Collegiate Wind Competition: Mechanical Design

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Abstract

The wind energy industry is rapidly growing. Thus, the Collegiate Wind Competition (CWC) offers wind energy experience by tasking every collegiate team involved with the manufacture and implementation of a small-scale wind turbine. The assembly of the wind turbine must fit in the provided wind tunnel and survive wind speeds up to 20 m/s while maximizing power output. The mechanical aspects of the Northern Arizona University (NAU) wind turbine include the design, manufacturing and assembly of the blades, active-pitching hub, shaft, brake, nacelle, yaw fins, tower and baseplate. Each component is designed to complement their mates, to fit within the prescribed geometrical constraints, and to stay structurally secure while providing power at varying wind speeds.

Problem Definition

Collegiate Wind Competition 2018 (CWC) is a competition that is organized by The U.S Department of Energy and the National Renewable Energy Laboratory. CWC requires competitors to design, build, and test a small scale wind turbine. The U.S Department of energy has published a document that contain all the regulations, rules, constraints that are required for the competition. The table below is showing the most important requirements for the competition.

Table 1: Engineering Requirements

Engineering Requirements	Target
Turbine Size	45 X 45 X 45 cm
Operating Wind speed	20 ± 2 m/s
Cut-in Wind Speed	1 m/s< speed< 5 m/s
Cut-out Wind Speed	20 ± 0.5 m/s
Power Generation at 10 m/s	> 10 W

Design Process

The wind tunnel test turbine was designed with several mechanical components analyzed in a static environment. The software used to create several of the components include the use of MATLAB and SOLIDWORKS analyses. A Finite Element Analysis (FEA) is performed in SOLIDWORKS for several components. The turbine's tower analysis is shown in figure 3. The red values correspond to a higher movement (A) or a higher chance of failure for the component (B). The forces applied during the analysis are maximum values that are expected during the competition and while testing to show the design will not fail.

Engineering Design

Final Design

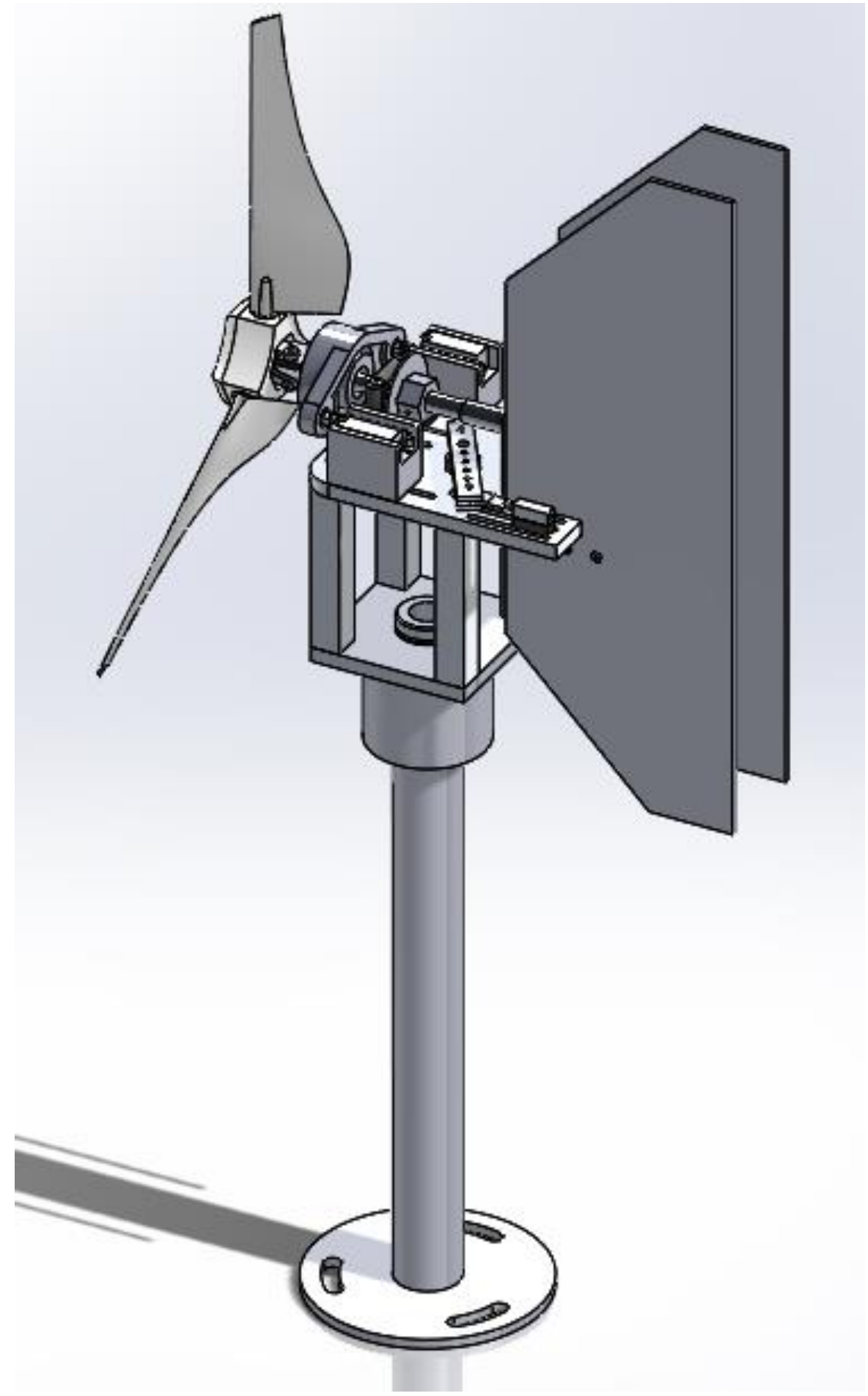
Figure 1: Final CAD Design


Figure 2: Final Assembled Design

The final design includes a dual finned passive Yawing system that pivots on two bearings located in a sleeve beneath the bottom Nacelle plate Shown in Figure 2. The turbine Blades are adhered to Blade roots that are then threaded into an active pitching Hub assembly. The active pitching system is pitched by two linear actuators that are controlled by a Voltage Regulator. The Hub assembly is threaded and adhered to the shaft. The active pitching Hub assembly is controlled to allow the turbine to only operate with the optimal Tip Speed Ratio. The shaft is fixed to the generator at the tail end of the Nacelle between the Yawing fins. The Braking assembly controls the speed of the shaft by actuating a latching solenoid that is connected to a lever arm. The lever arm is used to increase the force being applied to the Braking disk. This assembly allows the Turbine to operate within the optimal wind speed, prevent component failure, and fulfill competition tasks.

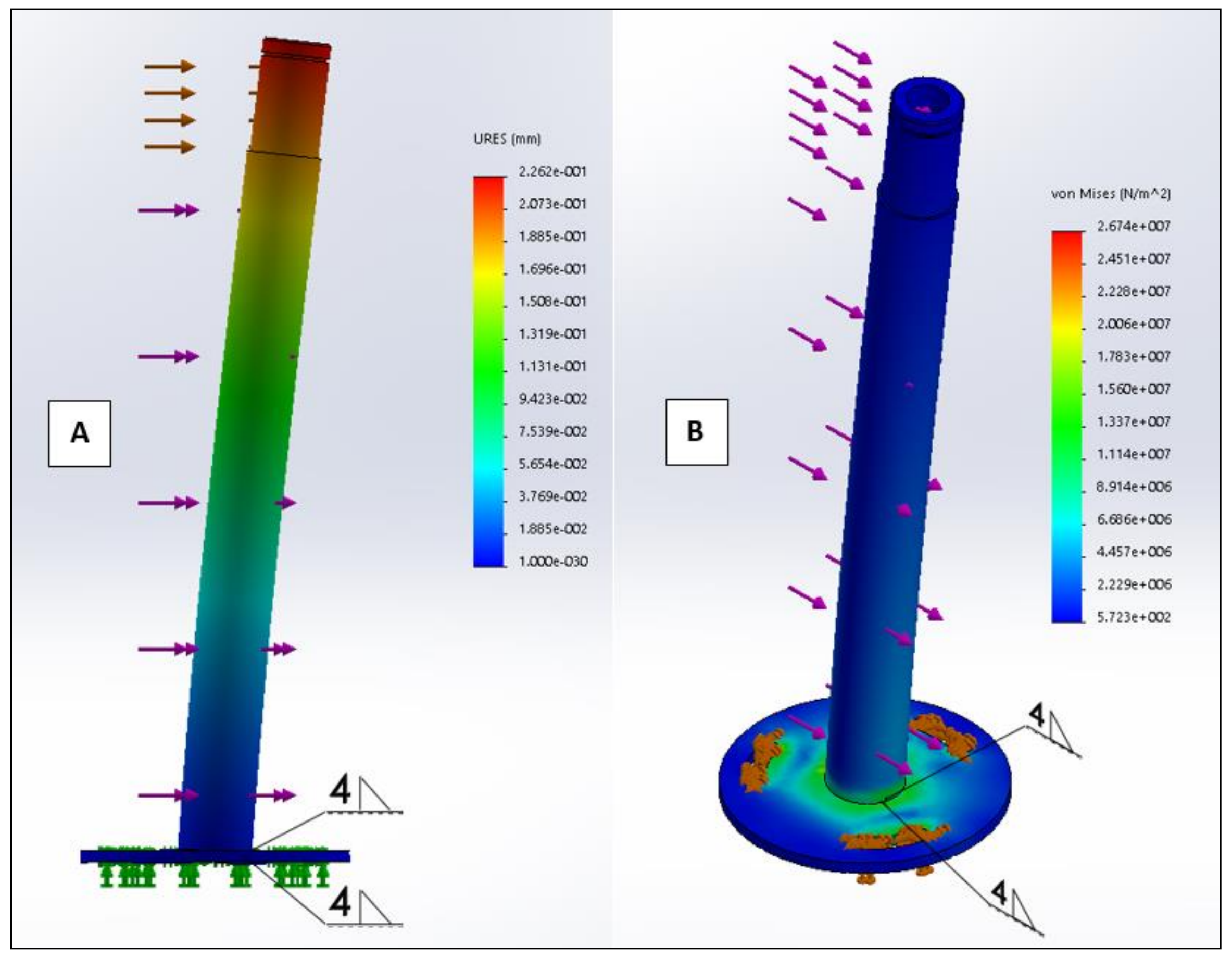

Figure 3: SOLIDWORKS FEA for Wind Tunnel Test Turbine

Manufacturing Process

During the Manufacturing process everything was made on campus at the machine shop. The baseplate and nacelle plates were cut on the Computer Numerical Controls (CNC) Mill shown in Figure 4. The blade roots, hub mounts, shaft, tower, bearing spacers, and tower sleeve were made on the lathe shown in Figure 5. All of the 3D printed parts were printed on a Fortus 400 3D Printer. The blades being bonded to the blade roots can be see in Figure 6. The welding that was done for the tower/baseplate and the lower nacelle plate/tower sleeve were done with a tig welder at the machine shop. The turbine was assembled with hand tools for ease of manufacturing and assembly.

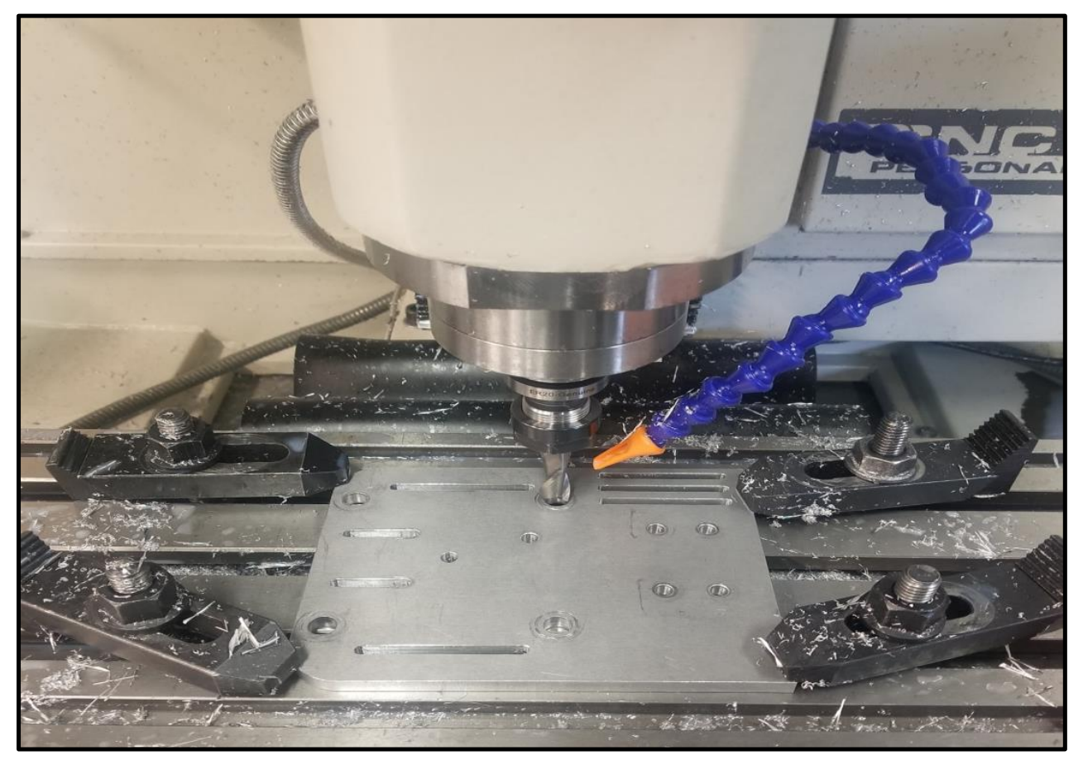
Figure 4: Top Nacelle on the CNC

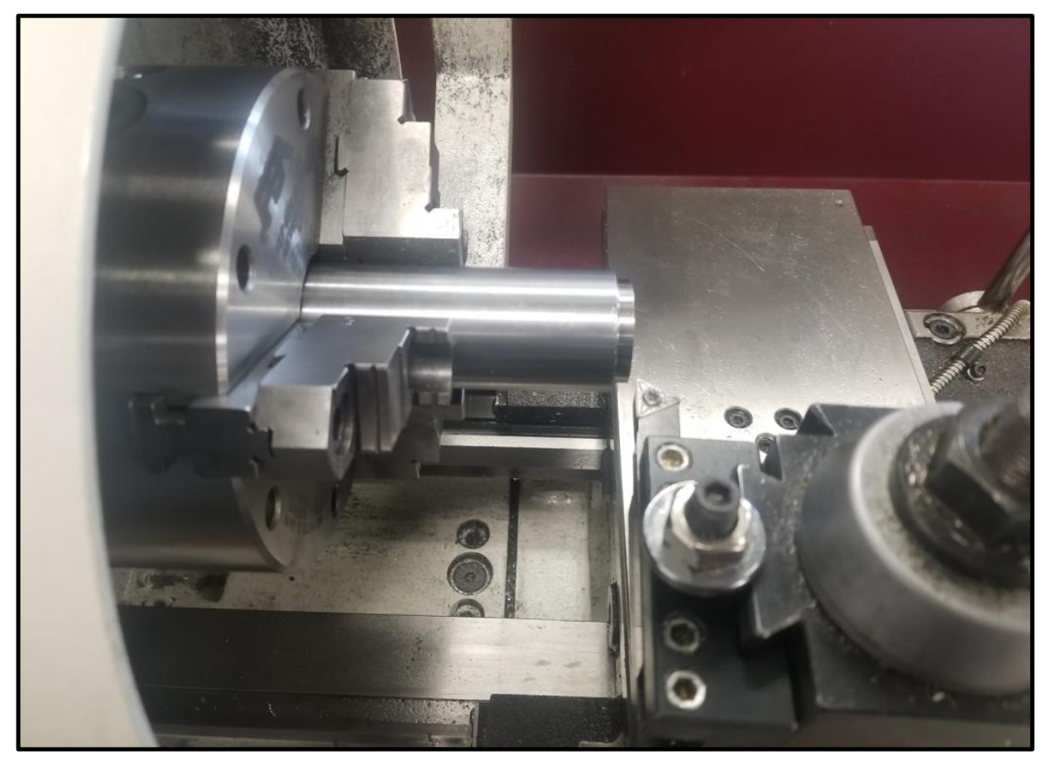
Figure 5: Tower on the Lathe

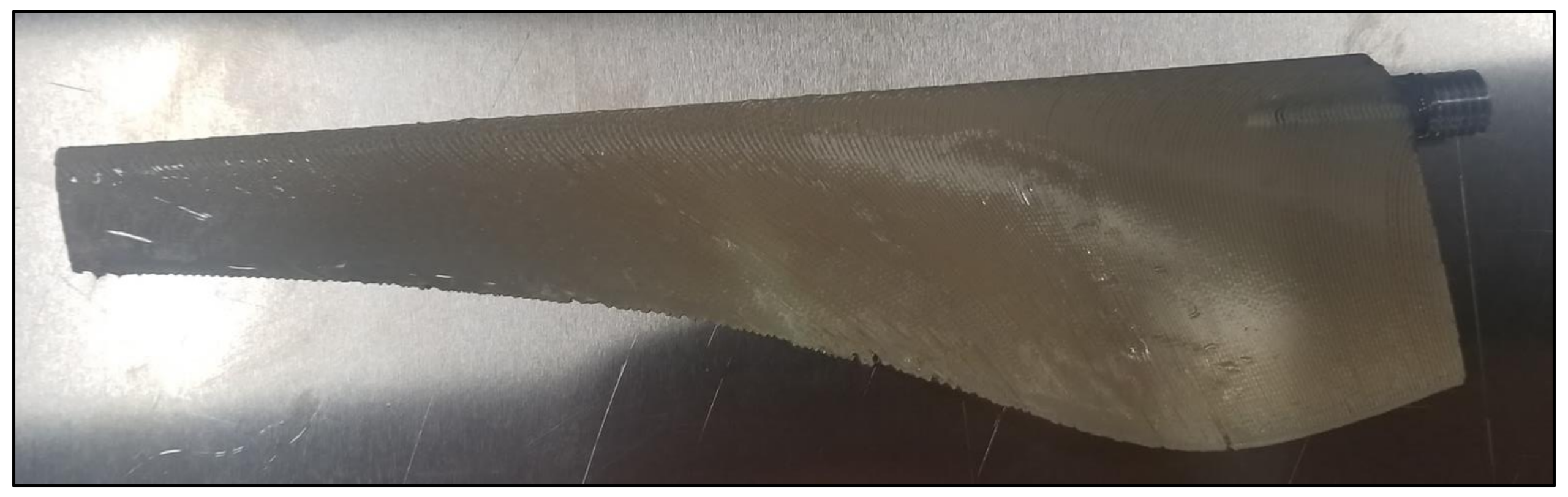
Figure 6: Blades and Blade Roots Bonding

Turbine Performance

The power curve is used to translate how much power can be generated at any given wind speed. Shown below in Figure 7 is the power curve for the turbine. This figure shows the turbine's Cut in, Cut out, and rated power values. When generating this correlation a coefficient is needed to determine how well the turbine is going to perform, this coefficient is known as the Power Coefficient (C_p). The turbine's C_p can be seen in Figure 8 for different expected wind speeds. At higher wind speeds the turbine is going to be more efficient. This curve allows the performance of the turbine to be predicted depending on the operating wind speed.

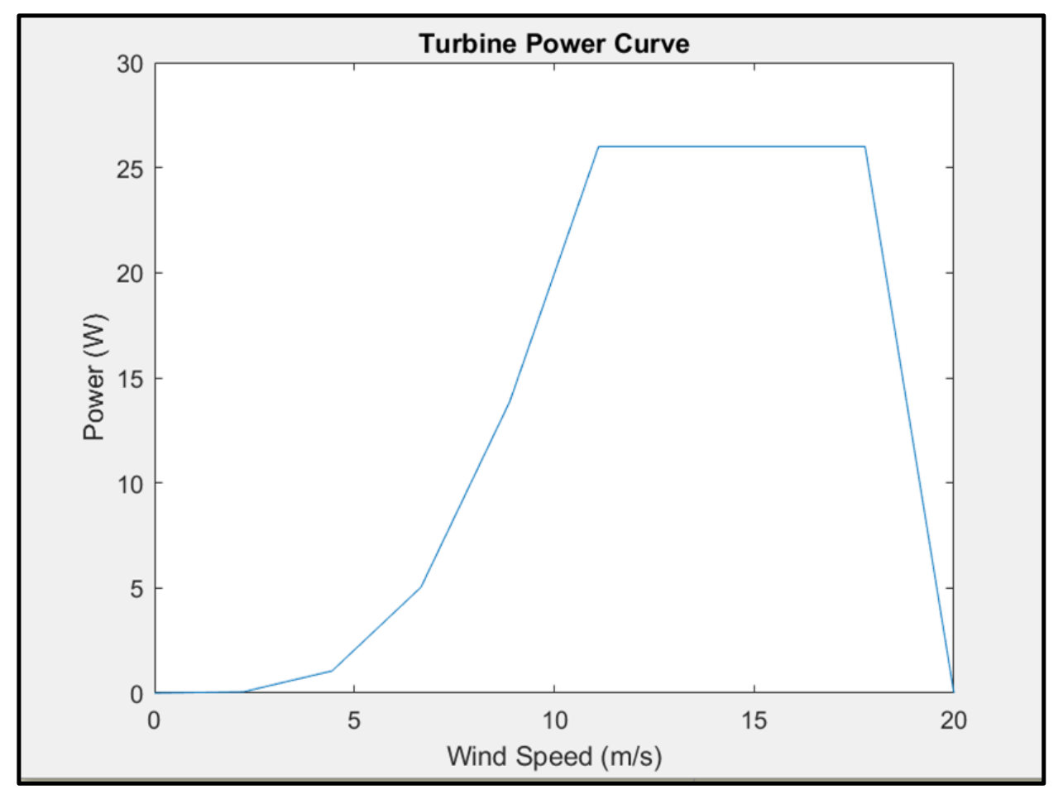

Figure 7: Power Curve for Turbine

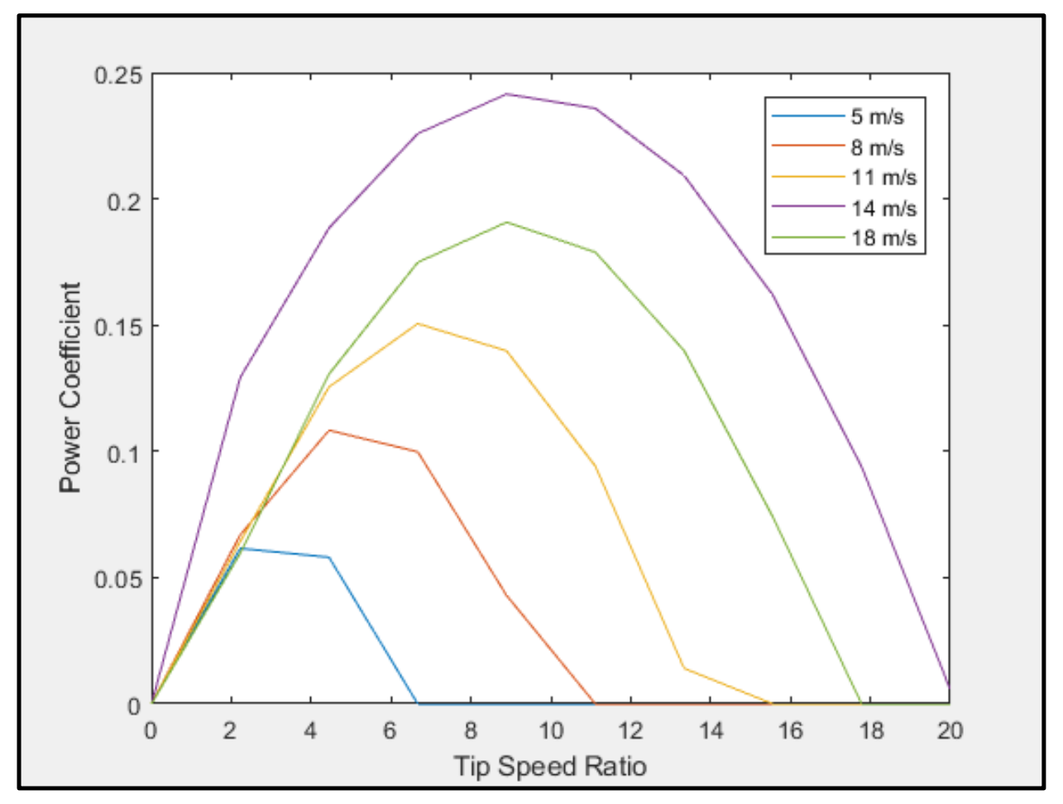

Figure 8: Power Coefficient at different Wind Speeds

Loads and Factors of Safety

Shown below in Table 2, is the loads for each component along with its lowest factor of safety (FOS). This calculations are done to verify that the component will not break for the loads that the component is going to experience, ie. above a value of 2. The loads shown in the table are for the highest expected values that the turbine will experience during testing.

Table 2: Loads and factors of Safety

Component	Maximum Expected Loads	FOS
Tower Shaft	Distributed Drag Force: $F_{D,D}$ = 9 N Targeted Thrust Force: F_T = 37.5 N	8.00
Baseplate & Tower Welds	Distributed Drag Force: $F_{D,D}$ = 9 N Targeted Thrust Force: F_T = 37.5 N	8.35
Nacelle	Targeted Thrust Force: F_T = 37.5 N	149.30
Blades	Lift Force: F_L = 30 N Drag Force: F_D = 5 N Centrifugal Force: ω = 650 rad/s	2.50
Hub	Thrust Force: F_L = 30 N Drag Force: F_D = 5 N Centrifugal Force: ω = 650 rad/s Braking Torque: T_B = 12.5 Nm	2.75
Shaft	Rotor Torque: T_R = 3 Nm Rotor Weight: W_R = 4 N Brake Torque: T_B = 12.5 Nm	2.99
Brakes	Pad Applied Pressure: p_a = 2210 kPa Braking Force: F_B = 1080.8 N Braking Torque: T_B = 12.5 Nm	88.71

Competition Tasks

Date: May 8, 2018 - May 10, 2018
Location: Chicago, IL
Tasks:

- **Power Curve Performance**
- **Control of Rated Power and Rotor Speed**
- **Cut-In Wind Speed**
- **Durability - Yawing and braking capability**
- **Safety - shut down and restart**

Acknowledgments

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References

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US Department of Energy, "Collegiate Wind Competition 2018," 28 August 2017.