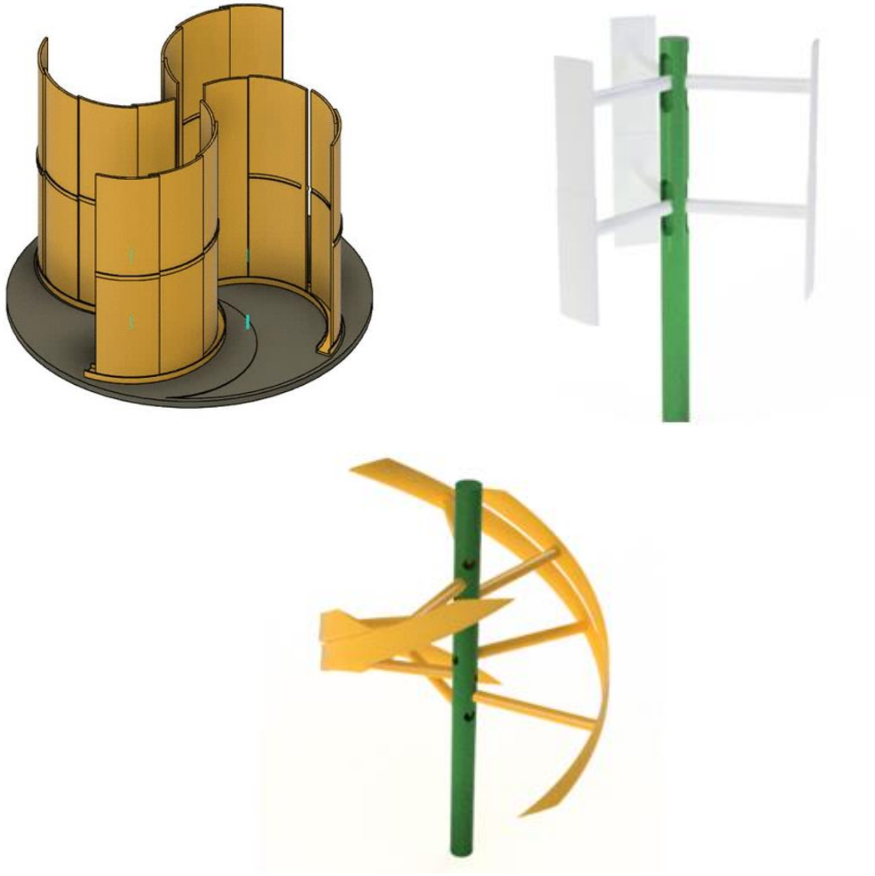


Fig. 1: New Turbine Designs

INTRODUCTION

STUDIED LOCATION

- The windiest city in Nigeria is Katsina, in Katsina state.
- Average annual wind speed is 8.3 mph.

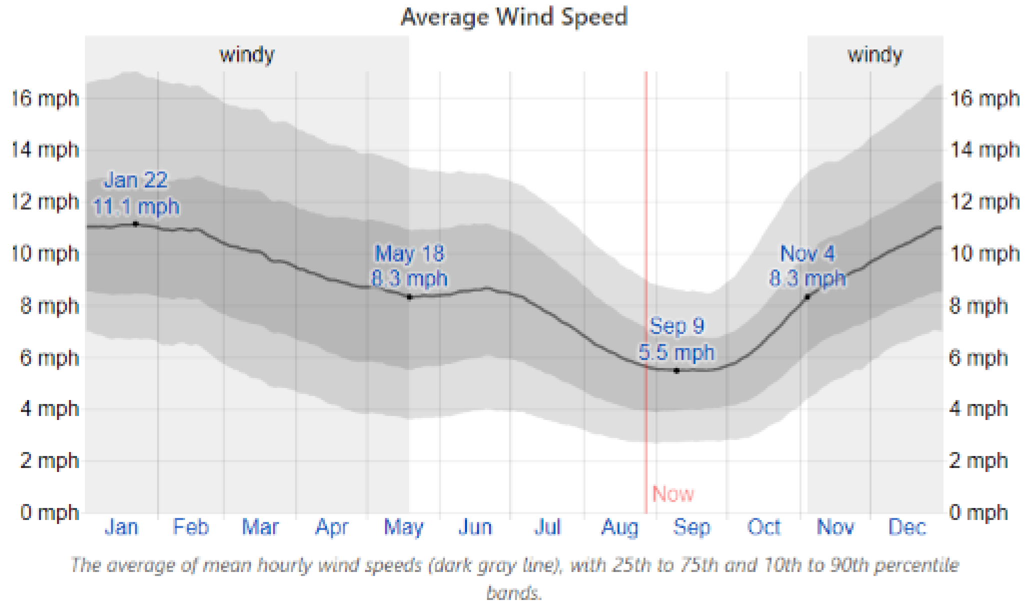


Fig. 2: Average Wind Speeds in Katsina
(Retrieved from http://weatherspark.com)

AIM AND OBJECTIVES

AIM

The aim of the project is to create virtual laboratories for ease of engineering education in African tertiary intuitions.

OBJECTIVES

The objectives of this project are to:

- Create a parametric 3D model of the turbine, using Fusion 360 API.
- Carry out simulations on the turbine, using Autodesk CFD.
- Carry out optimization of parameters and cost estimation.

SIMULATION SETUP

PROCEDURE

- Import the 3D model into CFD
- Edge Merging
- Assign materials
- Initial Boundary Conditions
- Mesh Sizing
- SOLVE

SIMULATION SETUP

The boundary conditions include:

- <u>Condition at the Inlet</u>: 3.7 m/s velocity & 0 Pa Pressure
- <u>Condition at the Outlet</u>: 0 Pa pressure
- <u>Type of fluid</u>: Air
- <u>Simulated time period</u>: 1000s
- <u>Material used for the turbine</u>: Glass Fiber Reinforced Plastic
- **<u>Parameter Considered</u>:** $\boldsymbol{Power = Torque * Rotational\ speed}$

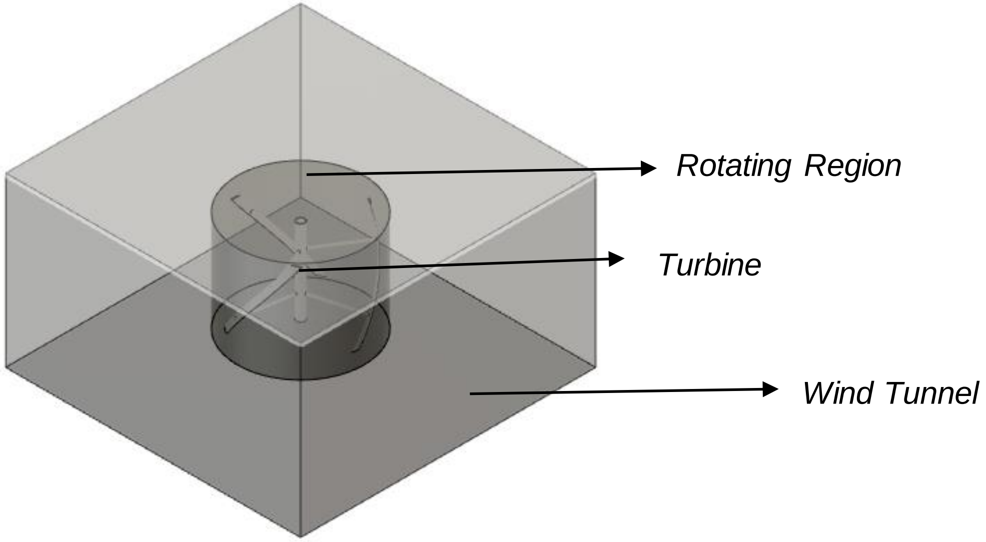


Fig. 3: Wind Tunnel Setup

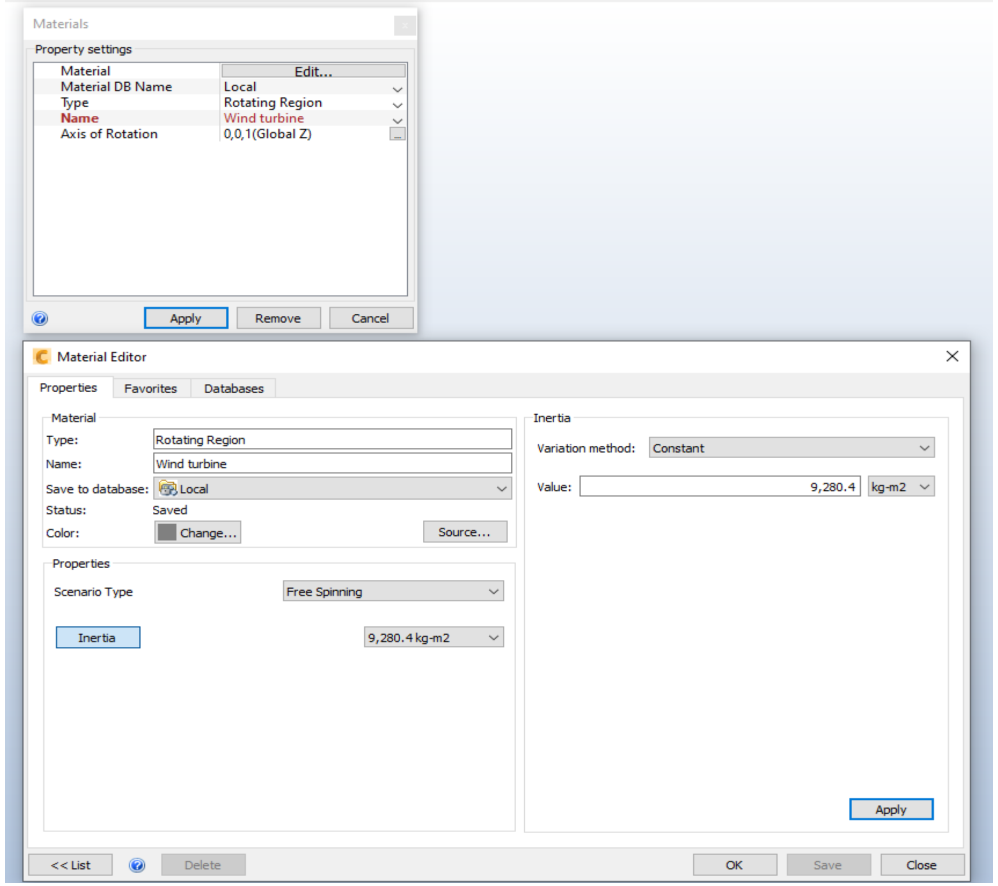


Fig. 4: Rotating Region Settings

DEMONSTRATION

VELOCITY DISTRIBUTION

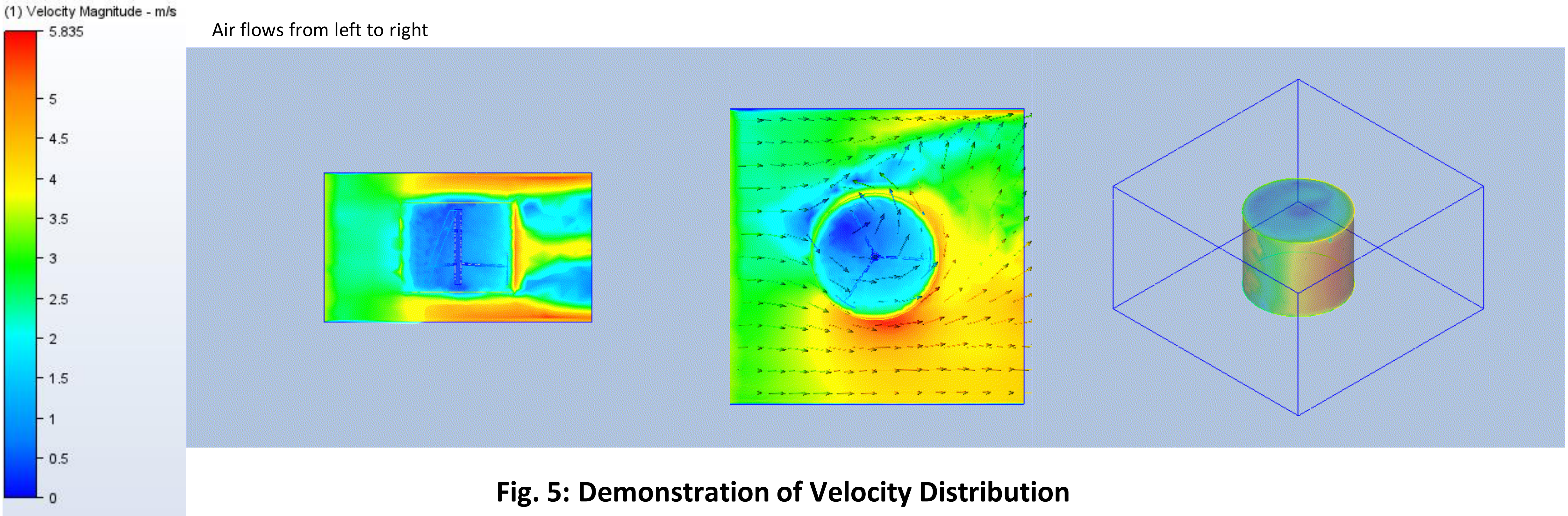


Fig. 5: Demonstration of Velocity Distribution

DEMONSTRATION

PRESSURE DISTRIBUTION

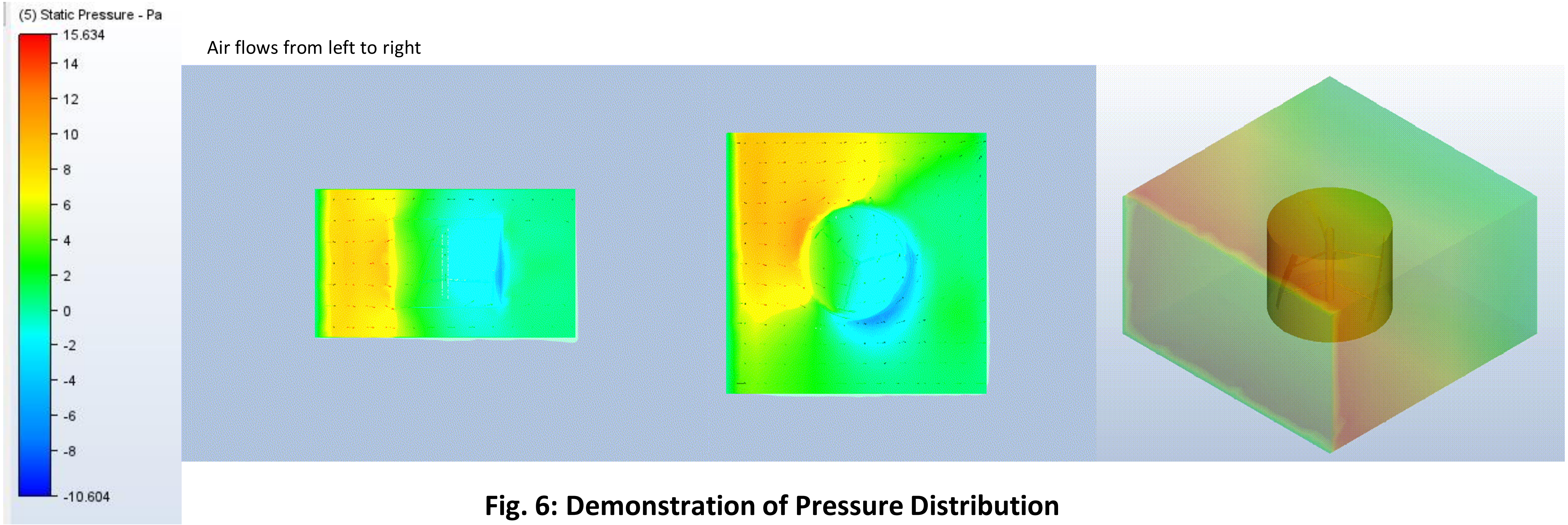


Fig. 6: Demonstration of Pressure Distribution

RESULTS

OPTIMIZED PARAMETERS

In order to fully optimize this turbine type, 4 geometric parameters had to be optimized:

1. Blade Curvature (BC)
2. Blade Height (BH)
3. Turbine Diameter (TD)
4. Number of blades.

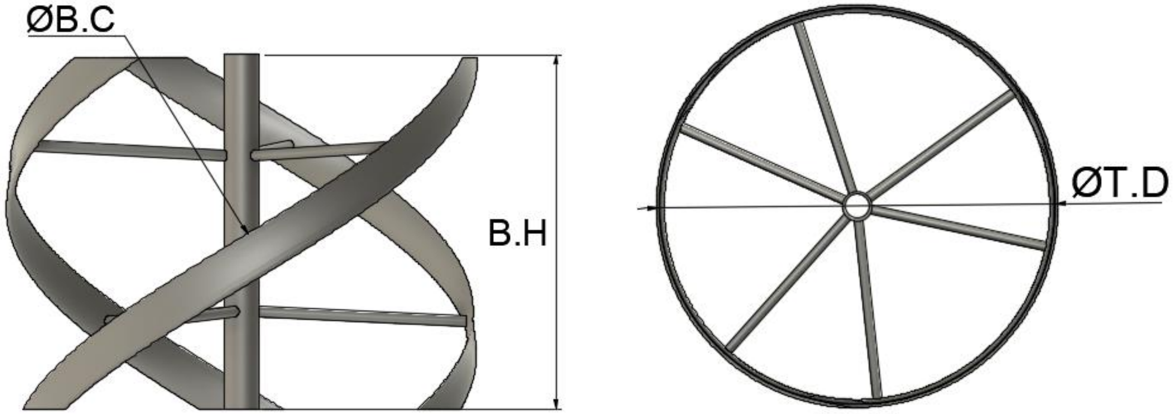
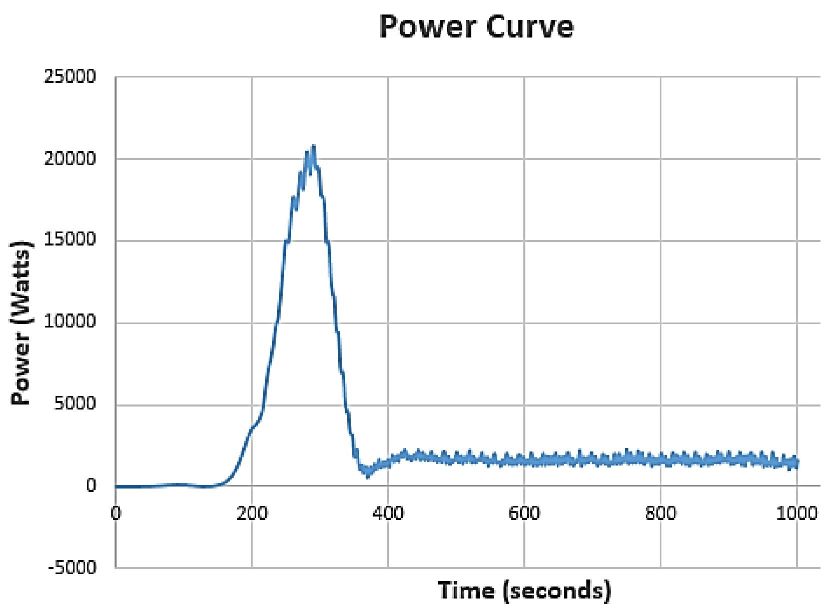
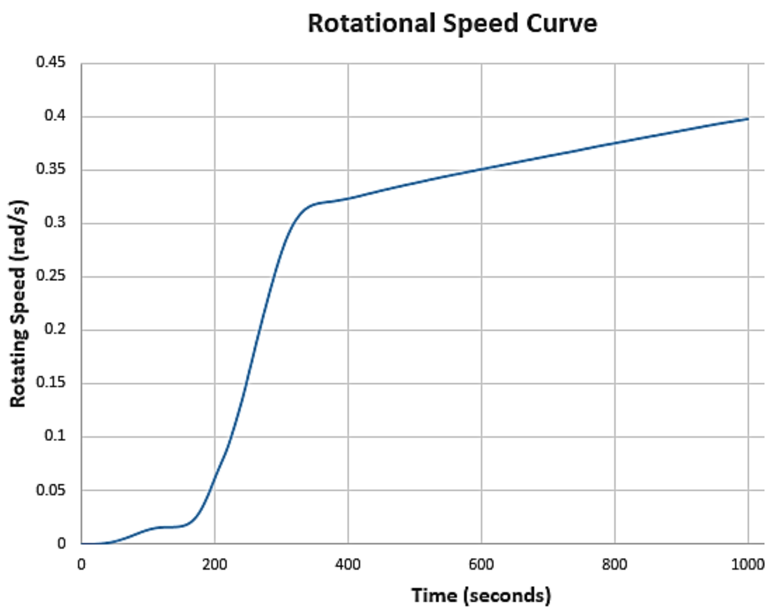


Fig. 7: Helical/ H-Darrieus Design Requirements

RESULTS

GENERATED CURVES





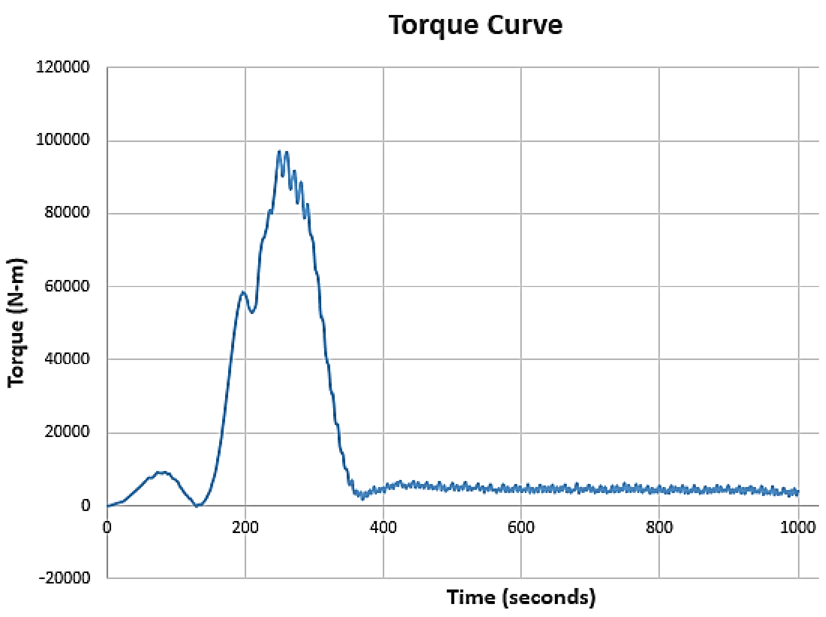


Fig. 8: Samples of the generated Curves

RESULTS

GENERATED CURVES

- The generated curves for all turbine scenarios are very similar in shape. The only differing the factor are the values.

- Hence, in order to compare each turbine geometry/ parameter, the value used is the average power.

- This is the sum of the power generated at each second, divided by the number of points.

RESULTS

<u>CASE 1</u>: Blade Curvature

- The number of revolutions of the blade was varied from 0 to 0.5 revolutions, in steps of 0.1 revolutions.
- 3 blades with 5m height & 6m diameter were used.
- These parameters were obtained from research done.

Number of Revolutions (n)	Angle Subtended (360*n)
0.1	36°
0.2	72°
0.3	108°
0.4	144°
0.5	180°

Fig. 9: Conversion between number of revolutions and angle subtended

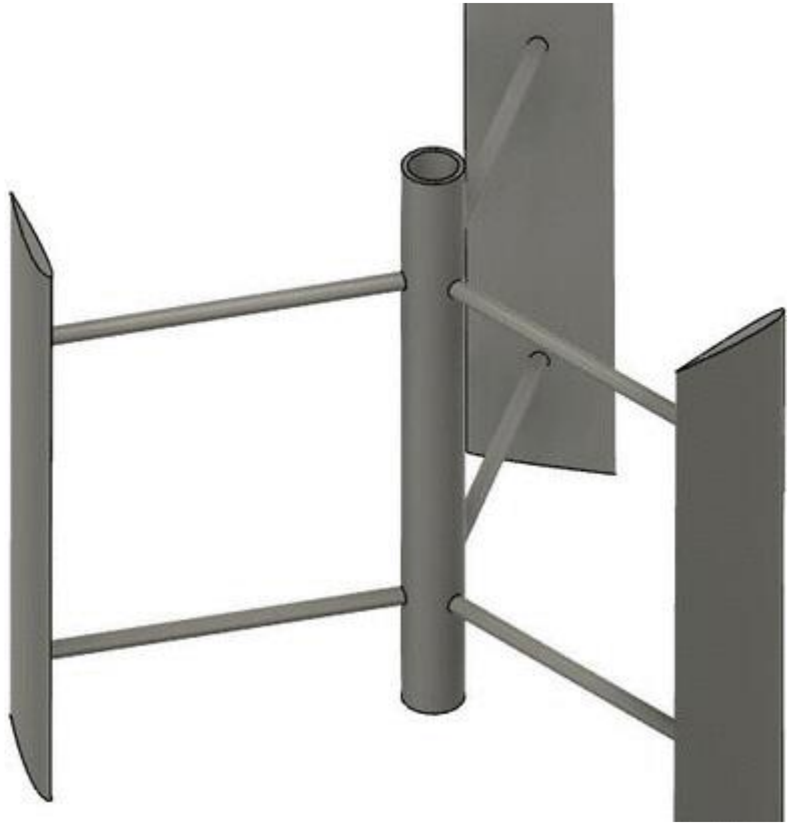


Fig. 10: Change in Blade Curvature

RESULTS

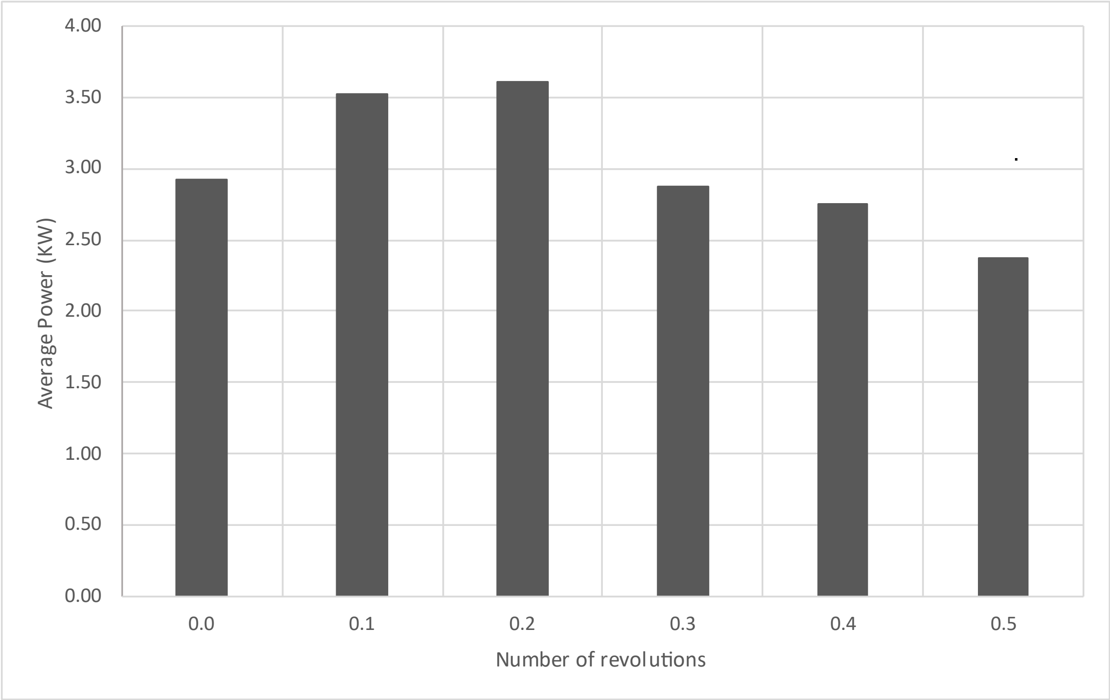


Fig. 11: Plot of Average Power against Number of Revolutions

Fig. 12: Turbine Blades with 0.1 revolutions

- The percentage increase in power generated between 0.1 and 0.2 revolutions is merely 2.3%.
- The mass (and consequently, the cost of material) of 0.2 revolutions is 40% higher than that of 0.1 revolutions.
- This is not a cost-effective relationship; hence, 0.1 revolutions is the optimal blade curvature.

Power generated = 3.52 kW

RESULTS

<u>CASE 2</u>: Optimising The Blade Height

- The blade height was varied from 1m to 7m, in steps of 2m.
- 3 blades were used.
- The no of revolutions was kept at 0.1.
- The diameter of the turbine was kept at 6 m.

Fig. 13: Change in Blade Height

RESULTS

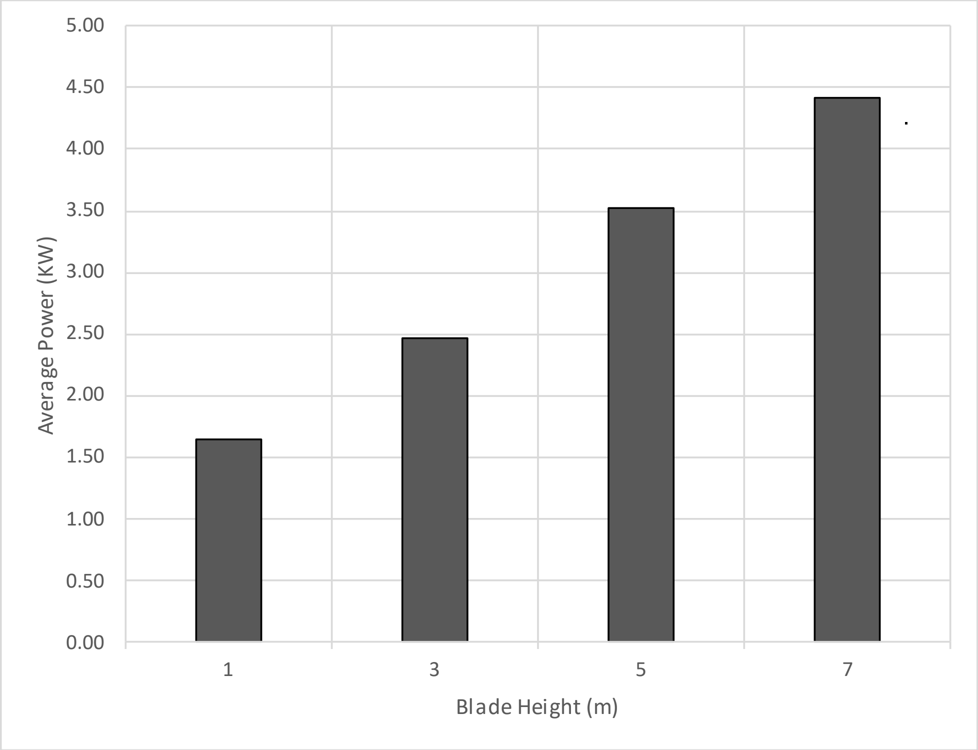


Fig. 14: Plot of Average Power against Blade Height

Fig. 15: Turbine Blades at 7m

The optimal blade height is 7m

Power generated = 4.41 kW

RESULTS

<u>CASE 3</u>: Optimising The Blade Diameter

- The blade diameter was varied from 2m to 8m, in steps of 2m.
- 3 blades were used.
- The no of revolutions was kept at 0.1.
- The height of the turbine was kept at 7 m.

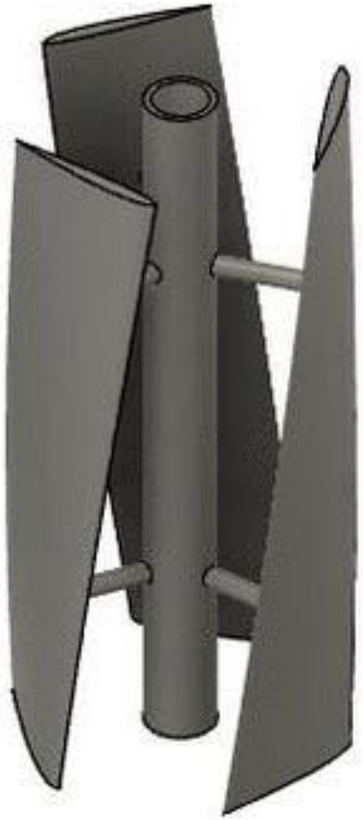


Fig. 16: Change in Blade Diameter

RESULTS

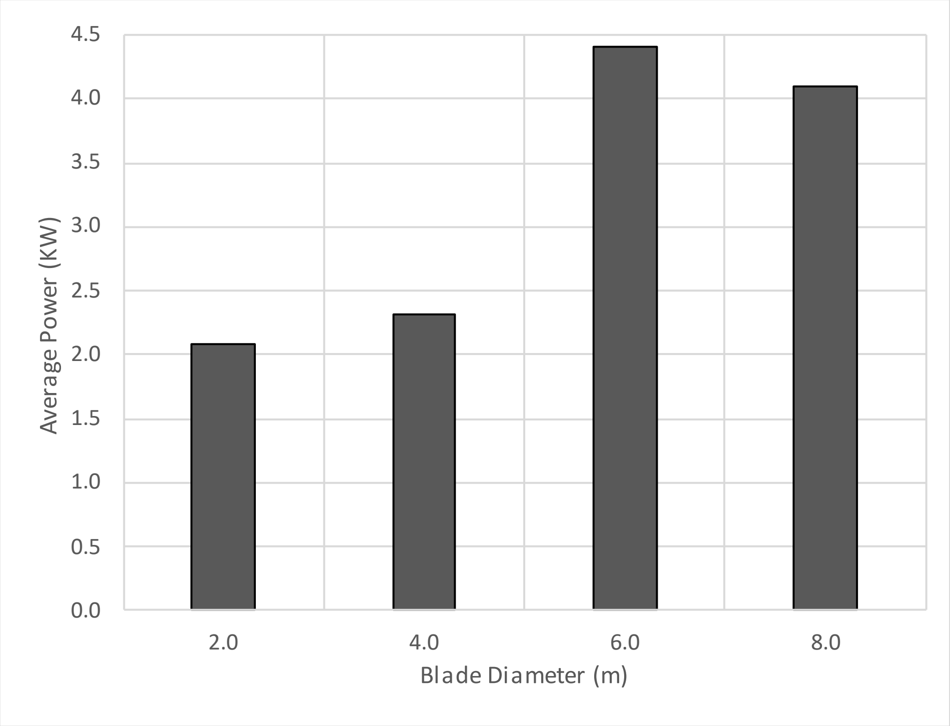


Fig. 17: Plot of Average Power against Blade Diameter

Fig. 18: Turbine at 6m diameter

The optimal blade diameter is 6m

Power generated = 4.41 kW

RESULTS

CASE 4: Optimising The Number of Blades

- The number of blades was varied from 3 to 7 in steps of 2.
- As advised by a paper, the blades are to be kept at an odd number; and they should not exceed 7 because of weight.
- The no of revolutions was kept at 0.1.
- The diameter of the turbine was kept at 6 m.
- The height of the turbine was kept at 7 m.

Fig. 19: Change in Number of Blades

RESULTS

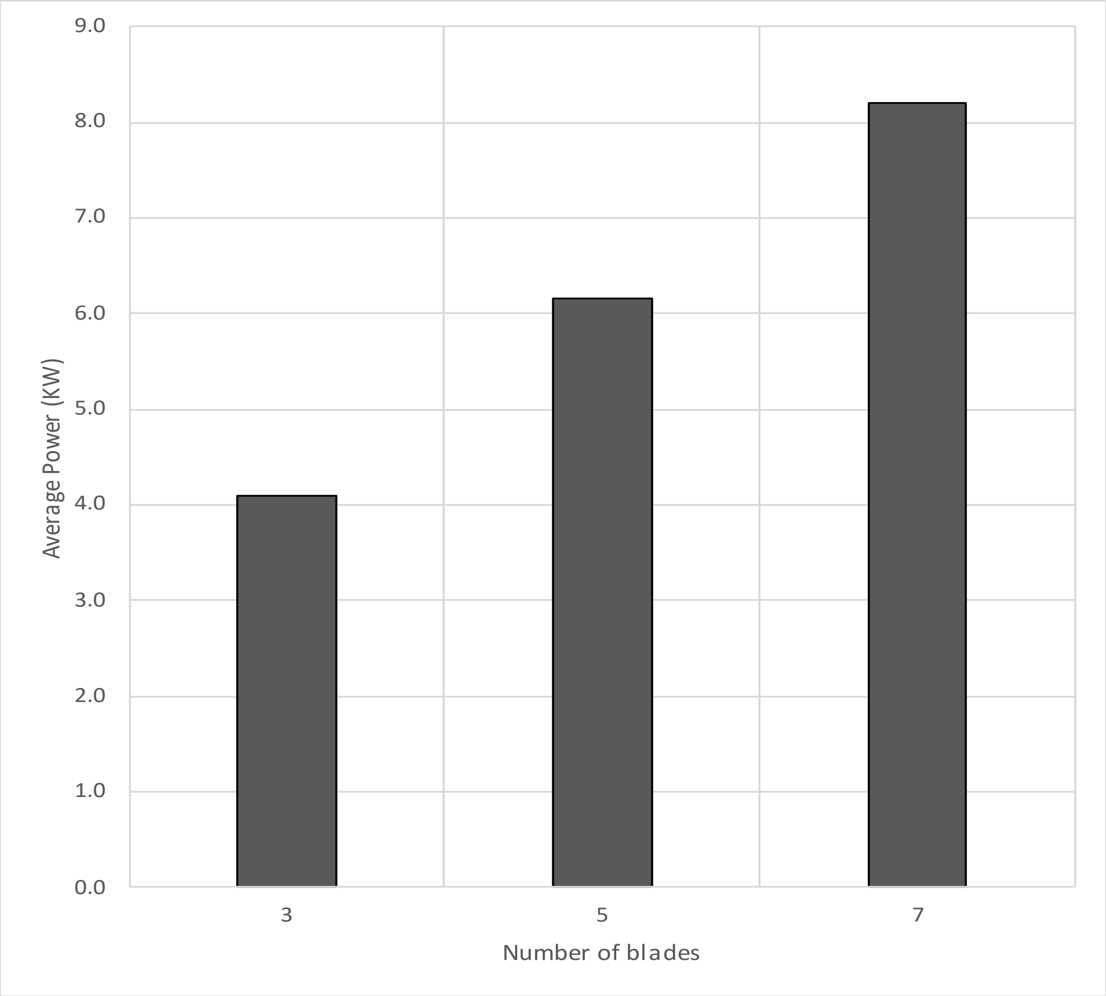


Fig. 20: Plot of Average Power against Number of Blades

- 7 blades gives the most power (8.2kW), but it may not be the most cost effective.
- More analysis was carried out to find out how many blades will be the most cost effective for the turbine.

RESULTS

COST COMPARISON

- Fibreglass is sold at a rate of **₦750 ($1.50)/kg**.
- Each blade weighs 1,200 kg.
- The cost of material for one blade is **₦900,000 ($1800)**.
- Comparison between the blades was done to show cost effectiveness. This was done by dividing the total cost of materials for each blade number scenario, by the amount of power generated.

RESULTS

COST COMPARISON

Number of Blades	Total cost for number of blades	Total Power Generated (kW)	Amount spent per kW of power
3	₦ 2,700,000	4.13	₦ 653,753.03
5	₦ 4,500,000	6.08	₦ 740,131.58
7	₦ 6,300,000	8.28	₦ 760,869.57

Fig. 21: Table of cost

- The above table shows that, although 7 blades gives us the most generated power, it is not very cost effective compared to the other blade number scenarios (3 & 5).

- The most cost-effective number of blades is 3, giving 4.13 kW of power at a cost of ₦2.7 million.

RESULTS

COMPARISON

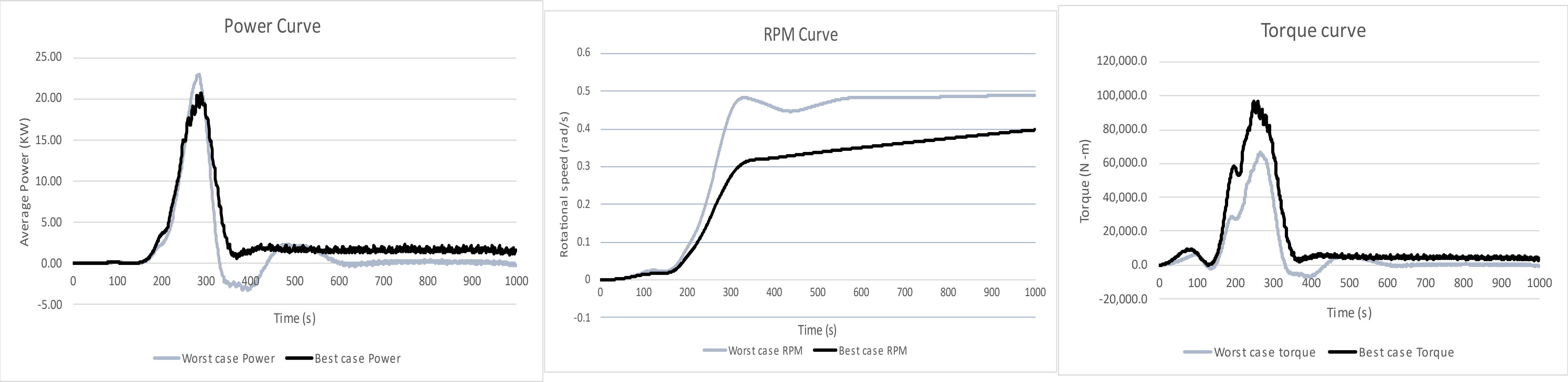


Fig. 22: Comparison between the best performing and worst performing blades simulated

- The best-case scenario is the turbine that has a 6m diameter, a 7m height and a curvature of 0.1 revolutions.
- The worst-case scenario simulated, on the other hand, has a 6m diameter, with a 1m height and a blade curvature of 0.1 revolutions.
- The worst case had a better RPM than our optimal blade but a much lower torque.

CONCLUSION

With the results obtained, it is deduced that the optimal Helical Turbine has:

- Blades of 0.1 revolutions
- Height of 7m
- Diameter of 6m
- 3 blades

The following combination gives **4.13 kW** of power at a cost of **₦2,700,000** in material cost for the blades.

Fig. 23: Rendered image of the optimal Helical Turbine