Technical Design Report

Texas Tech University
April 24, 2022

Presented By:

Team Lead: Trey Gloeckler, trey.gloeckler@ttu.edu

Vice Team Lead: Nathan Dyer, nathan.dyer@ttu.edu

Prototype Lead: Heather Aggen, heather.aggen@ttu.edu

Ian Davis, ian.davis@ttu.edu

Melanie Hsieh, melanie.hsieh@ttu.edu

Isaac Morales, isaac.d.morales@ttu.edu

Ade Omoloja, adeolaa.omoloja@ttu.edu

Advisors:

Kacey Marshall, M.A., Assistant Director, TTU Renewable Energy

Andrew Swift, Sc.D., Research Professor, TTU National Wind Institute

Suhas Pol, Ph.D., Associate Professor of Practice, TTU Renewable Energy

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1 Executive Summary

To meet the tasks given for the 2022 Collegiate Wind Competition (CWC), the Techsan Wind Team designed, built, and tested a wind turbine model that can function in emulated offshore conditions. The CWC required a model with the following specifications:

1. Model wind turbine diameter was limited to 45 cm,

2. Should withstand a maximum wind speed of 22 m/s wind speeds,

3. Utilizes a foundation design to emulate an offshore installation,

4. Foundation was limited to 25 cm square diameter,

1.1 Teams

The technical team was comprised of students from mechanical engineering, civil engineering, computer engineering, and wind energy majors and team members selected their sub-teams based on expertise as well as interest. The Techsan Wind team organized itself into three main teams: prototype, development, and communications. The prototype subteam was divided further into a mechanical subteam, controls subteam, foundations subteam, and blade subteam. The mechanical team was composed of mechanical engineers, the controls team was composed of computer and mechanical engineers, the foundation team was composed of civil engineers, and the blade team was composed of wind energy majors.

2 Design Objective

2.1 Design Overview

The design objective for this competition is to create a turbine that is stationed in offshore conditions. This turbine should be able to withstand wind speeds up to 22m/s at sea level. The foundation should not penetrate the sand more than 15cm (about 5.91 in) and keep the turbine from moving when presented with extreme wind speeds. Another foundation restriction is that the foundation should not exceed the square dimensions of 25cm (approximately 9.84 in). The foundation must also be made of ferrous metal with coatings excluded and be able to be installed without touching the water. The electrical wiring that connects the turbine to the outside components must be made through the top of the foundation and be both waterproof and connectors must be able to withstand the weight of the cables. Another key factor that is needed is a yaw system to turn the turbine into the predominant wind direction.

2.2 Design Components

The design components are intended to withstand the set restrictions mentioned in the design overview. The materials used, and the electrical load used for the turbine are designed to withstand wind speeds up to 22 m/s without seeing system failure. Components used include Blades, MN5008 Antigravity T-Motor drone motor, servos, relays, Raspberry Pi, power smoothing filters, optocouplers, full-bridge rectifier, and an electrical load model. For the foundation, the set restrictions were resolved with an installation plan to prevent any touching of the water using an anchoring system that is installed with battery-operated drills. The foundation is composed of steel ground augers, steel sheet metal, and nominal OD steel pipe.

3 Basic Static Performance

3.1 Blade Design

3.1.1 Blade Overview

The airfoil that was chosen for this project was the Davis airfoil. The Davis airfoil was chosen because of the non-symmetrical shape instead of the asymmetrical shape that has less lift. The thin thickness of the Davis airfoil is superior to the larger thickness of symmetrical airfoils. Along with the Davis airfoil, the Texas Tech team also researched the Eppler 62 airfoil. The research conducted was for low Reynolds number airfoils due to the small-scale turbine being the objective. The blades have been manufactured by the Texas Tech University mechanical engineering department out of aluminum. An important aspect that was tested is the aerodynamics, which was done by a Texas Tech developed blade element momentum (BEM) code. BEM code allowed for the blade to be simulated and put into an environment to react to. The pitch simulations that were run are important for the mechanical and electrical team to determine the optimal pitch angles for each wind interval. The BEM code also provides information such as the thrust and torque produced on the blades. This information helps with understanding the foundational loads present. For the Pitching of the blades, a preliminary test was done for the motor and pitch mechanisms.

The airfoil that was chosen for this project was the Davis airfoil. The Davis airfoil was chosen because of the asymmetrical shape instead of an asymmetrical shape that has less lift. The thin thickness of the Davis airfoil is superior at low Reynolds Number operation to the larger thickness of symmetrical airfoils. Along with the Davis airfoil, the Texas Tech team also researched the Eppler 62 airfoil. The research conducted was for low Reynolds number airfoils due to the small-scale turbine being the objective. The blades were manufactured by the Texas Tech University Mechanical Engineering Machine Shop out of aluminum stock. Blade performance analysis was done using a Texas Tech developed blade element momentum (BEM) code, as described in Section 3.2. Pitch simulations were run for the mechanical and electrical team to determine the optimal pitch angles for each wind speed interval. The BEM code also provided information such as the thrust and torque produced on the blades. This information helps with understanding rotor and foundational loads as well.

3.1.2 Design Process (QBlade)

The design processes for the Texas Tech aluminum blades came from extended research into different airfoils. Different airfoil thicknesses, Reynolds numbers, and shapes were considered with special consideration given to blades with superior performance at small Reynolds numbers to align with size constraints. The two main airfoils considered were the Eppler 62 and the Davis. Research on other airfoils such as the NACA symmetrical airfoils were incompatible with the project due to their mediocre performance at low Reynolds numbers. The Eppler and Davis airfoils are similar in their thickness, curvature, and small Reynolds number performance. Using QBlade, a publicly available wind turbine rotor design code, the rotor and airfoil specifications are used to estimate rotor performance. The blade shape and dimensions were also developed using the QBlade application. The Davis airfoil became our focus due to its superior power and performance. The blade prototypes were then printed in 3D using a 3DWOX printer. The blades went through multiple alterations to achieve the final design. The Davis rotor performance curves are shown in Figure3.1.1.

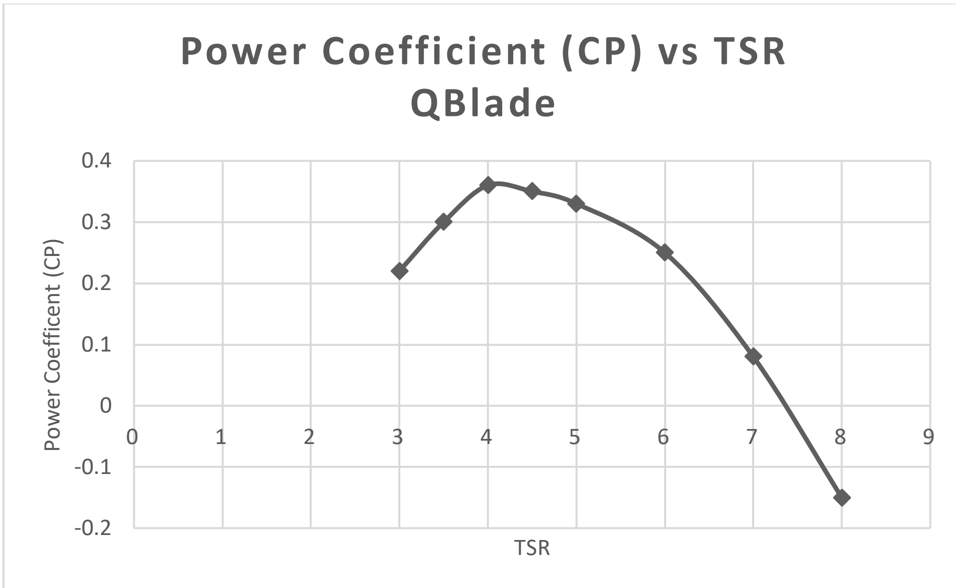


Figure 3.1.1. Davis Airfoil Cp/TSR Chart from Qblade

3.1.3 Final Blade Design

The final blade design uses the Davis airfoil but is modified for the prototype. After the modifications of the tip to make it thick enough for manufacturing as well as doubling the chord length the final blade design was created. The blade was machine milled by the Texas Tech Mechanical Engineering Department out of aluminum stock.

The final blade design of the aluminum blade and evaluation of theoretical performance was completed using QBlade. After the blade design was finalized, the blade design was exported as an STL file from QBlade. Then the STL file was used in Solidworks and converted to a surface model. The manufacturing steps are shown in the figures below.

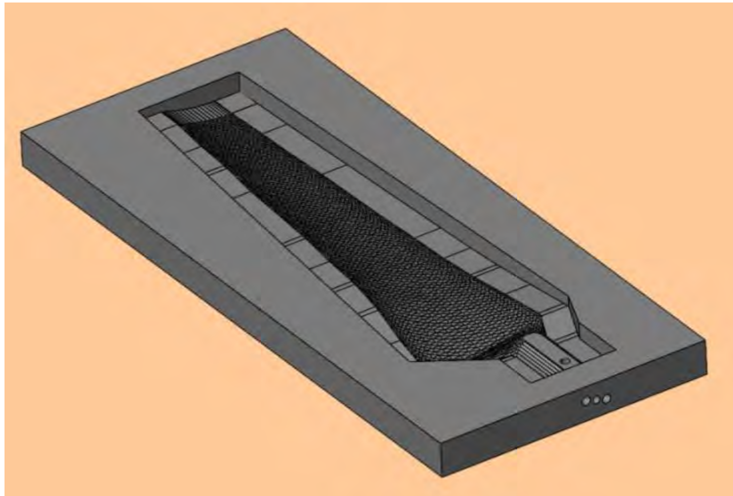


Figure 3.1.2 First pass to correctly obtain the curve of the airfoil.

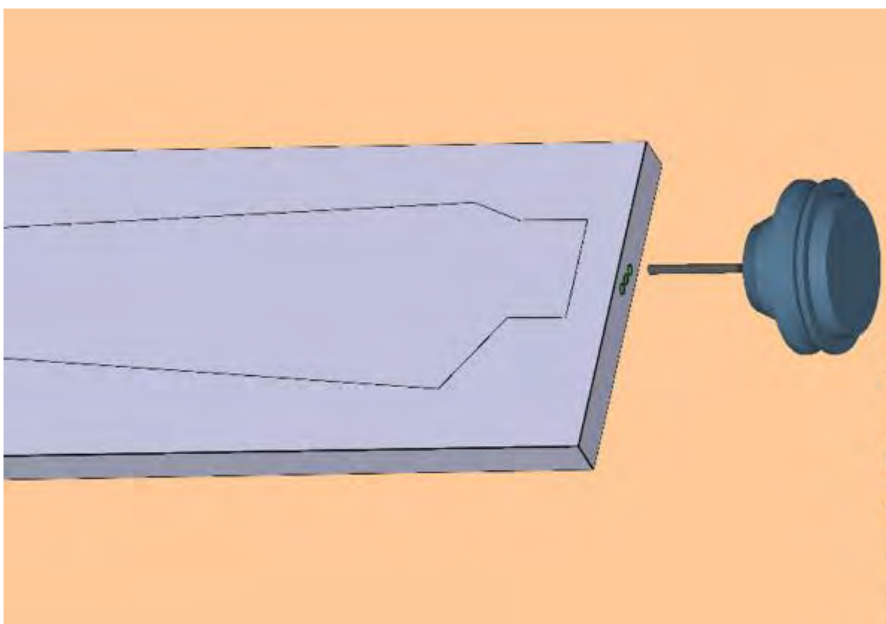


Figure 3.1.3 Stub mount drilling

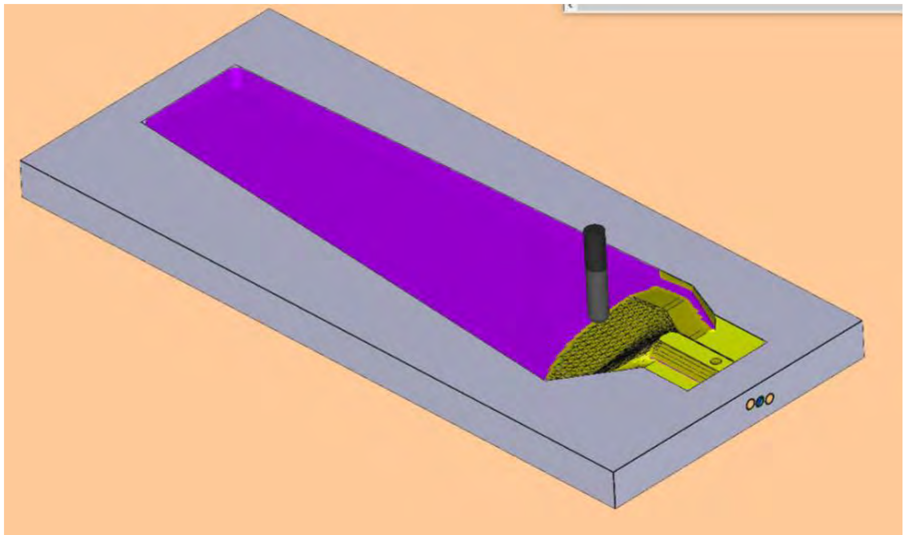


Figure 3.1.4 Concave side of blade manufacturing

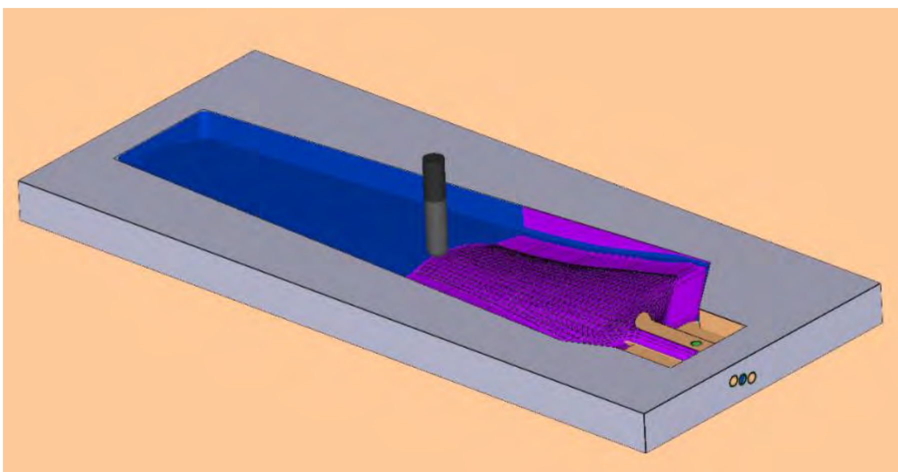


Figure 3.1.5 Convex side of blade manufacturing

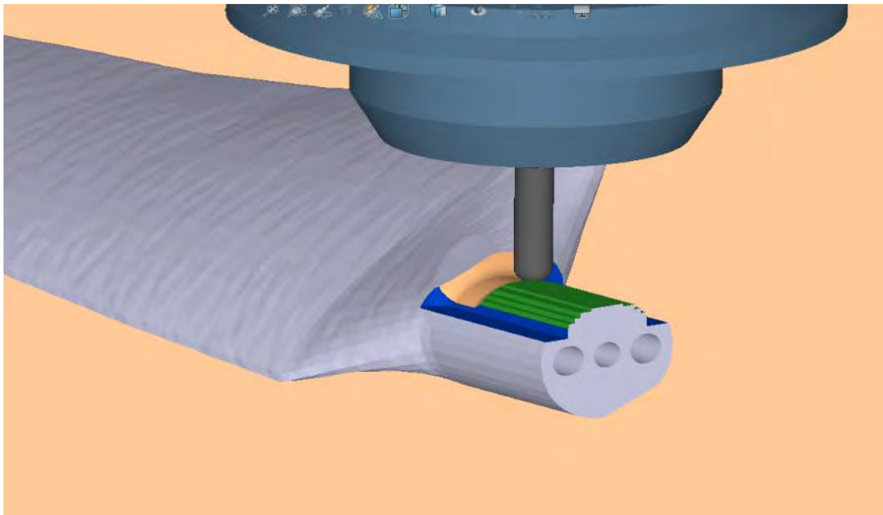


Figure 3.1.6 Final editing of stub during manufacturing

Figures 3.1.3-3.1.6 The first figure shows hole drill for CNC mounting. The second shows milling of the concave side, while the third shows the convex side. The final figure shows the milling of the connection stub.

Figure 3.1.7 shows QBlade stress analysis for this design. The figure shows low-stress areas in most of the final blade design, but high-stress areas near the stub of the blade are minimal. In a final design, these stress concentrators can be addressed by smoothing these areas minimizing the stress on the blade.

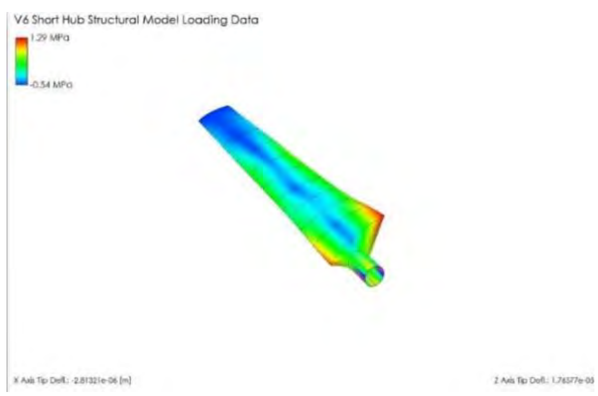


Figure 3.1.7 Stress analysis of the final blade design for wind speeds of 3 to 22 m/s

3.2 Rotor Performance Analysis

QBlade works well for blade design but can be difficult to use for performance analysis. Also, it does not include electric generator characteristics. To address these issues, a locally developed Blade Element Momentum (BEM Code) written in Excel for instructional purposes was used. The code is based on standard BEM Theory as presented by Hansen (Ref.) and adapted for MS-Excel as described by Swift (Ref). The Excel Code uses standard BEM algorithms and Excel

"Solver" for axial induced velocity calculations over each blade segment. Tip losses and other secondary effects are ignored for simplicity. Figure 3.2.1 shows the Power Coefficient TSR (Tip Speed Ratio) for a pitch angle of +1degree, with a maximum power coefficient (CP) of 0.45 at a TSR of 6.43. Figure 3.2.2 shows the Rotor Thrust (N) with a maximum thrust of 8.26 N at a wind speed of 11 m/s. Figure 3.2.3 shows a Variable Data Chart which includes Pitch Angle, output power in Watts (Electric), and RPM/100. Figure 3.2.4 shows Power Curves set at different air densities – including sea level (1.23 kg/m^3) with a rated power of 44.25 Watts, Lubbock, Texas (1.06 kg/m^3) at 38.5 Watts, and San Antonio, Texas (1.15 kg/m^3) at 41.25 Watts.

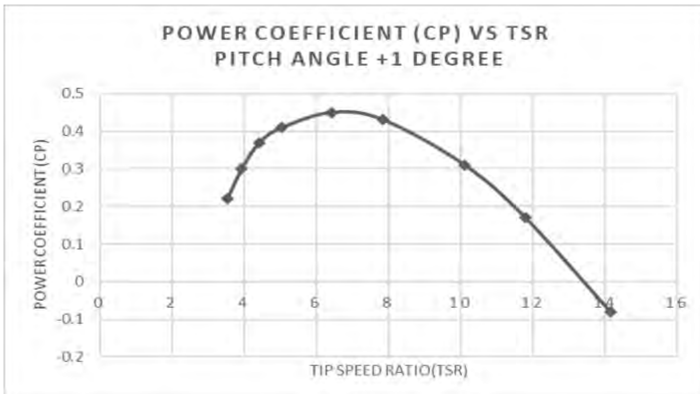


Figure 3.2.1 Power Coefficient; data from Blade Element Momentum (BEM) Code

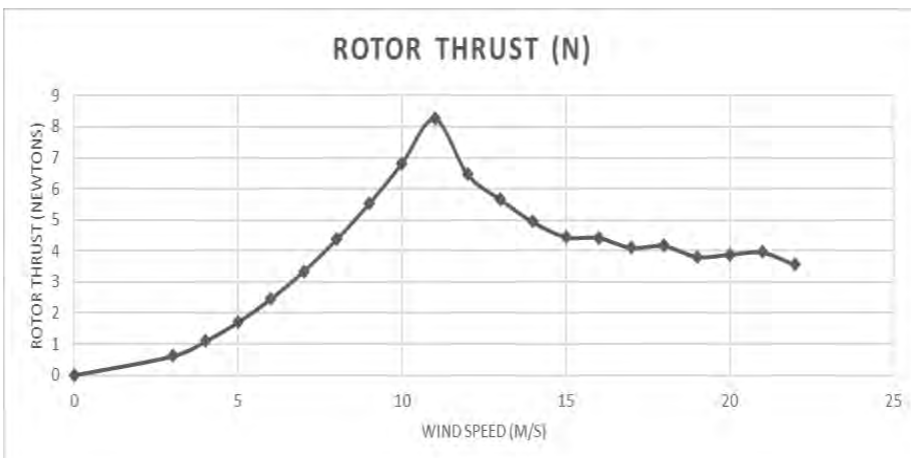


Figure 3.2.2 Complete Rotor Thrust (Newtons); data from Blade Element Momentum (BEM) Code

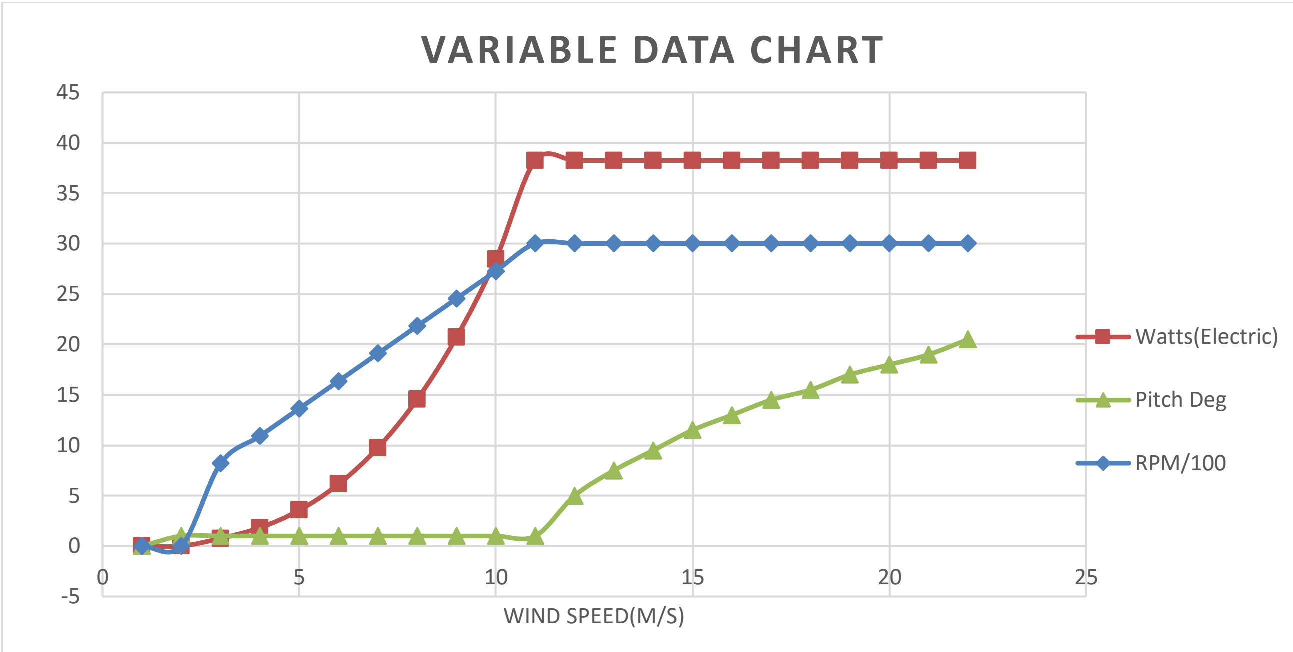


Figure 3.2.3 Variable Data Chart; includes Pitch, RPM/100, and Power Production (Electric); data from Blade Element Momentum (BEM) Code

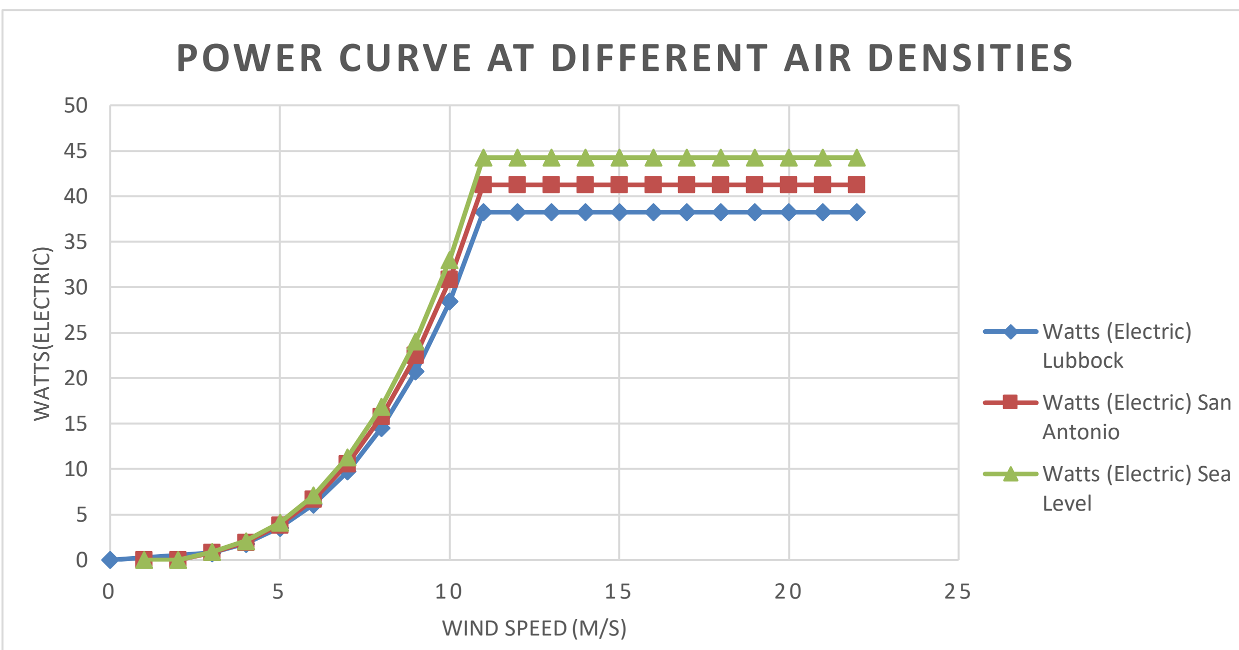


Figure 3.2.4 Power Curve at different air densities; Lubbock TX, (1.06 kg/m^3), San Antonio, TX (1.15 kg/m^3), and Sea Level (1.23 kg/m^3); data from Blade Element Momentum (BEM) Code.

3.3 Annual Energy Production

To estimate the annual energy production of the prototype turbine scaled to the size of the wind turbine chosen by the development team, we used the Rayleigh distribution of wind speeds at hub height provided by the development team (8.4m/s) and scaled it to the rated capacity of the wind turbine chosen by the development team (6.15 MW). Using the power curve adjusted to sea level for the prototype and the Rayleigh distribution, gross capacity factor of 46.7% was calculated. Applying this capacity factor to the full-scale turbine resulted in an Annual Energy Output of 25,160 MWhr.

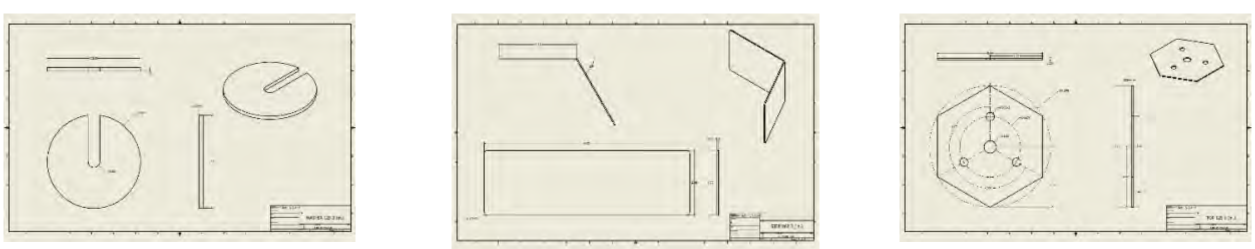
4 Foundation (Civil and Structure Analysis)

4.1 Foundation Overview

The foundation used is a version of a monopile foundation. The shape of the foundation is a hexagonal shape with three tie-downs that anchor the foundation into the sand. The main part of the foundation is a hexagonal plate with angled sides that go to a depth of 3 inches into the tank soil. Within the hollow foundation, flanges protrude from the bottom to add extra yaw support. Within the center of the top plate, there is a metal pipe that connects the turbine shaft to the foundation.

4.2 Design Process

The design for the top, sides, and washers was finalized in Autodesk Inventor. A CNC plasma cutter, supplied by the TTU Mechanical Engineering department, was used to cut the sheet metal parts. A sheet metal bender was used to create 60-degree bends for the sides. This helps reduce the total number of parts for the foundation and effectively halves the number of welds needed for the sides. Three ground tie-downs protrude through the top. They are held in place by washers welded to the shaft of the tie-down on either side of the hexagonal diaphragm. The top & washers will bear most of the load, so a thicker ¼ in. plate was selected for both the top and the washers The selected tie-downs have ⅜ in. socket heads to allow for quick installation with three battery-operated drills powered simultaneously. As the tie-downs are turned, a consistent downward force is required to screw into the sand to avoid auging the sand.



a) **b)** **c)**

Figure 4.2.1 Computer aided drawing (CAD) of a) washers, b) sides, and c) top

4.3 Analysis of Foundation and Anchoring System

Yaw; thrust; lift; soil failure

A single tie-down was vertically pull tested to a value of 25 lbs., using a hand-held Hanson spring scale, before soil failure. Next, the three (3) tie-downs were inserted 15 cm (about 5.91 in) below the sand surface level to maintain a 3 cm (about 1.18 in) clearance from the bottom of the tank. The tie-downs were placed in the sand to provide strength and stability to the turbine. Washers are welded above and below the top of the sheet metal foundation housing, as shown in figure 4.3.1 to prevent the hexagonal top from sliding up or down the tie-down shafts. This provides a thrust resistive moment of (27.9 N·m). Within the center of the three tie-downs, there is a nominal steel tubing connecting the center of the hexagonal top to the provided transition piece. A yaw moment of (41.8 N·m) was observed throughout the transition assembly before soil deformation occurred.

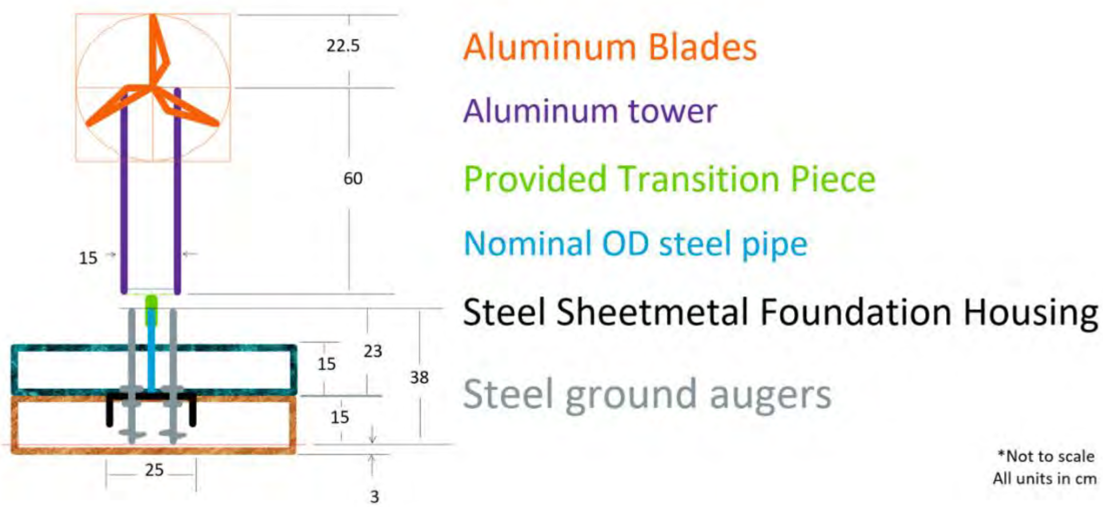


Figure 4.3.1 Assembly mockup

5 Electrical Analysis

5.1 Generator

The turbine was built around a MN5008 Antigravity T-Motor drone motor. This generator is a 3-phase AC generator with 24 poles or 12 pole pairs. The output voltage is limited to below 48V due to the nature of the motor. The Generator Efficiency was estimated from the Manufacturer's data, as shown in the Excel chart, and estimated to be 75% at a rated wind turbine rotor speed of 3,000 rpm.

Table 5.1.1 Calculated Electrical to Mechanical Efficiency from Manufacturers Motor Data Sheet

Table 5.1.1 Generator power efficiency

Voltage	Current	Elec. Pwr. W	RPM	Torque Nm	Mech. Pwr. W	Efficiency %
47.41	1.17	55	2868	0.13	39	70
47.39	1.57	74	3207	0.17	57	77

The generator load is a variable resistor bank controlled by relays and a Raspberry Pi computer. This is to provide a variable resistive load for the generator.

5.2 Power Electronics

P.E. for the prototype wind turbine consists of relays, servos, Raspberry Pi, power smoothing filters, optocouplers, and a full bridge rectifier. At turbine start-up, 24 Volt power is supplied to drive the turbine P.E. from a supplied power source. After the turbine starts and power output reaches 29 Volts ($24V_{supply} + 5V_{generated}$), the power supply is cut off and power is then supplied by the turbine generator. To ensure safe operation, all electronics are optically isolated.

5.3 Electrical Load Model

Voltage and current are measured to determine the power output of the generator. The generator load resistance is adjusted by a custom-designed variable load bank for optimizing the electric power output of the wind turbine generator. The calculated most efficient load resistance for the generator is 7.1 Ω. The tested load resistance that was the most efficient for power generation is between 6.9 - 7 Ω. This is assumed to be due to the resistance of the cables and connection points adding a small amount of resistance.

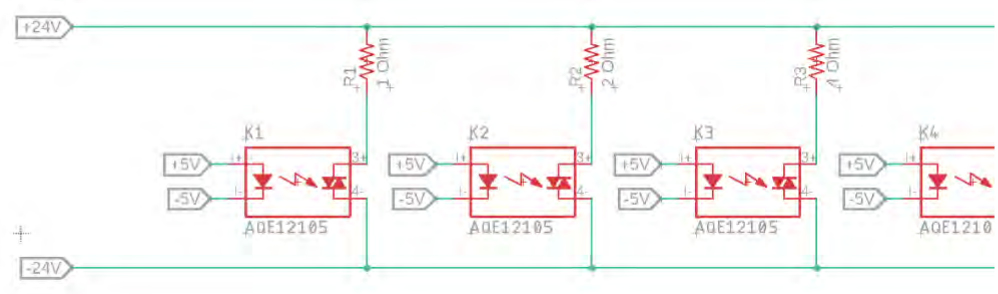


Figure 5.3.1 Schematic of electrical load

5.4 Operating Voltage

The operating voltage will be set to 12 Volts without a load, and 5 Volts with. This is for ease of operation for powering the servos. Regulators will be provided to the input power to the servos to prevent noise issues. Smoothing circuits have been applied to the power output of the generator to ensure peak-to-peak voltage is limited.

5.5 Plan to Regulate Voltage

The voltage will be regulated by the variable load resistor bank and the pitch control system to keep the turbine within designed and safe operating limits. Pitch will also be included in the voltage control however, blades will be focused on generating as much power as possible until rated values are reached (5 Volts, 2 Amperes). The generator purchased is unable to produce more than 48 Volts to follow the rule stated in section 3.1.4.

6 Control Model Analysis

6.1 Analysis of Operational Modes

Starting with the load system, operational modes include off (infinite resistance), high resistance (1024 Ohms), rated resistance (7 Ohms), and low resistance (1 Ohm). The resistor values in between the high resistance and rated resistance values are for dropping the load resistance in a controlled manner as so to not induce too many electromotive forces (EMF) on the generator. The resistances below 7 Ohms are to reinforce the emergency stopping while the load is still connected by generating EMF.

Operational modes of the generator include providing power to a relay and then powering the turbine electronics with the load. The relay's magnetic pole will be controlled by the voltage output of the generator. As soon as the rated voltage is reached (5 Volts), the relay will switch and allow the turbine to power the turbine's electronics and send power to the load. Prior to this, a power supply will be providing power to the turbine's electronics.

6.2 Description of Primary Operational Modes

The primary two operational modes include the turbine running while producing enough power and the turbine not producing rated power. These two modes account for the rest of what happens to the system. If the turbine is not running, power is provided from a source. If the turbine is running at rated speeds, the turbine will be producing the power and feeding electronics. The software will also be analyzing the turbine power output to adjust the load accordingly in real time.

The final mode is the emergency mode. If the e-stop is pressed, the whole system shuts down. The power is severed from the controls system and fed back into the turbine. This generates an EMF when passing the power back into the generation system. This EMF for stopping is also coupled with a set of springs on the hub that over pitches the blades when the servos stop holding position.

7 Software Architecture and Analysis

7.1 Software Architecture and Analysis

Software is scripted on a raspberry Pi 4 B+ 8Gb. The programming language used was Python. This program determines which relays to turn on to change the load resistance value.

```python
import itertools
import math
Ra = 1
Rb = 1/2
Rc = 1/4
Rd = 1/8
Re = 1/16
Rf = 1/32
Rg = 1/64
Rh = 1/128
Ri = 1/256
Rj = 1/512
Rk = 1/1024
Rl = 1/2048
numbers = [Ra, Rb, Rc, Rd, Re, Rf, Rg, Rh, Ri, Rj, Rk, Rl]
target = 3
result = [seq for i in range(len(numbers), 0, -1)
          for seq in itertools.combinations(numbers, i)
          if math.floor(1/sum(seq)) == target]
# or math.ceil(1/sum(seq)) == target or round(1/sum(seq)) == target]
print(type(result), "\n")
resist = [list(ele) for ele in result]
```

```python
print("List of Possible Resistance Combinations : " + str(resist))
length = len(resist)
equu = str(resist[0])
print("\n", equu)
```

```
/Users/Trey/PycharmProjects/pythonProject/venv/bin/python /Users/Trey/PycharmProjects/pythonProject/main.py
<class 'list'>

List of Possible Resistance Combinations : [[0.25, 0.03125, 0.015625, 0.0078125, 0.00390625, 0.001953125, 0.0009765625, 0.00048828125], [0.25, 0.0625, 0.007812

 [0.25, 0.03125, 0.015625, 0.0078125, 0.00390625, 0.001953125, 0.0009765625, 0.00048828125]

 Equivalent Resistance Value :  3.2050878247261347
 Target Resistance Value :  3

Process finished with exit code 0
```

Figure 7.1.1 Load Code

8 Final Assembly of Turbine Subsystems

8.1 Description of Final Turbine Assembly

The subsystems include the pitching mechanism, power control components, computation system, generator load, and the foundation system. The pitching mechanism includes a rack and pinion system attached to a mounted servo inside of the nacelle. The component will be powered by a power supply that is initiated by an air pressure switch. This will then be powered by the turbine after a power generation reading reaches the optimal power levels or generated voltage activates the relay to switch.

Power control components consist of a pressure switch for detecting air movement to turn on the power supply, relays for switching power supplies when the rated voltage is reached, and regulators to ensure that the voltage being supplied to components does not exceed the required inputs. The emergency stopping system is also included in power control in that it opens the circuit to the system, stopping the flow of electricity.

The computation system used is a raspberry pi 4 B+. This will take voltage and current readings from the bus line to control the variable load relays. The generator load will maintain a constant voltage for power control and consumption.

9 Results of Field and Lab Testing

9.1 Wind Tunnel Description

The wind tunnel being used is a (size by size) rectangle box that has a door on the back and a clear plexiglass side. On the front of the wind tunnel, there is a porous screen that allows only air to be sucked into and through the tunnel while the other side has a fan that pulls the air through. At the bottom of the wind tunnel, there is an opening made to fit the water tank. To ensure that the tank aligns with the 3-inch hole in the wind tunnel floor; there are two wood blocks that stop the tank. The tank is on wheels so that it can easily be removed and put back in place.

9.1.1 Introduction

A small, 5 m wind tunnel was recently constructed at Texas Tech University and made available to the CWC team for testing the prototype turbine. Before using the wind tunnel, tests were needed to find the velocity profile and boundary layer characteristics in the wind tunnel.

The 17 ft. (5 m) long wind tunnel has a 4 x 4 ft. (1.2 m) test section approximately 10 ft. (3 m) long with a venturi inlet and 6-inch (0.15 m) flow straightener. The 4 ft. (1.2) diameter fan uses a belt-driven 230/240 volt, 15 hp, frequency-controlled variable speed motor. Additionally, the lower frame has a 2 ft. (0.6 m) cut-out to allow for the offshore foundation tank to be inserted for testing. See Figure 2

9.1.2 Testing Process

The following equipment was used to measure the velocity profile and find the boundary layer. A Mark II Dwyer Manometer, Dwyer series 160-24 stainless steel Pitot Tube, and a Testo Digital anemometer. The differential pressure Pitot Tube is L-shaped, 24 inches long with a sensing probe length of 7 inches. For testing the Pitot tube was traversed across the flow in 1- or 2-inch increments to measure the velocity profile and find the edge of the boundary layer. The Dwyer manometer was used to show the differential air pressure (P(total) – P (static)) as the Pitot Tube was traversed from the tunnel center to the wall. The Testo Digital turbine anemometer was used to measure a reference wind speed inside the tunnel as testing was being done.

On March 6, 2022, a total of six tests were completed to find the velocity profile and boundary layer of the wind tunnel. The atmospheric conditions needed for air density calculations and required to convert manometer readings to wind speed during testing were the following: the measured room temperature was 66 degrees Fahrenheit and relative humidity was 30 percent, measured on a standard room thermometer and humidity gauge. The station air pressure was measured at Reese Mesonet Station at 897 hectopascals (hPa). For dry air calculations, the Gas Law equation (P = ρ R T) was used, which resulted in an air density of 1.071 kg/m^3. For moist air, to account for the humidity, the website Omnicalculator.com/physics was used to get a slightly lower value of 1.070 kg/m^3.

For the first three tests the variable speed fan motor was set at 30 Hertz, giving a reference wind speed of approximately 6.4 m/s (14.3 mph) on the Testo digital anemometer located, for all tests, approximately 84 inches in front of the fan screen on a small test stand 10 inches above the tunnel floor. For test #1 the Pitot Tube was inserted from the tunnel ceiling 84 inches forward from the fan screen and 44 inches, (about 2.5 rotor diameters for the CWC prototype turbine) upstream from the expected turbine rotor location; the Pitot Tube traversed the tunnel flow from the ceiling of the wind tunnel to the tunnel center. For test #2 the Pitot Tube was inserted from the floor center 39 inches from the fan screen, the expected location of the DOE CWC turbine rotor. For test #3 the location of the Pitot Tube remained at the rotor location and was inserted from the center of the tunnel wall near the test section door. Tests #4, 5, and 6 were done at the same Pitot Tube location as test #1, but with variable fan motor speed settings and wind speeds. Test 4 was set at 30 Hertz or 6.4 m/s, test 5 was set at 20 Hertz or 4.3 m/s, and test 6 was set at 50 Hertz or 10.4 m/s.

9.1.3 Results

These test results show that the wind speed profile and 6-inch boundary layer stay the same at all measured locations and wind speeds. See Figure 3. This also shows that the wind tunnel velocity profile is expected to be symmetrical on all sides both at the wind turbine rotor location and 2.5 rotor diameters upstream. This ensures that the turbine rotor inflow is uniform across the rotor disc with approximately one-half a rotor diameter clearance from the rotor tip to the boundary layer throughout the wind tunnel test section.

Figure 9.1.1 Photograph of Reese 5 m Wind Tunnel used for CWC prototype testing.

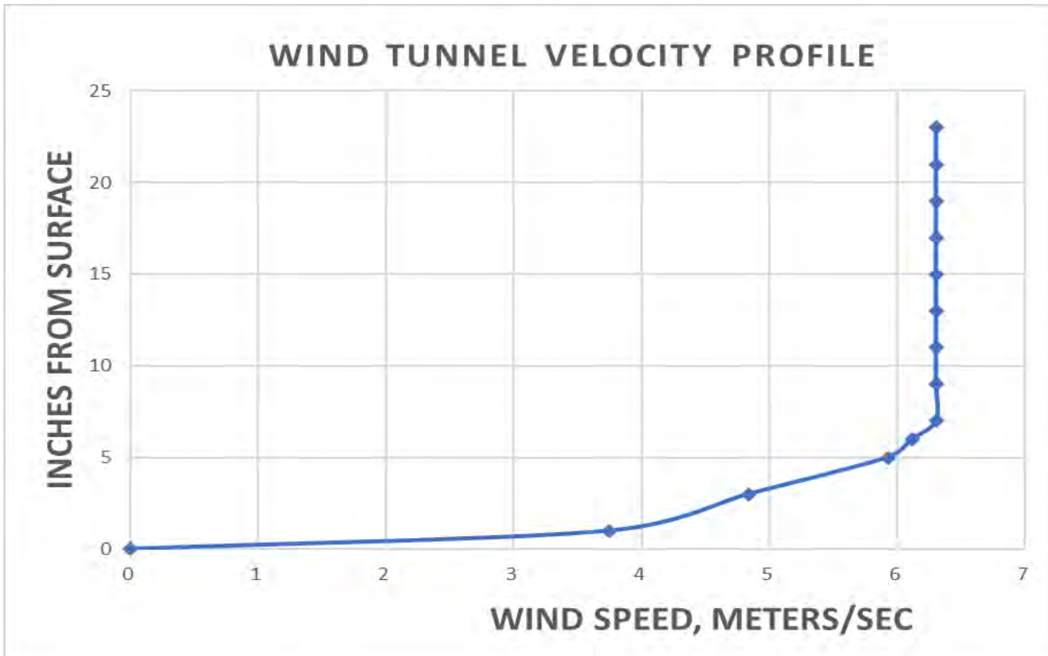


Figure 9.1.2 Reese 5m Wind Tunnel velocity profile showing 6-inch boundary layer.

9.2 Turbine Testing

9.2.1 Turbine Testing Overview

Turbine testing was conducted in a wind tunnel at a Texas Tech research facility. The turbine was tested using a purchased variable load. Using this variable load ensured accurate power readings from the generator output. This testing was done to find the optimal load resistance for maximum power output at the rated voltages.

Turbine testing has been limited due to vibrations linked to the balancing of the shaft. The servos have been tested and function as intended. The pitch variability was estimated to be 50 degrees total, with a negative 10-degree pitch for halting the blades.

9.2.2 Testing Process

Testing involved using off-the-shelf products to compare to the competition build components. Editing and testing has been continuously done to match the professional equipment.

The testing of the load included running the turbine with the built load and the purchased load. The turbine was analyzed to see if the built load was capable of recreating the effects of the purchased load on the turbine generator. Testing of the servos was done by running the turbine in the wind tunnel and pitching the blades to the desired positions.

9.2.3 Testing Results

The turbine startup speed tested was measured at 5 m/s and a power output of 2 Watts after pitching was initiated to the running angle.

Table 9.2.1: Electrical Load Testing results

Current (Amperes)	Resistors (Ohms)											Resistance Equivalent (calculated), $Req_{calc.}$	Resistance Equivalent (measured), $Req_{meas.}$
	1Ω	2Ω	4Ω	8Ω	16Ω	32Ω	64Ω	128Ω	256Ω	512Ω	1024Ω		
1.68 A	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	0.500244 Ω	0.5 Ω
0.91 A	×	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	1 Ω	1 Ω
0.48 A	×	×	✓	✓	✓	✓	✓	✓	✓	✓	✓	2.00 Ω	2 Ω
0.24 A	×	×	×	✓	✓	✓	✓	✓	✓	✓	✓	4.01569 Ω	4 Ω
0.12 A	×	×	×	×	✓	✓	✓	✓	✓	✓	✓	8.06299 Ω	8 Ω
0.06 A	×	×	×	×	×	✓	✓	✓	✓	✓	✓	16.254 Ω	16 Ω
0.03 A	×	×	×	×	×	×	✓	✓	✓	✓	✓	33.0323 Ω	33 Ω
0.01 A	×	×	×	×	×	×	×	✓	✓	✓	✓	68.2667 Ω	68 Ω
0.01 A	×	×	×	×	×	×	×	×	✓	✓	✓	146.286 Ω	146 Ω
0.01 A	×	×	×	×	×	×	×	×	×	✓	✓	341.333 Ω	341 Ω
0.01 A	×	×	×	×	×	×	×	×	×	×	✓	1024 Ω	1024 Ω

9.2.4 Conclusion

There are vibration issues that need to be handled before further testing can commence. The components of the turbine work as intended; however, the turbine will not be able to utilize these systems until the vibrations are mitigated.

10 Reflection on Last Year's Competition

10.1 Similarities to Last Year

The only things similar to the previous year are the material of the blades, a reused control box, generator type, and hub system. None of these, however, are the exact same component as the previous year.

11 References

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